Review article
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The effect of maize crop cutting height and the maturity at harvest on maize silage chemical composition and fermentation quality in silo

Utjecaj visine košnje i zrelosti usjeva kukuruza za siliranje na kemijski sastav kukuruzne silaže i kvalitetu fermentacije u silosu

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ABSTRACT

Maize silage (MS) has become one of the major energy components in ruminant nutrition. The maize crop is suitable for ensiling and is of high dry matter (DM) yield and nutritive value. The aim of this review is to provide a comprehensive overview of the effect of cutting height and maize crop maturity at harvest on the chemical composition of MS and fermentation quality in a silo. With an increase in cutting height and maize crop maturity, the content of dry matter (DM) in MS increases to about 400 g DM/kg of fresh crop, after which it does not change, crude protein (CP) CP content increases or remains the same, the ash content decreases or remains the same, starch content increases, and the content of neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) decreases or remains the same. The cutting height and maize crop maturity at harvest have no effect on pH value, lactic, acetic neither butyric acid but increases the amount of ethanol and decreases the ammonium nitrogen (NH_3-N) in MS.

Keywords: maize plant ensiling, silage quality

SAŽETAK

Kukuruzna silaža (KS) je jedna od glavnih energetskih komponenti obroka u hranidbi preživača. Usjev kukuruza je pogodan za siliranje i ima visoki prinos suhe tvari (ST) po jedinici površine i visoku hranidbenu vrijednost. Primjenjena tehnologija siliranja usjeva kukuruza može utjecati na hranidbenu vrijednost KS. Cilj ovog preglednog rada je prikazati rezultate ranijih istraživanja utjecaja visine košnje i zrelosti usjeva kukuruza za siliranje na kemijski sastav KS i kvalitetu fermentacije u silosu. S povećanjem visine košnje i zrelosti usjeva kukuruza za siliranje, sadržaj ST u KS raste do oko 400 g ST/kg svježeg usjeva, nakon čega se ne mijenja, sadržaj sirovih proteina (SP) raste ili ostaje isti, sadržaj pepela se smanjuje ili ostaje isti, sadržaj škroba raste, a sadržaj neutralnih detergent vlakana (NDV), kiselih detergent vlakana (KDV) i kiselog detergent lignina (KDL) se smanjuje ili ostaje isti. Visina košnje i zrelost usjeva kukuruza za siliranje ne utječu na pH vrijednost, sadržaj mliječne, octene i maslačne kiseline, ali povećavaju sadržaj etanola i smanjuju sadržaj amonijskog dušika (NH_3-N) u KS.

Ključne riječi: siliranje biljke kukuruza, kvaliteta silaže

INTRODUCTION

Maize (*Zea mays* L.) is a widely grown crop in various parts of the world as highly adaptated to different climate and soil conditions (Akbar et al., 2002; Khan et al., 2014; Santiago Lopez et al., 2017). Maize silage (MS) is of high fermentation quality (Vranić et al., 2004, 2005), palatability and nutritive value (Akbar et al., 2002; Aoki et al., 2013) thus one of the major forage components in animal nutrition (Khan et al., 2014). The production of MS has increased, both in EU – 28 (CEPM, 2016) and in the Republic of Croatia, whereas in 2016 about 3.5 times more MS was produced compared to the year 2000. (Državni zavod za statistiku RH, 2009, 2018). The nutritive value of MS depends on various factors, from climatic and genotypic to applied ensiling technologies (Allen et al., 2003). Different harvest practices, such as plant cutting height, maturity at harvest, kernel processing, etc. can improve the physical and chemical properties of MS (Caetano et al., 2011b; Ferrareto et al., 2018).

Aoki et al. (2013) reported a number of changes in the nutritive value of MS caused by different cutting heights of maize crops for ensiling. Higher cutting height increases the content of DM, crude protein (CP), starch, net energy of maize crops for ensiling and the digestibility of MS (Horst et al., 2021). However, the DM content of maize crop for ensiling increases with cutting height to a certain maturity (> 400 g DM/kg fresh crop), and the CP content increases or remains the same with increasing cutting height, depending on the hybrid and maturity of the maize crop (Horst et al., 2021). Depending on the hybrid, with an increase in cutting height, the content of neutral detergent fiber (NDF), acidic detergent fiber (ADF) and acidic lignin detergent (ADL) decreases (Wu and Roth, 2005) or remains the same (Kung et al., 2008).

