Chapter 4

Ensiling of Forage Crops in Semiarid Regions

João Paulo Farias Ramos, Edson Mauo Santos,
Ana Paula Maia dos Santos,
Wandrick Hauss de Souza and Juliana Silva Oliveira

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/101990

Abstract

Edaphoclimatic condition of the semiarid region is unfavorable for the forage production of livestock. Silage is considered a better alternative to conserve forage crops. Ensiling is a technique for preserving forage, in which the ensiled mass is acidified under anaerobic conditions. The lactic acid bacteria present in the environment produce lactic acid, thereby making the environment acidic, and convert soluble substrates into organic acids. Many microorganisms are involved in the fermentation process of silage and their development depends on the characteristics of ensiled materials, such as dry matter, water-soluble carbohydrate content, buffering capacity and presence of indigenous microbial. Ensiling is a favorable technque used in the semiarid region because it preserves the nutritional values of the crops and the water. Some plant species are produced in semiarid regions because they are resistant to water deficit and high solar radiation. The main crops of semiarid regions are sorghum, pearl millet, grasses, cactus pear, and leguminous. Due to agronomic conditions available for their production during periods of rain, for ensiling these plants are important for the fermentation profile of each species because the ratio of the dry matter to water-soluble carbohydrate content and buffering capacity directly influence the end product of silage.

Keywords: cultivate crop, drought, forage preservation, forage silage, tropical crop

1. Introduction

The semiarid regions are characterized by an irregular distribution of rainfall with greater variability between years and within the same year, and high solar radiation. This hydric variability originates from complex systems of the formation of rain, with the occurrence of concentrated rain in a few months of the year and alternate years, irregularity, existence of geographic barrier concentrating higher humidity in the valleys and leaving dried slopes, and variability of soil with greater or lesser ability to retain water [1].

The variability of rainfall provides the diversity of fauna and flora species in the semiarid region. The soil and climate conditions are associated with the characteristics of species, such as solar radiation, sunshine, and air temperature. The climatic variations suggested that animal production systems operate according to the availability of resources and controlled principally by the availability of water, adopting rational strategies for production.

In semiarid regions, annual rainfall is irregular, low, and highly variable in space and time, with permanently high evapotranspiration rate. Therefore, the agricultural systems used in the semiarid region should be based on plants that develop efficiently and quickly by using the resource availability of pulses [2], because the water dynamics is the main variable for controlling the transformation process of individual nutrients available for plants.

Tropical regions, such as semiarid regions of Brazilian, may have a high capacity for forage production, but climatic variables make it difficult for the development of the animal production system. The quantity and quality of forage are key factors for animal production. The management also influences the forage characteristics and animal production. During the dry season, a significant reduction in native vegetation occurs, and this affects animal forage production.

The shortage of forage during the dry season and low nutritive value of forage may compromise the animal production, resulting in decreased productivity. In this situation, the producers become dependent on the availability of the preserved forage, hay, and silage, cultivated forage crops, and crop residues to feed cattle in the semiarid region [3].

For the efficient production of forage in the semiarid regio, it is essential to know conditioning factors inherent to soil, climatic condition, and plant interaction mechanisms to drought and production capability. Adapted crops, due to their efficiency in the accumulation of green matter in these climatic conditions, are available as a more viable option to the semiarid region. Among other considerations. the forage conservation practices, silage is a better alternative to reduce the qualitative and quantitative fluctuations in the supply of forage to the animals.

As a literature review, this chapter presents scientific reports on ensilage of forage with productive potential for the semiarid regions. This study presents the main crops for ensilage in the semiarid regions and their fermentation characteristics.

2. Influence of drought on the production of the crops in the semiarid regions

Drought is the meteorological event when there is inadequate water availability in the soil or rainfall, including quantitative and qualitative, during the life cycle of a plant, limiting full expression of the gene of the plant potential and preventing the maximum yield from a culture [4].

The planning activities of animal production in drought regions should take into consideration some factors, such as production yield, drought resistance, and water-use efficiency by plants, for crop production. Although a culture presents high production yield, this may not be compatible with higher drought resistance or increased water-use efficiency [5].

In rainfed situations where crops depend on unpredictable seasonal rains, the maximum use of soil moisture is a crucial component for drought resistance, that is, water-use efficiency allows the production yield even in the situations of water deficit [5].

Drought resistance is the ability of a plant to produce with minimal loss in a water-deficit environment. Drought resistance mechanisms can be classifieds into the following three categories: drought escape, drought avoidance, and drought tolerance [6].

Drought escape is the ability of plants to complete the life cycle before there is a serious water deficit for plant and soil. The phenological development of plants is fast with early flowering and maturity and the duration of the growing season depends on water deficit [6]. The success of these species depends on the efficient reproduction before a more intense water stress. With short life cycle and high growth rates and storage, this process uses reserve for seed production [7].

Drought avoidance is the ability of plants to maintain some potential of water in the tissue even with low moisture in the soil. The better absorption of water, mobile water storage, and reduction of water losses are some of the processes that are used for these plants. The balance between turgor, increased depth of rooting, higher absorption efficiency, and lower losses of water allows the survival of plants under dry conditions [6]. Furthermore, older leaf senescence reduces the energy cost of the plant [7] directing all the energy to dry the adaptive mechanism.

Drought tolerance is the ability of plants to resist water deficit with low potential of water in the tissues [6]. In water-limited environments, the plants can produce forage mass using water maintenance mechanisms in the plant. One of the processes is the osmotic adjustment. Osmotic adjustment is an adaptive response to cellular stress that in some cultures increases the avoidance dehydration and supports the production yield under stress [5]. Osmotic adjustment maintains turgor and resists to dehydration through solute accumulation in the cell, an increase in cell elasticity, and a decrease in the cell size [6].

In drought, these plants maintain the water content accumulating several nontoxic solutes that do not interfere with metabolism; these are compatible solutes such as fructan, trehalose, polyols, glycine, proline, betaine, and polyamines [4, 8].

Although the drought resistance is important for crop production in semiarid, the adjustments resulting from this drought tolerance have disadvantages because of lower production output. The stomata closure and reduction in leaf area result in lower carbon dioxide assimilation and higher osmotic adjustments that can have a negative effect on the plant energy requirement [4].

