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Intake and Digestibility of Silages

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Additional information is available at the end of the chapter

Abstract

The intake of DM (DMI) is determinant for ingress of nutrients to cater to the require-ments for animal maintenance and production, principally the intake of protein and energy. The end-products of fermentation can affect the intake of silages and influence animal performance, since some organic acids negatively influence the intake of silage and digestibility of nutrients. For example, acetic and butyric acid have large effects on the intake of silage. Ammonia also can negatively affect the intake of silages. The digestibility can be influenced by end-products of fermentation and change the characteristics of ensiled plants. The objective of this chapter is to explain how silage end-products of fermentation and changes in the structure of forage resulting from the ensiling process can affect the intake and digestibility of silages. Some control mechanisms of silage fermentation can be used to improve the intake and digestibility of silage. Biological or chemical additives may contribute to the increased intake of silage and improve digestibility. Appropriate management techniques can influence the result.

Keywords: acetic acid, ammonia, animal nutrition, butyric acid, forage ensiling

1. Introduction

Ensilage is the method of forage conservation based on conversion of water-soluble carbohy-drates in organic acids by the activity of lactic acid bacteria, which reduces the pH and preserve the fresh forage [1].

The ensiling process show advantages such as conservation of large quantities of forage in short time and forage conservation is less weather dependent. However, a disadvantage of the ensiling process is the relative reduction of feeding value of the silage when compared to the

original crop [2]. Although, correct management of silages and use of additives may stimulate the intake of silages and improve the digestibility of silages.

The forages may have changes in the nutritive value due to the procedures during production, conservation and post-opening management and biochemical and microbiology phenomena [3]. Besides the conversion of carbohydrates in organic acids occurs by the partial breakdown of proteins, which gives the non-protein structures. These changes depend on the interaction between microorganisms on the material to be ensiled and amount and type of the substrate [4].

The silage quality affects the intake and digestibility of ruminants. Basically, the main factors that can interfere with the fermentation of the silage is the dry matter (DM) content, water-soluble carbohydrate (WSC) concentration and microorganism populations present in the forage. Forage with low DM and WSC concentrations may show undesirable fermentation and forage with excessive WSC content may generate acidic silages, which reduces silage intake.

Some end-products of fermentation, such as acetic and butyric acids and ammonia, are associated with the decrease in the intake of silages. Poorly fermented silages have large concentrations of undesirable compounds that explain the low silage intake.

Some changes resulting from the ensiling process influence the digestibility of silages. High concentration of ammonia, for example, can interfere in digestibility of the silage, and enter the N recycling cycle and increase the animal energy costs.

The objective of this chapter is to explain how end-products of fermentation of the silage and changes in the structure of forage resulting from the ensiling process can affect the intake and digestibility of silages.

2. Effect of silage quality on the intake and digestibility of ruminants

The feeding value of silage is mainly determined by intake and digestibility of silage [5]. The silage quality and availability of nutrients influence animal performance [6].

The intake of silage is generally lower than the intake of fresh forage [1] because the presence of toxic substances produced during the fermentation as amines; also due to the high concentration of organic acids and decrease in the water soluble carbohydrate content which lower availability of energy for the growth of microorganisms in the rumen [7]. However, we should question the validity of this conclusion [2].

Proper management in the ensilage can result in well-preserved silage and result in a similar intake of fresh forage. In addition, the use of additive may increase the silage intake values. Balieiro Neto et al. [8] evaluated the intake of sugarcane *in natura* and silage and observed higher values to sugarcane silage intake (0.720 kg/day) than to sugarcane *in natura* intake (0.657 kg/day). The silages were additive with 0.5% of calcium oxide (fresh matter basis).

The fermentative profile and the vegetable species available can influence the silage intake. Due to the fermentative process, many changes occur in chemical characteristics of forage. The

organic acid concentration is variable and it is influenced by management of the ensilage process, use of additive and principally by forage characteristics. This variation is recognized and search object of researchers worldwide (**Table 1**).