The optimal maturity of maize crops for ensiling is at a dry matter (DM) content of about 350 g/kg of a fresh crop which is 3-4 weeks before the technological maturity of maize grains (Thom et al., 1981), i.e. when the milk line is at half of the grain (Allen et al., 2003). In that stage, an optimal relationship is achieved between starch, as the energy component of the ration, and water-soluble carbohydrates that preserve the whole maize plant by natural fermentation (Vranić et al., 2004). The type and concentration of fermentation end products affects nutrient conservation in MS (Allen et al., 2003; Hoffman et al. 2015; Chibisa and Beauchemin, 2018).

The aim of this paper is to summarize previous results of the effect cutting height and maturity of maize crop at ensiling to chemical composition of MS and fermentation quality in silo.

Effect of cutting height of maize crop on chemical composition of maize silage

The nutritive value of MS is mostly defined by the content of DM, ash, CP, NDF, ADF, ADL, and starch (Garcia et al. 2003; Hoffman et al. 2015; Vranić et al., 2020). The results of previous studies regarding the effect of maize crop differing in cutting height at harvest on the chemical composition of MS are presented in table 1.

The DM content of maize crop for ensiling affects the fermentation quality and conservation of nutrients, and consequently the DM feed intake and animal performance (Garcia et al., 2003; Chibisa and Beauchemin, 2018). Most of the studies presented (Table 1) were conducted by ensiling maize crops with DM content close to the optimal (350 g DM/kg fresh crop) (Thom et al., 1981) or in the DM content range of 300–350 g/kg fresh crop that is recommended for the production of high quality MS (Anonymous 1; Chamberlain and Wilkinson, 1996).

The maturity stage of maize crop affects the DM content of MS due to DM accumulation in plant material by the maturation (Allen et al., 2003; Hoffman et al., 2015; Chibisa and Beauchemin, 2018). Higher cutting height results in increased DM content in maize crop for ensiling due to a higher proportion of stover and grain in the plant mass for ensiling (Caetano et al., 2011a; Horst et al., 2021), whereas the cutting height does not affect the DM content of the matured maize crop (< 400 g DM/kg fresh crop) (Neylon and Kung, 2003). Furthermore, cutting maize crop at height of 10 – 12 cm from the ground level resulted in lower MS DM (from 359 – 382 g/kg fresh crop), compared to cutting at a height of 50 cm

Table 1. The effect of cutting height on chemical composition of the maize silage

CH (cm)	DM	Ash	CP	Starch	NDF	ADF	ADL	Reference
10-12 vs. 50	+	/	NS	NS	-	-	/	Kruczyńska et al. (2001)
20 vs. 42	-	+	+	/	-	/	/	Restle et al. (2002)
13 vs. 46	+	/	-	+	NS	-	-	Neylon and Kung (2003)
15 vs. 55	+	/	NS	NS	-	-	NS	Kruczyńska et al. (2011)
10.2 vs. 30.5	NS	NS	NS	/	NS	NS	/	Bernard et al. (2004)
20.3 vs. 61	+	/	/	+	-	-	-	Kennington et al. (2005)
5 vs. 80-100	+	-	NS	/	-	-	/	Caetano et al. (2011a)
30 vs. 78	+	NS	+	+	NS	NS	NS	Aoki et al. (2013)
20 vs. 40 vs. 60 vs. 80 vs. 100	+	-	+	/	-	-	-	Hulse et al. (2017)
25 vs. 40	+	NS	+	/	-	-	NS	Mendonca de et al. (2020)
5 vs. 20	+	-	NS	/	-	-	-	Caetano et al. (2011b)
15 vs. 39	NS	NS	NS	/	-	-	/	Neumann et al. (2007)
17 vs. 50	+	/	+	+	-	-		Wu and Roth (2005)
20 vs. 45 vs. 70 vs. 95	+	/	-	+	-	-	-	Pedó et al. (2009)
20 vs. 50 vs. 80 vs. 110	+	/	+	+	-	-	-	Rezende et al. (2015)

CH, cutting height; DM, dry matter; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin; +, significantly increased by the cutting height ($P<0.05$); -, significantlly decreased by the cutting height ($P<0.05$); NS, cutting height did not affect the value significantly ($P>0.05$); /, not determined

(from 381 – 421 g/kg fresh sample) in the same research (Kruczyńska et al., 2001).