Cultivate crops are grown using more than one mechanism to resist drought [9]. Thus, it is interesting to note that the adaptive mechanisms of crops grown in the semiarid region have a balance of escape, avoidance, and drought tolerance, maintaining the yield production as much as possible. Through conventional breeding or biotechnological methodology, the development of superior genotypes resistant to drought is possible [4].

Most of the crops produced in the world are sensitive to water deficit. Even cultivative crops, such as pearl millet, sorghum, and pigeon pea, in semiarid regions are affected by drought during the reproductive stage [4].

The C4 plants are considered to be dominant in resistance and drought tolerance because they are capable of maintaining photosynthesis with closed stomata. Even with the small reduction of photosynthesis under water stress conditions, the C4 crops such as sorghum and panicum have the ability to grow in dry region and are considered to have a great potential for enhancing forage production and food security in the world [7]. The C4 plants provide competitive conditions of low availability of water, high temperatures, and high light intensities [10]; they have high water-use efficiency and mechanisms for CO_2 concentration [7].

Other factor that influences the nature of response of plants to drought is the thermal stress. Thermal stress can reduce transpiration and can dehydrate the plant cells, reduce the availability of nutrients, and cause osmotic stress together with the drought. In the plant growth stage, water stress can interfere with the final yield production of the crop [7]. Corn yield, for example, is a culture that is extremely sensitive to water stress during the period of the previous life cycle of flowering. Crops such as sugarcane may have a greater impact of water stress when its leaves are establish than in the initial period, which may affect the final yield [7, 11].

The adaptive responses are based on complex changes to cope with stress, primarily to maintain water potential in main tissues. Crops such as sorghum and pearl millet are drought tolerant and cultivated on a large scale in the semiarid region. These crops are able to maintain photosynthetic activity under water stress conditions and thus increase the final yield [12].

The osmotic adjustment required for drought tolerance forage can increase the solute values as fructan [4, 8] increases the values of soluble carbohydrate in these forage.

The concentration of water-soluble carbohydrates (WSC) in ensiled materials influences the fermentation profile because the WSC concentrations are used for the production of lactic acid [13]. The minimum content of WSC to appropriate fermentation of good silage varies between 6 and 12% [14]. In contrast, a large amount of WSC concentration may predispose to undesirable occurrence of fermentation realized from yeasts because of the excessive lactic acid production, which leads to losses resulting from the alcoholic fermentation [15].

In the semiarid region, there is a tendency that the forage contains a higher WSC content. The forage sorghum, pearl millet, and buffel grass show a WSC concentration (DM basis) of 13–20, 9, and 3.1%, respectively [16].

3. Ensiling process

Ensiling is a method of forage conservation. It is based on natural fermentation, in which lactic bacteria convert the WSC into organic acids (principally lactic acid) under anaerobic conditions. As a result pH decrease and the silage is preserve [17]. The primordial objective of forage ensiling is to preserve the original composition of nutrients found *in natural* plant during storage with minimum losses [18].

The forage conservation as silage depend on favorable conditions, such as the amount sufficient WSC to lactic acid production and low buffering capacity, which promote rapid lowering of pH that inhibits the growth of some deleterious microorganisms, maintaining the nutritional values of forage.

Before the ensiling process, aerobic and facultative anaerobic microorganisms are able to grow in high pH and predominance. As long as pH decrease and oxygen is consumed, the anaerobic and anaerobic facultative acid tolerant bacteria grow in the environment.

Ensiling is divided into four phases with different time and intensity [19, 20].

• Aerobic phase: It occurs during filling of silo and extends until a few hours after the packing of silo. The aerobic phase is undesirable because all obligatory and facultative aerobic microorganisms (yeasts, molds, and bacteria) are active in this phase, but it is an inevitable phase. As it is associated with the fermentable substrate and energy losses, it is important to reduce the duration of this phase. It recommended that the forage be chopped, compacted, and rapid packing of the silo [13]. The final stage of the phase includes exhaustion of oxygen in silo.

• Active fermentation phase: After exhaustion of oxygen in silo, there is a decrease in silage pH because of organic acids production from WSC. In initial, enterobacteria and heterofermentative lactic bacteria grow in ensiled mass. With the larger decline of pH, homofermentative lactic bacteria dominate the anaerobic environment. In this phase, there is the more production of organic acid, such as acetic and lactic acids, and also ethanol and CO_2. The major growth of lactic acid bacteria (LAB), and consequently, larger lactic acid formation inhibit the development of other microorganisms, principally due to lowering of pH. This phase extends to the stability and reduces excessive microbial activity.

• Stability phase: It a phase with low biologic activity, since it does not penetrate air in the ensiled mass. The pH permanence is stable in 3.8–4.2, inhibiting microbial activity. Only some acid tolerant enzymes maintain activity [20]. The acid pH and anaerobic conditions maintain the ensiled mass stability to the silo opening.

• Discharge phase: It occurs at the opening of the silo and expose the ensiled mass to high oxygen concentration, which favors the growth of enterobacteria, molds, yeasts, and other microorganisms. Yeasts are the first microorganism to develop in silage after the opening, causing deterioration of the conserved forage [13]. There are heat and CO_2 production due respiration, which results the decrease in lactic acid and residual WSC, and increase in silage pH [13]. The appropriate management may minimize the losses after opening of silo.

3.1. Microorganism involved in the ensiling process

The ensiling process is complex and variable. It consists, basically, in conjunct action of the large number of microorganisms and may be considered a metabiose because it occurs at simultaneous and successive development of different microorganisms that depends on specific pH, substrates, and potential redox in environment of silo.

The microorganisms present in plant before ensiling may be aerobic and anaerobic, desirable and undesirable to fermentation. **Table 1** presents the most common types of microorganisms and their presence in plants.

Groups	pH
Total aerobic bacteria	>10,000,000
Lactic acid bacteria	10–1,000,000
Enterobacteria	1000–1,000,000
Yeasts	1000–100,000
Molds	1000–10,000
Clostridia	100–1000
Bacillus	100–1000
Acetic acid–producing bacteria	100–1000
Propionic acid–producing bacteria	10–1000

Source: Adapted from Pahlow et al. [20].

Table 1. Typical bacterial and fungal population of plants groups before ensiling.