Crop	Ensiling characteristics								Author
	pH	LA (g/kg DM)	AA (g/kg DM)	PA (g/kg DM)	BA (g/kg DM)	Ethanol (g/kg DM)	NH₃-N (mM/g DM)	WSC (g/kg DM)	
Corn silage (*Zea mays* L.)	3.7	38.6	14.3	1.4	2.0	3.5	10.1	17.5	Hassanat et al. [12]
Sorghum silage (*Sorghum bicolor* L. Moench)	3.66	61.5	16.7	0.1	0.4	18	6.68	–	Santos [13]
Pearl millet silage (*Pennisetum glaucum* LR)	3.9	63	14.4	2.8	0.71	–	48	–	Dos Santos et al. [14]
Calliandra silage (*Calliandra calothyrsus*)	4.0	20.4	5.85	0.15	0.38	–	43.5	17.99	Ridwan et al. [15]
Alfafa silage (*Medicago sativa*)	4.2	74.2	26.1	2.4	0.9	2.2	27.7	18.3	Hassanat et al. [12]
Napiergrass silage (*Pennisetum purpureum* Schum)	4.1	37.6	12.7	0.1	12.1	–	100.1*	21.2	Rong et al. [16]
Cactus palm silage (*Opuntia ficus indica*)	3.81	80.2	22.5	8.1	05	–	9.0	20.4	Nogueira [17]

*NT.

Table 1. Fermentative characteristics of silages.

Restle et al. [9] evaluating the performance of feedlot calves receiving grass silage (*Brachiaria plantaginea*) and corn and sorghum silages, found that corn and sorghum silage promoted higher intake and better performance than the animals fed grass silage. Although the authors justify the higher dry matter intake of animals fed with corn and sorghum silage was due to an increasing difference in weight, which interfere directly in the intake values, the result may have also occurred because the fermentative characteristics and different end-products of fermentation concentration.

3. Factors that interfere on the silage intake

The dry matter intake (DMI) is determinant to ingress of nutrients to cater to the requirements for animal maintenance and production, principally the intake of protein and energy [10]. The DMI is the factor that affects the animal productive performance, since 60–90% variation in

animal performance is associated with the metabolizable energy intake and only 10–40% with the diet digestibility [11].

The silage fermentative profile can influence the animal intake. In **Table 1**, the fermentative profile of some silages used in animal feed is described. The corn silage (*Zea mays* L.) shows a good fermentation process and result in adequate lactic acid production (38.6 g/kg DM), low acetic, propionic and butyric acid concentrations [12], which implies adequate dry matter intake.

The sorghum silage (*Sorghum bicolor* L. Moench) has similar fermentative characteristics of corn silage, but in some cases, the higher WSC content of forage can cause acid silage and increase the ethanol produce due to yeast activity [13]. The lactic acid production in sorghum ensilage is quick and pH may decrease below than desirable pH. Sorghum silage can show average values lactic acid of 61.5 g/kg DM and 18 g/kg ethanol concentration [13]. Ethanol may result in decrease in DMI, so excess ethanol is a negative point in these silages.

Another important forage to semiarid regions is the pear millet (*Pennisetum glaucum* LR). The fermentative profile of pear millet silage has high volatile fatty acids (VFA) products, with lactic acid 63 g/kg DM and higher propionic acid content (2.8 g/kg DM) [14] than corn and sorghum silages.

The forage species is an important factor for determining the fermentative profile and intake silage. Silages legumes, such calliandra (*Calliandra calothyrsus*), for example, has higher ammonia content (43.5 mM/g DM) [15] compared to corn silage. This large ammonia amount can influence the intake and digestibility of silages.

Alfalfa silage (*Medicago sativa*) have large amount of organic acid. Research evaluation of replacing effects of alfalfa silage for corn silage, Hassanat et al. [12] found different concentrations of organic acids into silages. The lactic acid content of alfalfa silage (74.2 g/kg DM) is higher than corn silage. However, other compounds such as acetic acid and ammonia can decrease intake silage. The high values found (acetic acid 26.1 g/kg DM and ammonia 27.7 mM/g DM) may have negatively influenced the silage intake by cows. The silage intake increased according to elevated levels of corn silage in the diet. Probably, the differences of the fermentative profile of silages alter the intake by the animal.

Grasses ensiling result generally in higher pH and lower values of lactic acid. Resistance to change in pH or buffer capacity is one of the main obstacles to the quality of silage. The rapid lowering of the pH is effective in reducing the activity of deleterious microorganisms to nutrient forage ensiled. Although the buffering substance content may hamper acidification of the silo environment, Rong et al. [16] observed pH values of 4.1 in Napiergrass (*Pennisetum purpureum* Schum) silage; still, high butyric (12.1 g/kg DM) and acetic acid concentrations (12.7 g/kg DM) and ammonia content (100 g/kg NT). Butyric acid can negatively influence the silage intake in ruminant animals [2].

In semiarid regions, the use of cactaceous in animal feeding is unexceptional. Nogueira [17] tested the cactus palm (*Opuntia ficus* indica) ensiling and found large amount of lactic acid (80.2 g/kg DM) and a high propionic acid content (8.1 g/kg DM). These acids have no relation

with the decrease in silage intake. Then it is possible that cactus palm silage may show a high animal intake index.