Previous results reported a positive correlation between the MS DM content (cutting height 15 – 30 cm) and the maturity of the maize crop (Figure 1) (Neylon and Kung, 2003; Jensen et al., 2005). However, at the lowest (10 – 15 cm) and the highest cutting height (45 – 60 cm), the effect of maize crop maturity on MS DM content was variable.

From the figure 1 it is obivous that DM content increases with crop maturity when cutting height is between 10 and 30 cm above soil level, but in the case of high cutting height (45 to 60 cm above soil level), the DM content is not dependent on the maturity stage when maturity is in the intervals reported in the available 7 references. According to the literature data (Phipps et al., 2000; Khan et al., 2012; Hatew et al., 2016) and presented results, a higher maize crop DM content in harvest is associated with a higher DM content in MS (Figure 2).

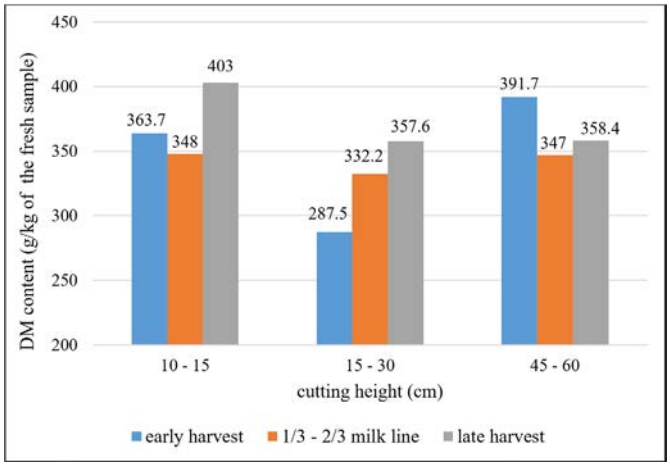

Figure 1. The effect of cutting height and maize crop maturity on dry matter content in maize silage (g/kg of the fresh sample) (Neylon and Kung, 2003; Bernard et al., 2004; Jensen et al., 2005; Kennington et al., 2005; Kruczyńska et al., 2001, 2011; Peyrat et al., 2016)

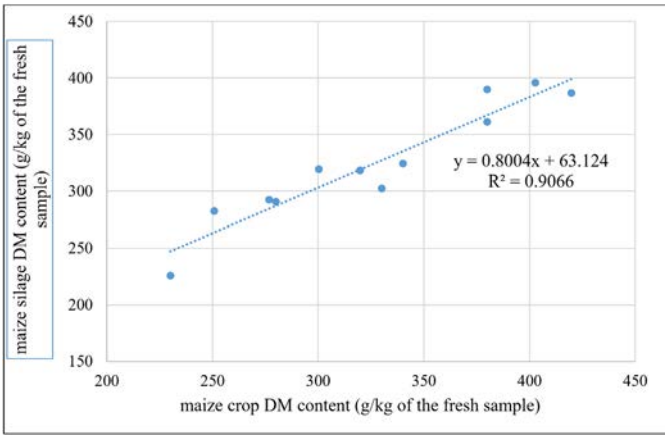

Figure 2. The effect of maize crop DM content (g/kg of the fresh sample) on the maize silage DM content (g/kg of the fresh sample). The corresponding equations and determination coefficients (R^2) are indicated in the Figure (Phipps et al., 2000; Khan et al., 2012; Hatew et al., 2016)

The MS DM content, apart from the cutting height and maturity stage, depends on the maize crop hybrid, microclimatic factors, and applied agrotechnics of cultivation and ensiling (Struik, 1982). For instance, the addition of additives or other supplements to the maize crop at ensiling, filling and closing of a silo, etc., may increase or decrease the DM content in the produced MS (Struik, 1982).