				Recuperation (%)	
Organism	Rota	Substrate	Product	Energy	DM
LAB	Homofermentative	Glucose	2 Lactate	96.9	100
LAB	Heterofermentative	Glucose	1 Lactate + 1 Acetate + CO_2	79.6	83
LAB	Heterofermentative	Glucose	1 Lactate + 1 Ethanol + CO_2	97.2	83
Yeast		Glucose	2 Ethanol + 2 CO_2	97.4	51
Clostridia		Glucose	1 Butyrate + 2 CO_2	77.9	66
Enterobacteria		2 Glucose	1 Lactate + 1 Acetate(1 Ethanol) + CO_2	88.9	83

Source: Adapted from de McDonald et al. [13].

Table 2. Acidify efficiency and fermentation and main fermentative routes of microorganisms in silage.

The microorganisms present in plants are diverse in genera and species with different fermentative routes. Each group has specific temperature and substrate to grow with higher or lower energy demand. In the fermentation process, microorganisms convert soluble substrates into organic compounds. **Table 2** presents the main fermentative routes of microorganism in silage.

The growth of lactic acid bacteria in ensiled mass is important because its metabolism does not result in considerable DM losses, following the principle of forage preservation. The LAB converts one mole of glucose to two moles of lactic acid without DM losses [13].

In situations where the forage has a low amount of substrates may have predominant of other microorganisms, such as enterobacteria, because the pH is not low sufficiently. In the opposite situation, ensiling of forage with excess WSC may be in the presence of acid tolerant microorganisms such as yeasts that are able to consume lactic acid and WSC. The excess WSC in the plant leads to the formation of acid silage due to excessive lactic acid production. Acid silage, such as sugarcane and saccharine sorghum silages, has high ethanol concentration because of alcoholic fermentation.

3.2. Characteristics of forage to ensiling

The dry matter content is an important factor that affects the fermentation and preservation of ensiled mass. The ideal DM content is between 30 and 35% [13]. However, research studies indicated the values to corn silage being necessary attempt to characteristics of each culture, because it might occur good fermentative profile in silage of forage with inferior DM values.

Generally, the high content of moisture favors undesirable microorganisms, such as *Clostridium* and enterobacteria that are butyric and acetic acid and ammonia producers, implying in nutrient losses. However, higher DM content impacts the compaction and reduction of air present [21].

The WSC concentration in ensiled materials influences the fermentative profile, because the WSC concentrations are used for the production of lactic acid [13]. The minimum content of WSC required for appropriate fermentation of good silage varies between 6 and 12% [14].

Other important factors that influence the silage are the buffering capacity that is resistance to lowering the pH of ensiled materials. The compounds able of buffering the environment in forage are some organics acid, potassium, and calcium inorganic bases and nitrogen substances, such as protein and products of their degradation, free amino acids, amine, and ammonia [22]. The action of buffering capacity in silage is associated with other factors such as WSC and DM concentration. Thus, the pH of silage is determined by relationship of protein and water-soluble carbohydrate [22].

3.3. Fermentation loss in the ensiling process

The ensiling process changes the natural structure of forage and may cause some losses. Besides the natural physical losses, such as crop losses, chemical losses also occur and may compromise the energy and nutritive value of silage. Although some losses may be

Process	Losses (%)	Causative agents	Classification
Respiration	1–2	Plant enzymes	Inevitable
Fermentation	2–4	Microorganisms	Inevitable
Effluent	5–7	Moisture	Inevitable
Secondary fermentation	0–5	Plant, moisture, silo environment	Preventable
Aerobic deterioration in storage	0–10	Ensiling time, density, plant, packing	Preventable
Aerobic deterioration in discharge	0–15	Moisture, season, density, technical	Preventable
Total losses	8–43		

Source: Adapted from McDonald et al. [13].

Table 3. Losses in the ensiling process.

unavoidable, such as biochemist changes, plant respiration, and fermentation (**Table 3**), other types of losses can be avoided with appropriate practice of the ensiling procedures.

The energy and dry matter disappearance is an indicative of losses in the ensiling process. The residual respiration during filling the silo and immediately after sealing, types of fermentation, effluent production, undesirable fermentation during the storage, and aerobic deterioration are the main causes of energy and dry matter losses [21].

The losses related to respiration usually occur early. The respiration in silo initially occurs due to the presence of oxygen in the ensiled materials, thus the cellular respiration use the air oxygen and substrates producing CO_2, heat, and H_2O. Some factors can affect the respiration rate in the silo, such as temperature, which increase the initial rate of reaction and destruction of enzymes, usually by denaturation; oxygen concentration, the high amount of oxygen in the silo promotes an increase in the respiration rate and higher the temperature, and consume more energy; WSC content: the amount of soluble substrates in ensiled materials can influence the respiration, since they are consumed during respiration.

Silage fermentation usually causes DM losses due to the activity of microbial and enzymes. The losses related to the fermentation represent the highest percentage of losses in the silage process. These losses can be resulting from the production of water, gas, heat, and effluents during the fermentation process [22].

The effluent losses are associated with the DM content of plant, the activity of the water metabolism and the physical procedure of cutting and application of additives in ensiled forage [23] and DM losses can be highly variable [16]. After evaluating the sorghum silages in Brazilian semiarid we observed a variation of 10–24% DM losses.

In ensiling, besides DM losses, nutritional losses should also be taken into account. Sugarcane and sorghum silages can show high nutritional losses because of a high content of WSC, which may result in increase in alcoholic fermentation. Many studies indicate that the application of additives in the ensiled material considerably reduced these losses of substrates [24–26].

Other fermentation can also occur and reduce the nutritive value of silage, as proteolysis. The proteolysis is associated with DM, protein, WSC content, pH, and ensiling time [27]. It is an undesired reaction because the resulting products of the process (ammonia and amines, principally) indicate high nutritional losses.

In discharge of silo to offer silage to animals aerobic deterioration can also occur, which is one of the main problems after exposure to air [28]. This process occurs due the penetration of air in ensiled materials, which is favorable for the grown of aerobic microorganisms, acid tolerant, and the oxide products resulting in silage fermentative process [29]. The air exposure of silage can chance its chemical compositions and alter the nutritional value.

4. Crops for silage production in semiarid regions

The mains characteristics that determine the fermentation profile during ensiling involve the interaction of factors such as: DM content, WSC concentration, and buffering capacity of plant.