Chemical composition of forage pass by changes that alter the forage structure ensiling (**Table 2**). When ensiling, maize showed decrease in WSC (-59.5 g/kg DM), Neutral detergent fiber (NDF) (-25 g/kg DM), hemicellulose (-25 g/kg DM) and cellulose contents (-11g/kg DM), and increase on acid detergent lignin (+11 g/kg DM) [18].

Crop	Chemical composition									Author
	DM	CP (g/kg DM)	WSC (g/kg DM)	NDF (g/kg DM)	ADF (g/kg DM)	ADL (g/kg DM)	HEM (g/kg DM)	CELL (g/kg DM)	ASH (g/kg DM)	
Fresh maize	297.0	–	88.0	555.0	325.0	57.0	230.0	268.0	–	Filya and Sucu [18]
Maize silage	297.0	–	28.5	530.0	325.0	68.0	205.0	257.0	–	Filya and Sucu [18]
Fresh sorghum	361.0	108.0	67.0	608.0	359.0	65.0	–	–	46.0	Amer et al. [57]
Sorghum silage	352.0	116.0	18.0	609.0	361.0	43.0	–	–	50.0	Amer et al. [57]
Fresh pearl millet	230.8	116.8	–	595.0	321.4	–	273.6	279.8	–	Guimarães Jr. [58]
Pearl millet silage	241.9	112.5	–	486.8	288.8	–	198.1	256.2	–	Guimarães Jr. [58]
Fresh calliandra	450.5	212.1	–	551.8	488.8	215.7	63.0	299.8	–	Ridwan et al. [15]
Calliandra silage	465.4	202.2	17.9	538.4	448.8	134.1	89.6	307.0	–	Ridwan et al. [15]
Fresh Piatã grass	184.0	139.0	–	673.0	372.0	43.0	–	–	–	Costa et al. [59]
Piatã grass silage	265.5	97.8	–	632.5	405.8	43.0	–	–	–	Costa et al. [59]
Fresh *P. Purpureum*	312.5	45.2	–	746.2	510.1	382.0	236.2	73.5		Ridwan et al. [15]
P. Purpureum Silage	311.9	56.0	–	665.8	492.1	343.6	173.7	87.9		Ridwan et al. [15]

Table 2. Chemical composition of pre-ensiling of forage and silage.

Some forage after ensiling, as Pearl Millet and Calliandra, show increase in the DM content and decrease in CP concentration and fibrous fractions of forage (NDF, NDA, ADL, hemicellulose and cellulose). The reduction in fibrous fraction is positive to silage degradability, because it expands the activity area of rumen microorganisms and resealing energy.

Others forages, such as sorghum, may show higher ash content after ensiling. This can occurs due the biochemistry reactions of organic acids and salt formation. The exposure of the silage to air, making the anaerobic environment to aerobic, is one of the factors that influence the

nutritional value of silages. In the presence of air, deleterious and opportunistic aerobic microorganisms can develop rapidly and degrade nutrients from silages.

Sugarcane and corn are forage susceptible to aerobic stability problems because the high lactic acid concentration and residual WSC promote an ideal environment for the development of deleterious microorganisms, such yeasts. In **Table 3**, it is observed that after exposure to air over time (8 and 9 days), there was a reduction in the WSC content of corn silage and an increased DM content [8]. The sugarcane silages showed an increase in the NDF and CP contents and reduced lignin (ADL) and non-fibrous carbohydrate (NFC) contents [19]. These changes in the chemical composition of silages can interfere on intake and digestibility of silages.

Crop	Chemical composition							
	DM (g/kg DM)	CP (g/kg DM)	NDF (g/kg DM)	ADF (g/kg DM)	ADL (g/kg DM)	NFC (g/kg DM)	WSC (g/kg DM)	ASH (g/kg DM)
Sugarcane	269.1	30.0	554.8	439.5	72.5	375.8	–	–
Sugarcane silage	238.2	31.9	633.3	479.2	83.7	282.0	–	–
Sugarcane silage (d3)	340.5	38.9	659.7	493.3	82.3	245.2	–	–
Sugarcane silage (d6)	359.2	37.8	709.7	440.4	69.2	195.8	–	–
Sugarcane silage (d9)	299.7	42.7	704.7	414.6	59.4	196.0	–	–
Maize	339	71	409	198	–	–	–	35
Maize silage	317	78	384	206	–	–	18	37
Maize silage (d0)	360	75	354	203	–	–	17	35
Maize silage (d2)	366	73	370	209	–	–	18	37
Maize silage (d4)	371	76	358	217	–	–	15	35
Maize silage (d6)	389	75	356	208	–	–	9	35
Maize silage (d8)	395	76	362	206	–	–	11	35

Source: Adapted from Balieiro Neto et al. [8] and Gerlach et al. [19].