Ash is a source of minerals in the feed and it has no energy value. Higher ash content (higher than usual for a certain plant species) indicates possible feed contamination by soil particles or other impurities (Hoffman et al., 2015) which results in lower feed intake, lower fiber digestibility, and absorption of certain minerals in the digestive system of animals (Khan et al., 2007; Vranić et al., 2020). The ash content in MS can reach a maximum of 60 – 65 g/kg DM (Anonymous 1; Chamberlain and Wilkinson, 1996), whereas in the presented studies the ash content was below the stated values regardless of the cutting height and maize crop maturity. Furthermore, too low cutting height (5 cm) results in higher soil contamination thus possible higher ash content in MS while most of the results, comparing higher than 5 cm cutting heights, show no effect of cutting height on ash content in MS (Table 1).

MS is quantitatively and qualitatively poor at the CP content. It ranges from 47 – 93 g/kg DM (Anonymous 1) and is preferably greater than 70 g/kg DM (Chamberlain and Wilkinson, 1996). According to NRC (2001), the daily ration of dairy cows should contain at least 12 % CP for dry cows to 18 % which supports production of 40 kg of milk/day. In the presented studies (Table 1), the CP content ranged from 63 g/kg DM (cutting height of 10 – 12 cm) to 101 g/kg DM (cutting height of 55 cm) (Kruczyńska et al., 2001). Furthermore, with the maize crop cutting height (Table 1), there was an increase (Restle et al., 2002), decrease (Neylon and Kung, 2003) or the cutting height did not affect the CP content in MS (Kruczyńska and et al., 2001) (presented in Figure 3).

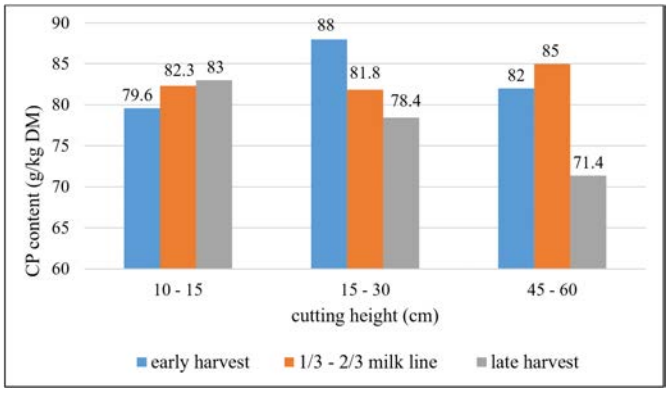

Figure 3. The effect of cutting height and maize crop maturity stage at harvest on the crude protein (CP) in maize silage (Kruczyńska et al., 2001, 2011; Neylon and Kung, 2003; Bernard et al., 2004; Jensen et al., 2005; Kennington et al., 2005; Peyrat et al., 2016)

It can be observed (Figure 3) that with the maize crop maturity, CP content in MS of lowest cutting height increases, in medium cutting height decreases, whereas in highest cutting height is variable. The decrease of CP content with maize crop maturity may be considered in terms of starch and fiber accumulation in maize crop DM, although not always, due to the influence of hybrids, microclimate and technology applied in MS production (Neylon and Kung, 2003; Bernard et al., 2004). The CP content in MS is proportional to its uptake from the soil (Moss et al., 2001), decreases with a maturity of maize crop, and with increase in starch content (Dado, 1999). Likewise, nitrogen fertilization increases the CP content in the whole maize crop (Chereny and Cox, 1992), so part of the CP content variability in MS can be partly explained by different types and amounts of applied nitrogen fertilizers.