In the case of semiarid, plant species resistance to hydric deficit and climatic conditions are indicated to ensiling. The main forages are sorghum, pearl millet, tropical grasses, leguminous, and cactus pear.

4.1. Sorghum

Sorghum (*Sorghum bicolor* L. Moench) is an appropriate grass for silage with agronomic and nutritional characteristics, because it is tolerant to drought and responds even in soils with limited nutrients [30] and its phenotypic characteristics facilitate planting, management, harvesting, and storage. The other significant characteristic of sorghum is that it will regrowth after each harvesting [31].

The sorghum is a resistant to hydric deficit in semiarid. Their resistance is associated with the physiology characteristics and efficiency of rain. Researchers evaluated the efficiency of rain in sorghum genotypes in semiarid and found positive results, values between 944.37 and 126.25 kg DM/ha/mm that indicated high efficiency in covert water of rain in production [32].

In addition to their agronomic traits, sorghum has desirable characteristics for fermentation, such as a suitable dry matter content, high carbohydrate concentration, and low of buffering substance content [33, 34].

Sorghum is a crop that has desirable characteristics for the production of silage; however, as the WSC concentration is higher in the stem, forage sorghum and saccharine sorghum usually have high concentration of carbohydrates, which can facilitate the multiplication of yeasts, molds, and enteric bacteria. The presence these microorganisms cause losses in silage process of sorghum.

In general, the fermentation losses imply in the reduction of the availability of the ensiled forage, since there is no way to recover the DM losses in the form of gases and effluent.

The exposure of silage to air, converting the anaerobic environment (responsible for the conservation of forage) to aerobic, can cause changes in its chemical composition, altering its nutritional value, because the population of microorganisms that were dormant (bacteria, yeasts, and then mold action) and with oxygen began intense metabolic activity [35].

There is reduction in soluble components of silage, which are used as substrates for these microorganisms [30] and may even be a degraded part of the fibrous portion of food by fungal microbiota [28].

Evaluation of the aerobic stability of sorghum silages [26] found the aerobic deterioration losses of 85.6 kg/t DM in silages upon exposure to air during 48 hours. As the air to silage exposure is unavoidable during discharge, many research studies aim to reduce the aerobic deterioration with the use of additives [36].

The adding urea to acidic silage can neutralize part of acidity in the chemical reaction by partial neutralization, where, in an acid environment, an agent that has alkalizing action forms salts of organic acids [37] and subsequently providing the nitrogen applied [24].

Chemical additives such as urea can also benefit from the silage sorghum (**Table 4**). Although sorghum silage with urea present pH values and higher N ammonia, it does not mean that the

TRAT	pH	NH_3/TN	LA	AA	ET
Sorghum	4.73	0.228	6.01	0.83	0.44
Sorghum + LB	4.78	0.257	3.09	3.93	0.46
Sorghum + LP	4.25	0.189	12.46	0.56	0.40
Sorghum + 0.5% urea	3.69	0.169	5.27	0.85	0.60
Sorghum + 1.0% urea	3.73	0.401	6.69	0.37	0.26
Sorghum + 2.0% urea	3.76	0.525	5.71	0.70	ND
Sorghum + 4.0% urea	3.98	0.767	6.72	0.83	ND

Note: LB = *Lactobacillus buchneri*; LP = *Lactobacillus plantarum*; ND = Not detected.
Sources: Adapted from Filya [38] and Santos [26].

Table 4. Values of pH, relation ammoniacal nitrogen/total nitrogen (NH_3/TN), lactic acid (LA), acetic acid (AA), and ethanol (ET) of sorghum silage.

fermentation process is undesirable. Urea may act primarily in the metabolism of microorganisms, such as yeasts, reducing the conversion of the soluble compounds to ethanol, reducing DM losses. Furthermore, the addition of urea in sorghum silage had no negative effect on the production of lactic acid [26].

The sorghum has high WSC that can excessively acidify the silage due to excessive lactic acid production. The effect of different doses of urea on sorghum silage [26] found that the addition of urea reduced DM and WSC losses, reducing the production of ethanol from treated silages. Another benefit noted by the author was a high possibility of recovery of the nitrogen applied in the silages by incorporating the biomass ensiled.

The use of microbiological and chemical additives in sorghum silage can benefit from the fermentation process, and prolong the aerobic stability of silages [26].

After evaluating sorghum silage inoculated with lactic acid bacteria homofermentative and heterofermentative (**Table 4**), the researchers observed that the pH and WSC concentration decreased during fermentation, while increased lactic acid, acetic acid, ethanol, and ammonia content [38].

The addition of inoculants from lactic acid bacteria, such as *Lactobacillus buchneri* and *Lactobacillus plantarum* can benefit fermentation. Sorghum silages additive with *L. plantarum* showed low pH, lower content of acetic acid, ammonia nitrogen, and increased the production of lactic acid [38]. While silage inoculated with *L. buchneri* had a higher content of acetic acid and ethanol and lower lactic acid concentration [38].

L. buchneri is heterofermentative bacteria capable of converting water-soluble carbohydrates into lactic acid and other compounds with less acidifying power of the medium, such as acetic acid [39]. Still, these bacteria are capable of producing ethanol, which justifies higher values in the silage [39].

Another alternative is production of sorghum silage mixed with grasses. The sorghum silage has a high carbohydrate concentration, which implies the production of acid silage with predisposition to the development of deleterious microorganisms such as yeasts, and when under aerobic conditions in the silo-opening phase, aerobic stability is reduced.

In turn, grasses silages have lower amounts of WSC, buffering capacity, and relatively larger pH, which would lead to an increase in the production of acetic acid, the resulting product is essentially heterofermentative bacteria. Acetic acid has antifungal properties and may delay the development of fungi and degradation of nutrients in silage with high nutritional value, thus increasing the aerobic stability.

Considering these characteristics, the production of mixed silage sorghum with grass could promote appropriate fermentation profile, resulting in silage quality, as well as increase the aerobic stability of silage when exposed to air in the discharge phase, resulting in the reduction of aerobic degradation losses.

Evaluating sorghum silage mixed with 0, 25, 50, 75, and 100% of elephant grass, researchers found losses are reduced by gases (up to the level of 50%) and effluent (when added 75% grass elephant) in sorghum silage mixed with elephant grass [40]. Still mixed with elephant grass silages showed high resistance to heating after exposure to air of silage, there was an improvement in the aerobic stability of silage.