Table 3. Changes in the chemical composition of fresh forage, silage at silo opening and silage exposure to air.

In ruminant animals, the intake is regulated by psychogenic, physiological or physical mechanisms [11]. The psychogenic mechanism is related to aspects of smell and palatability of the food [20].

Palatability is the property of a food that affects its taste or smell as perceived by animals with particular experiences under specified conditions. The palatability may be a basis to the silage

intake problem [21]. The end-products of fermentation in silage can affect the animal intake through palatability [22]. In addition, the palatability depends on the animal species.

The regulation of intake in ruminants can occur through of humoral factors because the volatile fatty acids (VFA) have the ability to limit the intake. The intake varies with the energy requirements of the animal. The physiological mechanism can be observed when provided with high concentrate diets, as animals in confinement. As silage has a considerable content of organic acids due the fermentative process, the intake of silage tends to be lower than the original forage. Some silage fermentation products can reduce the intake of silage, such as acetic acid [23].

Animals with diet rich in forage prevails the intake limited by the physical capacity rumen. The NDF is the main fraction of diet that provides this effect because it is slow and incomplete digestion in gastrointestinal [11]. In this situation, repletion has a significant effect on animal capacity in DM intake. The physical distension of the reticulum-rumen is the main factor limiting the intake of fodder and many diets rich in fiber [14].

Fiber fraction is an important parameter to be considered for the animal intake, because it is negatively correlated with intake and digestibility [7]. Even with the lower fiber content when compared to hay, silage tends to be less intake by the animals. In the experiment evaluating the effects of fermentation on the intake and digestibility of silage [24], the authors found an average of 16% lower intake of silage compared to the intake of hay. They noted that this reduction in intake was due to the presence of fermentation end-products.

The major source of ingredients in dairy cow diets is the forage. Despite their important (economically and nutritionally), the forage has been a study object for a long time [12].

Crop	Intake dry matter (kg/d)	Digestibility			Animal species	Author
		IVD (%DM)	TIVD (%DM)	AD (%DM)		
Corn silage	22.80	–	–	71.30	Cow	Hassanat et al. [12]
Alfalfa silage	21.70	–	–	69.70	Cow	Hassanat et al. [12]
Sugarcane *in natura*	–	63.93	66.50	–	–	Balieiro Neto et al. [8]
Sugarcane silage	–	59.72	62.11	–	–	Balieiro Neto et al. [8]
Sorghum silage (SS)	5.91	–	–	48.32	Sheep	Simon et al. [35]
SS + 15% concentrate	7.09	–	–	61.96	Sheep	Simon et al. [35]
SS + 15% concentrate	7.81	–	–	68.12	Sheep	Simon et al. [35]
SS + 15% concentrate	7.98	–	–	69.77	Sheep	Simon et al. [35]

IVD = *in vitro* digestibility; TIVD = true *in vitro* digestibility; AD = apparent digestibility.

Table 4. Intake and digestibility of silage index.

Evaluating the effect of replacing alfalfa silage to corn silage on diet intake of dairy cows, among other parameters, Hassanat et al. [12] found values of 21.7 kg/day DMI alfalfa silage and 22.8 kg/day DMI corn silage (**Table 4**). The difference on intake silage in these silages may occur due chemical composition and fermentative profile. As mentioned before, butyric and acetic acid are associated with decreased intake silages. These acids were found in greater quantity in alfalfa silage than in corn silage.

3.1. End-products of fermentation

The ensilage is a complex process and it yields a variety of compounds and forage quality is a term used to refer to the nutritional value of plant in interaction with the animal intake and performance potential. About silage, the animal response is dependent on its fermentative profile that affects the food structure, nutrient concentration and intake [3].

The quality of the silage is influenced by factors such as plant species, indigenous microbiota, crop management, cutting and ensilage procedure, as well as environmental factors and storage. The variation of silage quality can influence the intake by animals. The composition and concentration of fermentation end-products of the silage are variable, most commonly found fermentation produces lactic acid, however, other types of fermentations occur and may decline the nutritional quality of the silage [4]. The fermentation quality should be included in assessment of the DMI potential of grass silages [24].