The fiber content (Table 1), which ranged from 320 – 486 g/kg DM for NDF, 185 – 279 g/kg DM for ADF, is consistent with the usual fiber content in MS (Anonymous 1; Chamberlain and Wilkinson, 1996; Vranic et al., 2004, 2005; Lukšić et al., 2018). The fiber content in MS increases with the maize crop maturity (Garcia et al., 2003), however in total maize crop DM, the relative fiber content decreases, whereas the starch content increases (Thom et al., 1981). Furthermore, the previous results mostly reported decrease in fiber content (NDF, ADF, ADL) in MS with an increase in the cutting height while only limited number of research show no significant effect of cutting haight on fiber content in MS (Table 1). The trend of decreasing NDF content in MS with maize crop maturity at all 3 cutting heights is presented in figure 4.

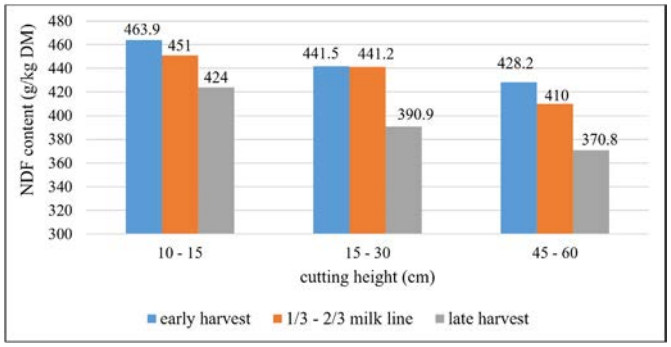

Figure 4. The effect of cutting height and maize crop maturity stage on the neutral detergent fibre (NDF) in maize silage (Neylon and Kung, 2003; Bernard et al., 2004; Jensen et al., 2005; Kennington et al., 2005; Kruczyńska et al., 2001, 2011; Peyrat et al., 2016)

Furthermore, a negative trend of ADF content in MS with maize crop maturity can be observed in figure 5. An exception is the lowest cutting height (15 – 20 cm) whereas a specific increase of ADF content is reported in the optimal cutting period (compared to early cutting). Higher cutting height of maize crop for ensiling, in MS, reduces the fiber content (Kruczyńska et al., 2001, 2011; Caetano et al., 2011a) due to the higher fiber content in the lower parts of the stem (Lewis et al., 2004). The exceptions are maize hybrids (Aoki et al., 2013) with lower ADL content and higher fiber digestibility (Ebling and Kung, 2004).

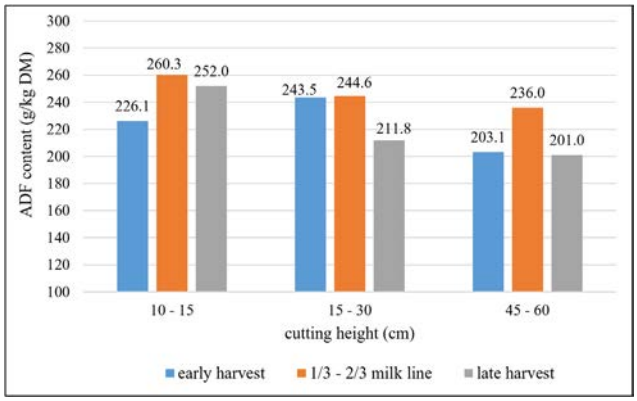

Figure 5. The effect of cutting height and maize crop maturity stage on the acid detergent fibre (ADF) in maize silage (Kruczyńska et al., 2001,2011; Neylon and Kung, 2003; Bernard et al., 2004; Jensen at al., 2005; Kennington et al., 2005; Peyrat et al., 2016)

The fiber content in the feed is positively correlated with the length of digestion, and negatively with the intake and digestibility of feed (Garcia et al. 2003; Vranić et al., 2020). According to Garcia et al. (2003), higher feed fiber content results in lower energy content in animal nutrition.

Unlike structural carbohydrates in MS, starch as a storage carbohydrate is about 5 times faster to digest and represents a significant source of energy in a daily ration of ruminants (Morgan, 2005). The starch content in MS typically ranges from 168 - 406 g/kg DM (Anonymous 1), and is preferably 320 - 360 g/kg DM (Chamberlain and Wilkinson, 1996). The proportion of starch in MS depends on maize crop maturity due to its accumulation in the grain endosperm, therefore in the two-thirds milkline and black layer stage a higher starch content was determined compared to milk ripening stage (Neylon and Kung, 2003; Jensen et al., 2005; Kennington et al., 2005; Mc Geough et al., 2010; Kruczyńska et al., 2011; Peyrat et al., 2016), that is 205 g/kg DM in milk ripening stage (Peyrat et al., 2016) to 396 g/kg DM in the black layer stage.