4.2. Pearl millet

The pearl millet (*Pennisetum glaucum*) is a grass of tropical region that can be considered alternative to forage production in Brazilian semiarid because it is a short cycled plant with high nutritive value adapted to climatic and soil conditions and it has great potential of production [41]. Because of its hardiness, rapid growth, adaptation to low soil fertility, and excellent biomass production capacity, it is an alternative to semiarid climates, where there are large climatic uncertainties.

This grass species has been widely used by producers as an alternative to attempt the requirements of animals in the critical part of the year. Pearl millet has been used as forage for the production of silage in periods of drought because of its specific characteristic such as more persistent drought, adapted to low fertility soils, fast growth, and good biomass production [35, 42].

Researchers evaluated the recovery of dry matter and losses of dry matter in the form of gases and effluent, and pH in silage of two pearl millet genotypes under nitrogen fertilization and found that the silages with lower pH were decreased the DM recovery and increased the soluble carbohydrates, which triggered the alcoholic fermentation [16].

The release of effluent can contribute to significant losses in the silage, considering that the DM content of pearl millet plants is relatively low. In many cases, good results have been achieved by using moisture-absorbing additives.

The incorporation of substances that absorb moisture inside the silo, such as citrus pulp, corn disintegrated with straw, corn cornmeal, and sorghum, favors the fermentation process. The incorporation of 3–7% of additives is sufficient to increase the DM content of the silage up to 25% DM, but this strategy should always be evaluated based on cost. Another alternative is to prewilting of the forage to be ensiled. This practice is effective. However, due to the significant increase in hand-to-work has proved more viable for small-scale silage production.

4.3. Grasses

Grasses cultivated under tropical conditions have high production in favorable season and reduction in unfavorable periods. Usually, there has been a fodder surplus in times of water, which should be maintained for subsequent supply in the drought period of the year. In this context, the grasses surplus ensiling can be a good practice to increase the supply of dry matter to animals in unfavorable times. Nevertheless, grasses have low DM and WSC content, as well as a limited number of indigenous bacteria, so that they require the techniques that increase their DM content and favoring the production of lactic acid bacteria [43].

The tropical grasses have low dry matter content, high power buffer, and low in soluble carbohydrates in the growth stages that have adequate nutritional value, which may harm the conservation process through the silage due to the possibilities of arising secondary fermentations, increasing the losses, and reducing the final quality of the ensiled material [44].

Researchers evaluated the effect of plant maturity on the DM content [45] and found the DM contents of 19.42, 21.06, 20.25, and 22.41% for 30 crops with heights of 40, 50, and 60 cm, which are unfavorable for appropriate fermentation of grass silage.

The WSC content in grasses is generally low depending on species and time of harvesting. The minimum WSC concentration to ensure the appropriate fermentation process is in the range 8–10% (DM basis) [13]. The WSC represents the main substrate for lactic acid bacteria, and must be at high concentration in plants prior to ensiling, so that the fermentation process is accelerate and the pH lowered rapidly, thereby inhibiting the growth of undesirable microorganisms.

The WSC and DM contents and buffering capacity influence directly the fermentation process of silage. Researchers [46] found that the DM and WSC content increases with the increase of regrowth age. Water-soluble carbohydrate levels in tropical grasses are low and thus it is difficult to reduce pH because of the absence of substrate for lactic acid bacteria, which suppresses the fermentation process.

Besides WSC and DM contents, buffering capacity also influences the ensiling process. The buffering capacity of forage resists changes in pH, which reduced the rapid lowering of pH necessary for forage preservation. The ratio of WSC and buffering capacity is important for the silage process. When the ratio is decreased it needs to increase in the DM content to avoid undesirable fermentation inside the silo.

The control of the ensiling process may be realized by the use of additives. Researchers [47] evaluated the effect of citrus pulp on Tanzania grass silage and found increased ratio of WSC and buffering capacity, which resulted in improved fermentation characteristics of silages with reduction of pH and ammonia-N values.

Another way to increase the level of soluble carbohydrates of forages before ensiling is the inclusion of sugarcane. The benefits of using sugarcane are similar to molasses to increase the

WSC content, resulting in reduction of pH and ammonia-N concentration and increasing the DM content [48].

Other sources that are used as additives, which are rich in soluble carbohydrates, are the residuals of fruit processing, such as cherry, pineapple, guava, passion fruit, mango, and papaya. These residues are usually dry, and used as both WSC sources and to increase the DM content of grass silage.

4.4. Leguminous

The leguminous species found in semiarid regions are drought tolerance. In order to reduce production costs, leguminous are often used as protein banks to feed ruminant animals, since the protein is expensive nutrient for animal nutrition [49].

The main leguminous fed to cattle in the semiarid region are leucaena (*Leucaena leucocephala*), pigeon pea (*Cajanus cajan*), Gliricidia (*Gliricidia sepium*), jitirana (*Merremia aegyptia*), sisal (*Agave sisalana*), perennial peanut (*Arachis pintoi*), among others.

Although these species are widely used as protein bank, some species of leguminous produced in the semiarid region have antinutritional compounds such as cyanide and tannin. These compounds may have a negative effect on ruminal degradation and become toxic when leguminous are present in excess. The ensiling process can soften or remove these undesirable compounds, improving the quality of food that provides to animals. This process has often been used for feeding animals in feedlot [50].

Leguminous species are not favorable for silage because of low concentrations of dry matter and water-soluble carbohydrates, and high protein content and buffering substances [51]. Because the amount of soluble carbohydrates, DM content, and buffer capacity [39], the fermentation process of leguminous silage may not be acceptable. However, the use of additives can improve the silage fermentation of these leguminous.

The fermentation of the silage leguminous is resistant to pH reduction due to the high buffering capacity and low content of soluble carbohydrates, which makes the highest production of lactic acid. There are a high number of pulses present in semiarid. Thus, it is important to use techniques which aimed at improving the ensiling process of legumes, making it favorable for silage.

The dry matter content directly influences the fermentative activity [13]. High moisture content and buffering capacity associated with low soluble carbohydrate content can lead to increased butyric fermentation, with losses of nutrients in the final food.

Leguminous have a high content of protein and minerals. Salts of organic acids, sulfate, nitrates, chlorides, and orthophosphate form the anion fraction of forage, which correspond approximately 68–80% of buffer capacity [52]. The disadvantages of leguminous silage are the need for increased lactic acid production to compensate for the high buffering capacity and reduce the pH to values below 4.0 [53].