Although intensively discussed, there is no agreement on the indices of fermentation quality when evaluating the dry matter intake of the silage [5, 24], however, some factors may be identified for reducing the intake of silage.

Researchers evaluated the production of fermentative compounds in silages and they found 13 esters, 5 aldehydes, 3 alcohols and 1 sulfide. They observed that the increase in ammonia, acetate and propionate levels, as well as decrease in the WSC content, decrease the intake [22].

Esters are volatile compounds that may take effect on silage flavor reducing the DMI, principally acetate [19]. Other compounds also may influence the DMI, as propionic acid and biogenic amine. According to some studies it is improbable that low propionic acid concentration directly influence the DMI, while the biogenic amine is naturally present in silages and reduce the intake from palatability or by influencing the nitrogen metabolism [5].

An indicator that can be related to the DMI is pH. Researchers evaluating changes in the fermentation of corn silage exposed to air [16] found a positive correlation between pH and DMI, if pH is relatively high, and a greater intake of silage. This is justified because of the absence of excessive organic acids or ammonia-N fermentation [5, 19].

The fermentation process of the silage not just can generate products that inhibit the animal intake; the reactions resulting from the silo opening procedure can also promote reduction of silage intake. The aerobic deterioration is a significant problem that affects the yield and quality of silage [25]. It is caused by the activity of bacteria, yeasts and molds that can compromise the final nutritional value of the silage, changing the volatile and depressed intake [19].

In a study on the effect of aerobic deterioration of silage on goat intake, the authors found intense degradation of lactic (by yeasts) and acetic acids, decrease in WSC after air exposure. After eight days, it was more than half with reductions ranging between 29 and 79% in comparison to fresh silages. Some end-products of fermentation (ethyl lactate, ethanol) were negatively related to silage intake. However, correlation coefficients were weak. Concentrations of acetic acid and ethanol were negatively correlated with DMI, but the authors justified that lower DMI is due to the greater concentration of acetic acid in fresh silages which compensate for improved aerobic stability and smaller decline in DMI is a consequence of aerobic deterioration [19].

3.1.1. Lactic acid

The lactic acid is an organic acid produced by conversion of soluble carbohydrates by lactic acid bacteria. The lactic acid content should be at least 65–70% of the total silage acids in good silage [26].

The lactic acid concentration in silages may to decrease the efficiency of microbial protein synthesis in the rumen whenever the values are high [27].

3.1.2. Acetic acid

Extremely wet silages or slow silo filling can result in silages with high concentrations of acetic acid (>3–4% of DM). Acetic acid concentrations are also related principally to long-acting of enterobacteria and heterofermentative bacteria [26].

The acetic acid content negatively relates to the intake of silage [28], therefore low levels of acetic acid are desirable in silages [29]. Though it may present a negative aspect to intake, silage inoculants specific with the largest production of acetic acid did not show a reduction in animal intake [26].

In assay sheep fed with silage, the authors [21] found decrease in the intake of silage when adding acetic acid. The reduction in intake is justified due to the taste and odor of silage. In other studies, DMI was negatively correlated with acetic acid [19].

3.1.3. Butyric acid

Concentrations of butyric acid are negatively correlated with digestibility [24]. A high concentration of butyric acid (>0.5% of DM) indicates that the silage has a poor fermentation, clostridia fermentation. Silages high in butyric acid have a low nutritive value and many of the soluble nutrients have been degraded. They may contain compounds such as amines that have sometimes shown adversely affect animal performance, also the intake [26].

The butyric acid content reflects clostridia activity on ensiled mass with a deleterious effect on quality and reduction of silage palatability [29].

3.1.4. Ammonia

The ammonia-N is often associated with the decrease in the intake of silage because of their presence in poorly fermented silage or clostridia. Some other products resulting of degradation of amino acids also can decrease the intake of silage [21].

The proteolysis by plant and microbial enzymes may lower the nutritive value of ensiling forage by degrading the forage protein fraction into peptides, amines, free amino acids and ammonia. This permit proteolytic bacteria ferment peptides and amino acids converting them into a diversity of organic acids, CO_2, ammonia and amines, products that decrease the voluntary intake of silage [30]. Generally, the ammonia concentration is used as an indicator of protein degradation in silage [5].

Although microorganisms as enterobacteria have low proteolytic activity, it can deaminate and decarboxylate some amino acids contributing to the formation of ammonia and biogenic amines in silage, which have a negative effect on silage palatability and intake in ruminants [31].

Ammonia concentrations are negatively related to the intake of silage. In grass silage, high moisture favors the butyric fermentation and release of ammonia, which negatively affect the intake of silage by animals [1]. According to Huhtanen et al. [5] index, ammonia concentrations greater than 50 g/kg N predict decrease in silage DMI.