The effect of cutting height and maize crop maturity stage on starch content in MS is presented in figure 6. An increase in the starch content is observed both with maturity and with the cutting height. The average starch content in MS of 374.8 g/kg DM is, apart from the later maturity stage of the crop, a result of higher cutting height (Kennington et al., 2005).

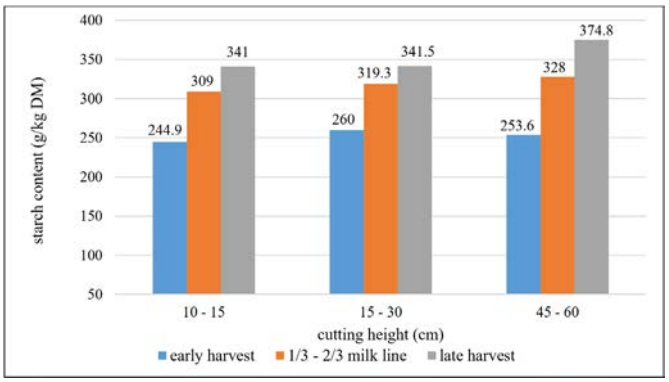

Figure 6. The effect of cutting height and maize crop maturity stage on starch content in maize silage (Kruczyńska et al., 2001,2011; Neylon and Kung, 2003; Bernard et al., 2004; Jensen et al., 2005; Kennington et al., 2005; Peyrat et al., 2016)

An increase in cutting height of maize crop results in a higher grain proportion in the forage, and consequently a higher starch content in MS (Neylon and Kung, 2003) which can negatively affect fiber digestibility (Kennington et al., 2005), microbial fermentation and animal performance (Jensen et al., 2005). However, starch is the source of energy in MS, therefore the aim is to produce silage with as much starch content as possible, and prevent possible negative aspects of nutrition by formulating rations.

Effect of cutting height and maturity at harvest on maize silage fermentation quality in silo

The ensiling of the plant produces various fermentation products whose content depends on the applied ensiling technology (Kung and Shaver, 2001; Aoki et al., 2013). Fermentation products can change the palatability and nutritive value of MS, animal performance characteristics, and animal health, and thus the quality of animal products (Kung and Shaver, 2001). Chemical parameters of fermentation quality in a silo are: pH value of silage, acid content (lactic, acetic, propionic, and butyric acid), ethanol, ammonium nitrogen (NH_3-N) and the presence of certain microbial species (Kung and Shaver, 2001; Kung et al., 2018). Cutting height mostly didn't affect the MS fermentation quality, as presented in table 2. However, The final pH value of MS was dependent on the maize crop DM content and the availability of fermentation substrates (Kung and Shaver, 2001). When ensiling maize crop with a high DM content (400 - 450 g/kg of fresh crop), the final pH value (pH 4.4) is also high (Kung et al., 2018) compared to ensiling maize crop with optimal (Kung and Shaver, 2001) or low DM content (Vranić et al., 2004). The lowest pH value was observed by ensiling maize crop in the earlier maturity phase (milk ripening) (pH value 3.6) (presented in Table 2) (Peyrat et al., 2016) while the lowest determined pH value, in the advanced maturity phases (two-thirds milkline, and black layer) was 3.7 independently on cutting height (Neylon and Kung, 2003; Kruczyńska et al., 2011).

Higher cutting height of maize crops for ensiling increases the proportion of starch in the plant mass as a substrate for the desired fermentation in the silo (Horst et al., 2021). In support of this, the pH value of MS produced from the maize crop harvested in the phase of black layer at a height of 78 cm with high DM content had high starch content and consequently low pH value (3.7) (Aoki et al. , 2013). The highest pH value (4.2), determined at the lowest cutting height (10-12 cm) (Kruczyńska et al., 2001), was lower than the undesirable pH values for MS (pH> 4.5) that favor the reproduction of pathogenic microorganisms (*Escherichia coli*, *Listeria monocytogenes* and *Clostridium* spp.) which might have a negative effect on the animal performance and health, the quality of milk and dairy products (Queiroz et al., 2018).