Some strategies are used which can modify and improve the fermentation process of leguminous ensiling. In **Table 5**, we found that the silage pH perennial peanut had reduced after the

TRAT	pH	NH_3/TN	LA	AA	BA	PA
Perennial peanut (PP)	5.48a	18.22a	0.67h	0.09c	1.21a	1.61a
PP + 5% corn meal	4.76c	11.70ab	0.64h	0.17c	0.65b	0.86b
PP + 10% corn meal	4.57c	8.06bcd	2.29e	1.74ab	0.20de	0.86b
PP Wilted (PPW)	4.70c	4.15cd	1.10f	0.60bc	0.04e	0.03b
PP + Inoculant	5.18b	14.04ab	0.21i	3.25a	0.34cd	0.39b
PPW + Inoculant	4.67c	3.93cd	0.86g	1.15bc	0.03e	0.02b

Note: Means followed by the same letter in the column do not differ by 5% Tukey test.
Source: Adapted from Paulino et al. (2009).

Table 5. Values of pH, relation ammoniacal nitrogen/total nitrogen (NH_3/TN), lactic acid (LA), acetic acid (AA), butiric acid (BA), and propionic acid (PA) of perennial peanut silage.

addition of corn meal. Furthermore, additive increased the amount of lactic acid and acetic acid and reduced the content of ammonia nitrogen, butyric acid, and propionic acid. The additive corn meal positively changed the fermentation process of silage perennial peanut.

Other techniques such as wilting reduce losses in silage legumes. The wilting reduces the formation of organic ions that can result in the buffering effect on the silage fermentation process [54]. In **Table 5**, we confirmed the effect of wilting on silage perennial peanuts. Wilting reduced the pH, ammonia nitrogen content, butyric acid, and propionic acid, and increased the amounts of lactic and acetic acid. These changes are desirable, since lactic acid has preservative effect on the fermentation of silage to acidify [13].

The biological additives can be used in leguminous silage. **Table 5** shows the results of the addition of inoculant in perennial peanuts silage, when the wilting before ensiling occurred. This can be explained by the fact that due to the lower moisture content in the forage activity of lactic acid bacteria is increases and reduced the activity of other bacteria, such as clostridia, which are sensitive to osmotic pressure.

4.5. Cactus pear

The cactus pear (*Opuntia ficus-indica* and *Nopalea cochenillifera* Salm Dyck) has been increasing in the face of constant climate changes in the current production scenario [55] and its use in the objective Brazilian semiarid minimize the action of seasonality in the production process, providing energy and increasing the availability of water via food for animals.

In order to rationalize the use of this forage resource, the cactus pear as a silage is an alternative to this region. From the productive point, and the conservation of the nutritional value of the forage, the cactus pear silage maximizes the use of natural resources found in the Brazilian semiarid, enabling ranchers a new alternative for conservation of foods rich in water and energy, which adds more value to this Cactaceae in arid and semiarid regions.

Cactus pear has a low DM content and high WSC content, which could lead to alcoholic fermentation. However, researchers [56] evaluated cactus pear silages added with urea and found appropriate fermentation and low nutrient losses in silage. Despite some unfavorable attributes for silage, other characteristic of the cactus pear as per their bioactive compounds must be taken into consideration.

During rainy seasons, the cactus pear crop is not recommend for the ensiling process, because of the high moisture content that may bring difficulties in handling this material.

Other aspects related to fermentation kinetics of cactus pear silage are the percentage of organic acids found in the cactus pear cladodes, such as oxalic, citric, malonic succinic, and tartaric acids [57], which buffers the environment that impedes the lowering of pH.

Cactus pear is forage with low DM content and high WSC concentration, which may favor the development of undesirable fermentation. However, the bioactive compounds present in cactus pear promote homeostatic conditions in ensiled mass.

The emulsifier gel is formed after cutting of cactus pear, resulting of breaking of chlorenchyma and parenchyma cells, it is store mucilage, a hydrocolloid that promotes fluid retention. The hydrocolloids are compounds formed by highly hydrophilic polysaccharides, which reduce the movement of water providing increased viscosity of materials and thus the mucilage formation [58]. These compounds may be responsible for reducing effluent losses due to mucilage aggregates of fluid compounds.

The interaction of forage characteristics and its associative effects, as well as the handling, during ensiling directly influence the efficiency of the preservation process. The additives, in general, have been test more often in order to facilitate the practice of forage silage with high moisture and WSC content. The reports evaluating the silage cactus pear are still incomplete, as well as studies indicating additives for silage.

In recent studies with silage palm, researchers [56] conducted experiments to evaluate the losses resulting from the fermentation of forage cactus pear using additives such as urea and wheat bran. It observed that the urea reduced the effect of the increasing DM content and the crude protein values of cactus pear silage.

The cactus pear has favorable characteristics for the ensiling process; it is possible to produce good quality silage. Although many believe that the characteristics of the cactus pear, especially high WSC content, imply in inadequate fermentation characteristics. Cactus pear consists of elements that make it potential to be used as silage. Still, cactus pear silage is composed of a diet rich in energy for ruminants, as well as serve as an alternative source of metabolic water readily available in animal feed, especially in times of drought.

5. Final considerations

The use of plant to appropriate silage in combination with cultivate, harvesting, and silo filling results in a successful preservation of forage as silage.

Tropical crops, due to the tolerance of low water availability, are ideal for preserving forage as silage. In semiarid regions, the fermentative process of forages varies with conditions, and sometimes it requires additives.

Author details

João Paulo Farias Ramos[1]*, Edson Mauo Santos[3], Ana Paula Maia dos Santos[3], Wandrick Hauss de Souza[1,2] and Juliana Silva Oliveira[3]

*Address all correspondence to: jpemepapb@yahoo.com.br

1 Empresa Estadual de Pesquisa Agropecuária, Paraíba, Brazil

2 State Company of Agricultural Research of Paraíba, João Pessoa PB, Brazil

3 Federal University of Paraiba, Areia PB, Brazil

References

[1] Sampaio, E. V. S. B. Characteristics and potential. In: Gariglio, M. A. et al. (eds.). Sustentable use and conservation of forest resources of caatinga. 2nd ed. Brasília: Serviço Florestal Brasileiro, 2010. pp. 29–42.