4. Factors that affect silage digestibility

Digestion is a process of conversion of food macromolecules into simple compounds that can be absorb into the gastrointestinal tract [10].

Concentration of ammonia-N in rumen is indispensable for microbial growth since it is associated with the energy source, and it is related to soluble protein of diet and to N retention of the animal. High ammonia concentrations may occur when excess protein in the diet is degraded in the rumen or a low concentration of carbohydrates is degraded in the rumen, which can cause changes in rumen pH changing the microbial activity and its functions in the digestive process [10].

The digestibility of ruminants is associated with the characteristics of food and the animal. The relationship between intake and digestibility, in which the increase in digestibility leads to increased intake, is influenced by forage residence time in the rumen [32].

Some factors, such as the proper processing of forage for silage, contribute to improve the digestibility of the final product. Researchers evaluated the effect of the length of the whole plant corn on intake, digestibility and production of milk [33], they found positive results regarding the effect of whole plant processing for corn silage with increased body weight, increased DM intake, greater starch and fiber digestibility. Still, the estimated average increase in starch digestibility in the ensiled plants was 4.2% above the initial herbage unprocessed digestibility.

The yield of fermentation end-products in silage is variable, depending primarily on the amount of substrates and microbial flora. Some silage may contain up to 200 g/kg DM of fermentation end-products, especially lactic acid and VFA, which provide low energy for the rumen microorganisms [34].

Other factors such as exposure to air and use of additives can influence silage digestibility. The fermentation type interferes in the result of silage intake and digestibility. Corn and alfalfa silages have different digestibilities (**Table 4**). Compared to fresh forage, digestibility of silages is lower [8], but this can be modified.

The use of additives as concentrate ration can increase intake and digestibility of silages. The total mixture ration is an efficient technique and may increase intake and digestibility of silages, obtaining considerable increases in apparent digestibility [35].

4.1. Changes in the fermentation process that affects silage digestibility

Degradability of silage is positively correlated with WSC and LA [24].

The fresh forage has approximately 75–90% of the total nitrogen present in the protein form [29], the rest called non-protein nitrogen comprises free amino acids and amides, and ammonia with concentration less than 1% of total nitrogen. During the fermentative process of silage, part of nitrogen fraction is degraded to soluble fractions as peptides, amino acids and ammonia, which are rapidly degraded in the rumen with low microbial synthesis efficiency and results in inappropriate protein post-rumen flow [36].

According to the research of Mckersie, in 1985 [29], compounds resulting from proteolysis and degradation of amino acids formed during fermentation of silage can inhibit the intake and have low utilization efficiency of the microorganisms present in the rumen [29]. The concentration of ammonia in good silages should be low, not to influence the silage intake negatively [7].
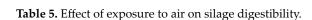
During the ensiling process the breakdown of hemicelluloses occurs to provide additional substrate for the fermentation, because concentrations of NDF in the silages are lower than the original herbage. The degradation of hemicellulose also can occur through hydrolysis by organic acids or action additives [4].

Compared with the herbage, concentrations of NDF can be altered by breaking the nitrogen bound to NDF, but an increase in the concentrations of NDF and ADL in silage may occur due to DM losses or effluent losses of soluble nutrients [24]. Concentration of ADL increases also due to synthesis of Maillard polymers [7], which may present positive correlation with ADIN. The changes in the fiber fractions attributable to the fermentative process of silage could influence digestibility [24].

Researchers evaluating different proportions of sorghum silage in diet of beef cattle compared to Tifton grass pre-dry, found an increase in dry matter, organic matter and total carbohydrate digestibility on adding a higher proportion of sorghum silage to diet. The authors justified that the increase of digestibility occurs due the lower NDF proportion and greater TDN (total digestible nutrients) which has rapid and complete availability in the gastrointestinal tract [10].

The exposure to air of silages affects the silage digestibility. The effects of air on silage can reduce the digestibility (**Table 5**). Sugarcane silage show lower digestibility than fresh sugarcane, and after 3, 6 and 9 days of exposure to air, sugarcane silage has reduced 7.20% of *in vitro* digestibility (IVD) and 2.7% true *in vitro* digestibility (TIVD). This reduction can be avoided or minimized by adequate ensiling management procedures and storage of silage, in addition, to the use of additives.

Crop	Digestibility	
	IVD (%DM)	TIVD (%DM)
Sugarcane	63.9	66.5
Sugarcane silage	59.7	62.1
Sugarcane silage (d3)	57.5	58.7
Sugarcane silage (d6)	54.5	58.3
Sugarcane silage (d9)	55.4	59.4

Source: Adapted from Balieiro Neto et al. [8].