In the presented results of the studies, the content of the fermentation products was consistent with the expected for MS of high quality (Chamberlain and Wilkinson, 1996) regardless of the cutting height and maturity of the maize crop. In all of the studies, compared to the other fermentation products, lactic acid dominated (mainly in the range of desirable values for MS (30 – 120 g/kg DM) (Kung and Shaver, 2001) as the most important acid that stabilizes silage and inhibits growth and development of undesirable microorganisms (Chamberlain and Wilkinson, 1996).

Acetic acid, as the second most abundant acid in MS of desirable fermentation quality, may be present in the range of 10 – 30 g/kg DM and is inversely proportional to DM content (Kung et al., 2018). All presented studies (Table 2) demonstrate low acetic acid concentration from

Table 2. The effect of cutting height and maize crop maturity on fermentation quality parameters in a silo

CH (cm)	pH	Acid			Ethanol	NH_3-N	Reference
		Lactic	Acetic	Butiryc			
10-12 vs. 50	NS	NS	NS	NS	/	/	Kruczyńska et al. (2001)
13 vs. 46	NS	NS	NS	/	/	/	Neylon and Kung (2003)
15 vs. 55	NS	NS	NS	NF	/	/	Kruczyńska et al. (2011)
30 vs. 78	NS	NS	NS	/	+	/	Aoki et al. (2013)
25 vs. 40	NS	NS	-	/	/	-	Mendonca de et al. (2020)
5 vs. 20	/	/	/	/	/	-	Caetano et al. (2011b)

CH, cutting height; NF, not found; /, not determined; NS, not significant (P>0.05)

only 2 g/kg DM (Mc Geough et al., 2010) to 30 g/kg DM (Kruczyńska et al., 2011) that can reduce the aerobic stability of silage, and represent the usual values of acetic acid content in MS of good fermentation quality (Kung et al., 2018). Furthermore, no higher content of acetic acid (> 40 - 60 g/kg DM) was found that would indicate increased activity of enterobacteria and clostridia (McDonald et al., 1991).

Propionic acid, butyric acid, and ethanol were not determined or were found in very low concentrations regardless of the maturity and cutting height of the maize plant for ensiling indicating a good fermentation quality of MS (Chamberlain and Wilkinson, 1996). The higher content of these fermentation products in silage may be an indicator of clostridia and yeast activity during fermentation (Kung and Shaver 2001, Kung et al., 2018) and result in DM loss, aerobic instability, negative milk characteristics (Kung and Shaver, 2001; Kung et al., 2018; Queiroz et al., 2018) and lower intake of digestible nutrients (Chibisa and Beauchemin, 2018).

During fermentation in a silo, proteolytic processes occur which increase the content of soluble proteins (55 – 60 % of total N) and NH_3-N in silage, whereas the duration of mentioned processes depends on the rate of pH value decline in a silo, and clostridia activity (Kung and Shaver, 2001). In the presented studies (Table 1), NH_3-N was not determined, found in low concentrations (Peyrat et al., 2016) or higher (Mc Geough et al., 2010) for MS of desirable fermentation quality (> 50 g NH_3-N/kg of total N) (Chamberlain and Wilkinson, 1996).

Studies revealed that parameters of fermentation quality in a silo were mostly unaffected by cutting height and stage of maturity likely due to low buffer capacity of maize crop thus its high suitability for ensiling (Vranić et al., 2004, 2005; Lukšić et al., 2018).

CONCLUSION

With an increase in cutting height and maize crop maturity, the content of DM in MS increases to the DM content of about 400 g DM/kg of fresh crop, after which it does not change, CP content increases or remains the same, the ash content decreases or remains the same, starch content increases, and the content of NDF, ADF and ADL decreases or remains the same. The cutting height and maize crop maturity at harvest has no effect on pH value, lactic, acetic and butiryc acid but increases the amount of ethanol and decreases ammonium nitrogen in MS.

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