[2] Menezes, R. S. C. et al. Cactus pear productivity in rural properties. In: Rômulo, S. C. et al. (eds.). Palm in Northeast Brazil: current knowledge and new perspectives of use. Recife: Ed. Universitária da UFPE, 2005. 258 p.

[3] Lima, C. D. S., Gomes, H. S., Detoni, C. E. Adding urea and *Saccharomyces cerevisiae* yeast in the protein enrichment of forage cactus pear (*Opuntiafícus indica* L.) cv. miúda. Magistra. V. 16, n. 1, pp. 01–08, 2004.

[4] Mitra, J. Genetics and genetic improvement of drought resistance in crop plants. Current Science. V. 80, n. 6, 2001.

[5] Blum, A. Drought resistance, water-use efficiency, and yield potential – are they compatible dissonant, or mutually exclusive? Australian Journal of Agricultural Research. V. 56, n. 11, pp. 1159–1168, 2005.

[6] Levitt, J. Responses of plants to environmental stresses. New York: Academic Press, 1972.

[7] Lopes, M. S. et al. Enhacing drought tolerance in C4 crops. Journal of Experimental Botany. V. 62, n. 9, pp. 3135–3153, 2011. Doi:10.1093/jxb/err105

[8] Yancey, P.H. Living with water stress: evolution of osmolyte systems.Science,V. 217, n. 4566, pp.1214–1222, 1982.

[9] Gaff, D.F. Adaptation of plants to water and high temperature stress. Turner, N.C and Kramer, P.J (eds). New York: Wiley, pp. 207–230, 1980.

[10] Edwards, G. E., Franceschi, V. R., Voznesenkaya, E. V. Single cell C4 photosynthesis versus the dual-cell (kranz) paradigm. Annual Review of Plant Biology. V. 55, pp. 173–196, 2004.

[11] Robertson, M. J. et al. Physiology and productivity of sugarcane with early and midseason water deficit. Field Crops Research. V. 64, pp. 211–227, 1999.

[12] Xoconostle-Cazares, B. et al. Drought tolerance in crop plants. American Journal of Plant Physiology. V. 5, n. 5, pp. 241–256, 2010.

[13] McDonald, P., Henderson, A. R., Heron, S. The biochemistry of silage. 2nd ed. Marlow: Chalcombe. 1991. 340 p.

[14] Ferreira, J. J. Corn maturation stage and sorghum ideal for silage. In. Cruz, J. C. et al. (Eds.) Production and use of corn silage and sorghum. Sete Lagoas: Embrapa Milho e Sorgo, 2001, pp. 405–428.

[15] Driehuis, F., Van Wikselaar, P. G. V. The occurrence and prevention of ethanol fermentation in high dry matter grass silage. Journal of the Science of Food and Agriculture. V. 80, pp. 711–718, 2000.

[16] Pinho, R. M. A. et al. Silages of pearl millet submitted to nitrogen fertilization. Ciência Rural. V. 44, n. 5, pp. 918–924, 2014.

[17] Weinberg, Z. G., Chen, Y. Effects of storage period on the composition of whole crop wheat and corn silages. Animal and Feed Science Technology. V. 185, pp. 196–200, 2013.

[18] Pereira, O. G., Rocha, K. D., Ferreira, C. L. L. F. Chemical composition, characterization and quantification of the population of microorganisms in elephant grass cv. Cameroon (*Pennisetum purpureum*, Schum.) and silages. Brazilian Journal of Animal Science. V. 36, n. 6, pp. 1742–1750, 2007.

[19] Kung Jr., L. A review on silage additives and enzymes. 2002. Disponível em: www.ag.udel.edu/department/anfs/faculty/kun…/a_review_on_silage_additivies_and.html [Accessed on 25 June 2014].

[20] Pahlow, G. et al. Microbiology of ensiling. In: Silage science and technology. Madison. Proceedings…Madison: ASCSSA-SSSA, Agronomy. V. 42, 2003. pp. 31–93.

[21] Santos, E. M., Zanine, A. M. Tropical grasses silage. Colloquium Agrariae. V. 2, n. 1, pp. 32–45, 2006.

[22] Van Soest, P. J. Nutritional ecology of the ruminant. Ithaca: Cornell University Press. 2nd ed. 1994. 476 p.

[23] Itavo, L.C.V. et al. Chemical composition and fermentative parameters of elephant grass and sugar cane with additive. Brazilian Journal Animal Health and Production, v. 11, n. 3, pp. 606–617, 2010.

[24] Schmidt, P. et al. Chemical and biological additives in sugar cane silage. 1. Chemical composition of silages, intake, digestibility and feeding behavior. Brazilian Journal Animal Science. V. 36, n. 5, pp. 1666–1675, 2007 (supplement).

[25] Santos, E. M. et al. Chemical composition, losses and fermentation profile of elephant grass silages with inclusion levels of jackfruit. Journal of Animal Health and Production. V. 9, n. 1, pp. 64–73, 2008.

[26] Santos, A. P. M. Sorghum silage BRS Ponta Negra with urea. 2013, 57 f. Dissertation (Masters in Animal Science) – Federal University of Paraiba, Areia.

[27] Neumann, M. et al. Characteristics of the fermentation of silage obtained in different silos under the effect of particle size and time of harvest of corn plants. Rural Science. V. 37, n. 3, pp. 847–854, 2007.

[28] Guim, A. et al. Aerobic stability of silage of elephant grass (*Pennisetum purpureum*, Schum) wilted and treated with microbial inoculant. Brazilian Journal Animal Science. V. 31, n. 6, pp. 2176–2185, 2002.

[29] Danner, H. et al. Acetic acid increases stability of silage under aerobic conditions. Applied and Environmental Microbiology. V. 69, n. 1, p. 562–567, 2003.

[30] Vieira, F. A. P. et al. Quality sorghum silages with additives. Brazilian Archives of Veterinary Medicine and Animal Science. V. 56, n. 6, p. 764–772, 2004.

[31] Botelho, P. R. F. et al. Sorghum genotypes Evaluation first cutting and regrowth for the production of silage. Brazilian Journal of Maize and Sorghum. V. 9, n. 3, pp. 287–297, 2010.