Table 5. Effect of exposure to air on silage digestibility.

5. Alternatives to improve intake and digestibility of silages

5.1. Use of biological additives

The use of inoculants, especially lactic acid bacteria (LAB), is in an attempt to improve the efficiency of preserving the nutritional quality of the forage. In a review of experiments with inoculants, researchers found positive results for improving the feed intake, fed efficiency and milk production by about a third of the studies review; it is justifying the use of inoculants on silage also the effect on animal performance [34].

Some studies suggest a possible effect of LAB probiotics, although the mechanisms are unclear. Probiotics is a live microorganism in the food supplement that beneficially affects the host animal by improving intestinal balance [37]. One hypothesis is that specific strains of LAB interact with microorganisms of the rumen improving their function and animal performance [38–40]. Researchers found that LAB from silage inoculants could survive in rumen fluid for at least 96 hours, which would allow the probiotic activity [41].

Although the effects of LAB inoculant are not well studied, there may be still, the action of a type of bacteriocin that limits the bacterial activity, which can inhibit or harm the microorganism in the rumen [39, 40]. Bacteriocins are biologically active proteins produced by LAB that are active against other bacteria, mainly grampositive bacteria as *Listeria monocytogenes* [42]. In an experiment, Amado et al. [42] observed that bacteriocin producing strain inhibits the activity of other undesirable microorganisms in silage.

Recent studies demonstrate that some heterofermentative bacteria [*Lactobacillus buchneri*, for example] produce ferulate-esterase, enzyme that increases the degradation of the cell wall. This enzyme release considerable soluble carbohydrates for fermentation or for use by rumen bacteria [43].

An enzyme-bacterial inoculant acts in two forms in silage: whereas bacterial inoculants improve fermentation profile and increase lactic acid bacteria population, enzyme inoculants act on the cell wall and the available higher quantity of soluble compounds, with improvement in silage digestibility [44].

Researchers study the effect of inoculants on silage, rumen function and digestibility. They found improvements in DM and NDF digestibility after 24 hours of incubation [38]. Others studies also found higher DM and NDF digestibility in inoculated corn silage than untreated silage [39].

Although there are some positive results, in the experiment realized by Fugita et al. [42], the addition of enzyme-bacteria inoculants do not significantly influence nutrient intake, performance and carcass characteristics of feedlot finished crossbred bulls.

The use of microbial additives in sorghum silage resulted in positive responses to the hemicellulose content and value on *in vitro* DM digestibility. The lower hemicellulose content of the silage treated compared to control may result from the action of enzymes associated with bacteria, and the greater IVDMD found may reflect the enzymatic hydrolysis effect [45]. However, it has been reported that the effects of LAB inoculants on fiber degradation are not consistent [18] as LAB cannot use fiber as an energy source [46]. The hemicellulose degradation by LAB inoculation is inhibited in lower environmental temperature, requiring optimum temperature for its activity [47].

5.2. Use of chemical additive

Additives in silage can affect the DM intake and intervene in the nutritive value of silage, as digestibility of nutrients. Chemical additives are substances that act in the control of biochemical reactions of silage. The inhibitor additives function without distinction in all processes in the silage acting on undesirable microorganisms and fermentations, as the secondary proteolysis or aerobic growth. Among the main additives chemical inhibitors there are urea [48], propionic and formic acid.

Urea is an additive that contains between 42 and 45% of nitrogen [48], commonly used in fodder ammonization due to ease of application, not a pollutant, but as a source of non-protein nitrogen, reduce the fibrous portion of forage (NDF), favor the partial solubilization of hemicelluloses, influence the increase in intake and digestibility of silage [49]. According to the classification McDonald et al. [4], urea is also a nutrient additive because it improves the nutritive value of silage.

Researchers showed the increase in the protein content of silage as result of high recovery of nitrogen applied and may reach up 77% recovery [50]. Nitrogen recovery is a positive feature of urea from both the nutritional and economical aspect. Urea also acts beneficially in the

fibrous portion of the ensiled forage. Two main processes occurring in ammoniated forage mass with urea: ureolysis and ammoniolysis.

The ureolysis process is an enzymatic reaction that release ammonia through hydrolysis of urea. The ureolytic bacteria produces urease [an enzyme catalyst present in plants], that acts in the presence of moisture hydrolyzing the urea and producing two ammonia molecules [which acts directly on the cell wall of forage] and one carbon dioxide [48, 51].

From the urea hydrolysis occur chemical reaction ammoniolysis between the ammonia and the ester bonds existing between chains of hemicelluloses and between groups of carbohydrates or carbohydrate molecules and lignin, resulting in formation of an amide [52]. The ammoniolysis cause lysis on bonds between the structural carbohydrates releasing and increasing the contact surface to the rumen microorganisms [53].

In addition, there is another important factor to consider, ammonia has a high affinity for water resulting in the formation of weak base, ammonium hydroxide [NH_4OH]. The high affinity of ammonia to water promotes expansion and rupture of the cell wall components of tissues of forage treated with urea. Through specific studies using electron microscopy, change of cell wall can be seen [49].

Another chemical additive, propionic acid is used as antifungal agent able of preserve forage for much time. It inhibits undesirable microorganisms and improves the aerobic stability of silages [54].

In an experiment test, Chen et al. [54] evaluated the effects and propionic acid applied on the fermentation quality and aerobic stability of total mixed ration silage (TMR) prepared with whole-plant corn in Tibet. They applied 0.4% propionic acid on a fresh matter basis of TMR, and found higher WSC concentration (88.92 g/kg DM) and decrease in butyric acid content (0.04 g/kg DM) in TMR after 45 days of ensiling, comparative to no additive TMR (WSC = 39.99 g/kg DM; butyric acid content = 0.19 g/kg DM). In aerobic stability assay, TMR silage with propionic acid showed low pH, higher WSC concentration and lower ammonia content than no additive TMR silage after 12 days of air exposure (**Table 6**).

	Control TMR silage				TMR silage with 0.4% propionic acid			
	0	6	9	12	0	6	9	12
pH	3.90	4.28	5.1	7.07	3.89	3.88	3.87	3.75
LA	86.53	66.95	38.63	15.49	65.44	83.34	83.42	67.09
WSC	39.99	29.16	34.64	29.56	88.92	78.23	72.23	54.23
NH$_3$-N	52.83	51.87	55.38	65.59	42.48	41.94	51.72	57.36

Source: Adapted from Chen et al. [54].

Table 6. Chemical characteristics of total mixture ration silages (TMR) at opening silo and after exposure to air.

The inhibition of undesirable microorganisms in silage (able to realize proteolysis) reduced the adverse compound formation. The decrease in ammonia and butyric acid in TMR silage is desirable because these compounds may affect food intake in the ruminants.

Besides propionic acid, formic acid is an inhibitor of undesirable fermentation. Selwet [55] evaluated the effects of different levels of mixtures of formic and propionic acid on changes in the chemical composition and on aerobic stability of maize silages exposed to air during the process of feeding to animals.

The results showed that the inclusion in maize silages of the propionic and formic acid mixture reduced undesirable microorganisms and positively influenced the changes in silage chemical composition. Silages treated with acids were characterized by higher dry matter, WSC and crude protein concentration, which could have been associated with the smaller losses of nutrients due the limitation of development of some groups of microorganisms [55].

Concentrations of acetic acid in additive silages were also decrease. The author concluded that this result is a favorable phenomenon because high concentration may limit feed intake by animals.

In an experiment, Kung et al. [56] tested different mixtures of preserving agents such as acetic and propionic acid and ammonia on the intake and digestibility of lactating cows fed TMR silages. The TMR were composed of alfalfa silage (27%), corn silage (43%) and pelleted concentrate (30%), and additives.

There was no significant difference between the dry matter intake, daily milk yield, fat and milk protein in dairy cows fed on untreated TMR and TMR treated with chemical additive after exposure to air. Although this study found no difference between the performances of dairy cows, other tests reported that feed intake by sheep was negatively affected after silage exposure to air for 5 days, when compared with fresh corn silage [56].

The use or not of a chemical or biological additive does not dispense the necessary care during the fermentative process of ensiling, because the quality of silage is directly related to species of plant, sol fertility, cultural tracts, ensiling point, compaction and sealing of silo, since only the additive does not match a considerable increase in silage quality produced [48].

6. Final considerations

The ensiling process is complex and yields a variety of end-products of fermentation. These products can influence directly and indirectly the intake and digestibility of silage. Some control mechanisms of this fermentation can be of use for improvement on intake and digestibility.

Biological or chemical nature, additives may contribute to the increased intake of silage, as well as improve digestibility. To choose the ideal additive, it is necessary to understand the factors that limit the intake and digestibility of food.

The exposure of silage to air is an inevitable phase and which may compromise the nutritional value of the silage when realized incorrectly. Appropriate management techniques can influence the result.

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