[32] Pinho, R. M. A. et al. Use efficiency rain for sorghum silage genotypes on Paraiba Semi-Arid. In: Congress animal production Northeastern, Vol. 6, 2010, Mossoró, Anais Mossoró: CNPA, 2010.

[33] Neumann, M. et al. Evaluation of different sorghum hybrids (*Sorghum bicolor*, L. Moench) as the components of the plant and produced silages. Brazilian Journal of Animal Science. V. 31, n. 1, pp. 302–312, 2002.

[34] Fernandes, F. E. P. et al. Sorghum silage with added urea in two periods of storage. Brazilian Journal of Animal Science. V. 38, n. 11, pp. 2111–2115, 2009.

[35] Amaral, P. N. C. et al. Nutritive quality of silage of three varieties of millet. Science and Agrotecnology. V. 32, n. 2, pp. 611–617, 2008.

[36] Jobim, C. C. et al. Methodological advances in evaluation of preserved forage quality. Brazilian Journal of Animal Science. V. 36, p. 101–119, 2007 (supl. special).

[37] Lopez, J. et al. Effect of nitrogen source, stage of maturity, and fermentation time on pH and organic acid production in corn silage. Journal of Diary Science. V. 53, pp. 1225–1232, 1970.

[38] Filya, I. The effect of *Lactobacillus buchneri*, with or without homofermentative lactic acid bacteria, on the fermentation, aerobic stability and ruminal degradability of wheat, sorghum and maize silages. Journal of Applied Microbiology. V. 95, pp. 1080–1086, 2003.

[39] Oude Elferink, S. J. W. H. et al. Anaerobic conversion of lactic acid to acetic acid and 1,2-propanediol by lactobacillus buchneri. Applied and Environmental Microbiology. V. 67, n. 1, pp. 125–132, 2000. DOI: 10.1128/AEM.67.1.125–132.2001

[40] Ramos, R. C. S. Silages mixed assessment of elephant grass with sorghum.2014. Dissertation (Masters in Animal Science) – Federal University of Paraiba, Areia.

[41] Kollet, J. L., Diogo, J. M. S., Leite, G. G. Forage yield and chemical composition of varieties of pearl millet (*Pennisetum glaucum* (l). R. Br.). Brazilian Journal of Animal Science. V. 35, n. 4, pP. 1308–1315, 2006.

[42] GuimarãeS J. R. R. et al. Dry matter, crude protein, ammonia nitrogen and pH of silages three pearl millet genotypes [Pennisetum glaucum (l). R. Br.] At different periods of fermentation. Brazilian Journal of Maize and Sorghum. V. 4, n. 2, pp. 251–258, 2005.

[43] Santos, D. C. et al. Nitrogen and phosphorus levels in forage cactus (Opuntia ficus-indica) IPA-20 clone in two spacings. In: Congress animal production Northeast, Vol. 4, 2006, Petrolina, Anais Petrolina: SNPA, 2006. pp. 381–383.

[44] Evangelista, A. R. et al. Production of silage marandu grass (*Brachiaria brizantha* Stapf cv. Marandu). Agrotecnica Science. V. 28, n. 2, pp. 443–449, 2004.

[45] Pinho, R. M. A. et al. Microbial and fermentation profiles, losses and chemical composition of silages of buffel grass harvested at different cutting heights. Revista Brasileira de Zootecnia. V. 42, n. 12, pp. 850–856, 2013.

[46] Ribeiro Junior, G. O., Agronomic characteristics and quality of grass silages *Andropogon gayanus* in four cutting ages and fermentation profile of silages after 56 days of growth. 2009, 46 f. Dissertation (Masters in Animal Science) – School of Veterinary Medicine, Federal University of Minas Gerais, Belo Horizonte.

[47] Ávila, C. L. S. et al. The levels of soluble carbohydrates of Tanzania grass ensiled with additives assessment. Brazilian Journal of Animal Science. V. 35, n. 3, pp. 648–654, 2006.

[48] Santos, G. et al. Pasture characterization of buffel grass deferred and cattle diet during the dry period in Pernambuco. Brazilian Journal of Animal Science. V. 34, n. 2, p. 454–463, 2005.

[49] Chen, C. P. et al. Fodder trees and fodder shrubs in range and farming system of the Asian and Pacific region. In: Legume trees and other fodder trees as protein sources for livestock.1991.

[50] Costa, C. X. Nutrients intake, production and performance characteristics of carcass santa ines lamb containment in aloft sergipe semiarid. 2008, 68 p. Dissertation (Masters in Animal Science) – Federal University of Paraiba, Areia.

[51] Leonel, F. P. et al., Consortium signal grass and corn: crop yields and quality characteristics of silages made with plants of different ages. Brazilian Journal of Animal Science. V. 37, n. 11, pp. 2031–2040, 2008.

[52] Playne, M. J., McDonald, P. The buffering constituents of herbage and of silage. Journal of the Science of Food and Agricultural. V. 17, pp. 262–268, 1966.

[53] Lavezzo, W. Elephant grass ensilage. In: Symposium pasture management, Vol. 10. Piracicaba: Foundation of Agrarian Studies Luiz de Queiroz, pp. 169–275, 1993.

[54] Ribeiro, J. L. Tanzania and Marandu grass silages evaluate for storage losses, fermentation profile nutritional value, performance of animals in the presence of chemical additives, microbial and absorbing moisture sources. Thesis (Agronomy doctoral degree). School of Agriculture, Luiz Queiroz University of São Paulo, Piraciba, 2007.

[55] Silva, A. P. G. Regrowth assessment maniçoba depending on planting density, organic and mineral fertilizers. 2010, 60 f. Dissertation (Masters in Animal Science) – Centre of Agricultural Sciences/Federal University of Paraiba, Areia.

[56] Nogueira, M. S. Fermentative profile and chemical composition of cactus forage silages added with urea and wheat bran. 2015, 60 f. Dissertation (Masters in Animal Science) – Federal University of Paraiba, Areia.

[57] Stintzing, F. C., Carle, R. Cactus stems (*Opuntia* spp.): A review on their chemistry, technology and uses. Molecular Food and Nutrition Research. V. 49, pp. 15–194, 2005.

[58] Saenz, C. et al. Opuntia spp mucilage's: a functional component with industrial perspectives. Journal of Arid Environments. V. 57, pp. 275–290, 2004.