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New technologies and challenges for silage production in semi-arid

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ABSTRACT

The feed conservation (ensiling process) is a technology almost obligatory for producersof ruminants in semi-arid regions. In those regions, especially in the hot ones, due to the high average annual temperature, there is the possibility of a more intense aerobic microorganism activity. The silo management and the utilization of silages in those regions are a cause of concern to producers. Even though feed conservation through silage production is a consolidated strategy, new technologies can be introduced in the process and reduce issues regarding losses related to the silage production and production system costs. This paper aims to discuss new technologies and challenges regarding silage production in semi-arid regions, as well as address perspectives related to the silage utilization in production systems on semi-arid regions. One of the major aspects regarding silage production in semi-arid regions is related to the choice of feeds to be produced or acquired for conservation. Moreover, the use of harvesters, silos, additives, and plastic film in an efficient way are primordial for good feed conservation. The feed-out management and the use of silages are another major important aspect in the ensiling process, whether the feed is for personal consumption or for commercialization. On the other hand, the true challenge is introducing the new technologies in systems characterized by their heterogeneity regarding production level, management, infrastructure, the availability of financial resources, knowledge, and the access to information. Regarding the perspectives of technological progress, it is possible to highlight a more accurate monitoring of both ensiling process and ambient aspects. The latter, even more emphasized when sustainable systems of animal production are discussed, especially ruminant animals.

Key words: feed storage, ensiling, fermentation, sensors in silages, production system

Novas tecnologias e desafios para a produção de silagens em regiões semiáridas

RESUMO

A conservação de alimentos por meio da ensilagem e uma tecnologia com uso quase que obrigatório para quem trabalha com produção de ruminantes em regiões semiáridas. Nessas regiões, em especial as de clima quente, a temperatura me dia anual e elevada e, por conseguinte, a atividade de microrganismos aeróbios se torna mais intensa. Tal cena rio gera preocupações com o manejo de silos e uso de silagens nessas regiões. A conservação de alimentos por meio da produção de silagens e uma estratégia bastante consolidada, contudo, novas tecnologias podem ser aplicadas no processo capazes de reduzir problemas com perdas no processo e custos do sistema produtivo. Objetiva-se com o presente texto versar sobre as novas tecnologias e desafios para a produção de silagens nas regiões semiáridas. Somado a isso, abordar sobre perspectivas relacionadas ao uso de silagens em sistemas produtivos no semiárido. Um dos principais aspectos relacionados a produção de silagens em regiões semiáridas refere-se a escolha dos alimentos a serem produzidos ou adquiridos para conservação. Ademais, o uso estratégico de máquinas na colheita, de silos, aditivos e filmes plásticos são fundamentais para o sucesso da conservação do alimento. Outro aspecto importante no processo e o manejo no desabastecimento do silo ao uso da silagem produzida, quer seja essa usada diretamente na propriedade ou destinada a comercialização. Por outro lado, o real desafio e exatamente aplicar novas tecnologias em sistemas caracterizados pela sua heterogeneidade em escala produtiva, gesta o, infraestrutura, disponibilidade de recursos financeiro, conhecimento e acesso à informação. Quanto as perspectivas de avanços tecnológicos na área podem-se destacar o monitoramento mais acurado do processo ensilagem, assim como os aspectos ambientais que estão cada dia mais evidentes quando se discute sistemas sustentáveis de produção animal, em especial de ruminantes.

Palavras-chaves: estoque de alimento, ensilagem, fermentação, sensores em silagens, sistema de produção

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INTRODUCTION

Semi-arid regions are present on almost all continents in the world and house approximately 1.0 billion people (Arau jo Filho, 2013). These regions are characterized by a semi-arid climate, whether hot or cold, with common characteristics, and irregular distribution of low-volume precipitations throughout the year (Alvares et al., 2013). Furthermore, most of them are regions characterized by a wide diversity of soil types. These peculiarities alone make feed production for livestock kept in these regions a challenge.

In the Brazilian semi-arid region, the challenges observed in animal production are recurrent. Thus, long-term nutritional planning following the concept associated with feed guarantee becomes necessary (Silva et al., 2013). To meet this demand, the use of silage as a feed preserving technology has proven to be suitable for situations that require feed storage for long periods. It is important to emphasize that such planning should already consider scenarios of possible climate changes that could directly impact the reduction of agricultural crops productivity.

Among the feed preservation methods, ensilage has been widely adopted in ruminant production systems worldwide. The availability of machinery and the application of this type of feed in diets of different categories and species of animal, added to the possibility of preserving a wide range of feeds, are the main factors that justify the frequent use of this conservation method. Especially in semi-arid regions, ensilage also makes it possible to maintain feed moisture, resulting in a reduction in water demand for animal hydration on rural properties (Silva et al., 2021; Nobre et al., 2023). Directing silage production strategies is important to reduce losses in the feed produced, increase the efficiency of its use, and reduce costs on the property. Even though new technologies related to both production and use of silage are available on the market to serve this purpose, they will only be adopted if able to increase the system's profit margin or to reduce labor, or both.

Thus, this text aims to address new technologies and the current challenges for their application in silage production in semi-arid regions. We will discuss new technologies related to cultivation strategies and the use of ensiled feeds available in these regions, as well as harvesting, types of silos, plastic films, additives, sensor monitoring, feed-out/use management, commercialization, and environmental perspectives.

Forage crops and other feed sources for silage production in the semi-arid region

Agricultural crops in the semi-arid region are mainly influenced by the level of precipitation. When looking at data from a region, we notice the occurrence of successive drought cycles over several decades, as represented by the 126 years of precipitation data from the municipality of Quixeramobim, Ceará (Figure 1). The year with the lowest rainfall was 1919, with 130 mm, while the year with the highest one was 1964, with 1501 mm. Therefore, strategies for forage storage are necessary. Moreover, temperature is also a climatic element that can interfere not only in agricultural crops but also in stored silage. In this case, conservation by ensiling is mainly influenced by this element, which affects fermentation and consequently the anaerobic stability of silages (Rêgo et al., 2018).

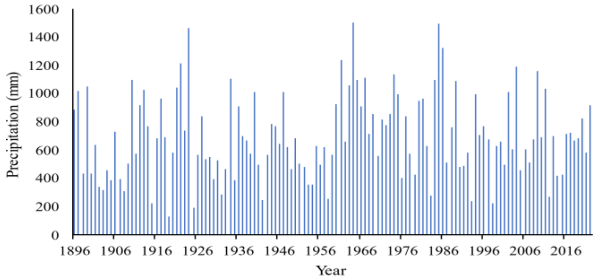

Figure 1. Annual precipitation in the municipality of Quixeramobim (1896 - 2022). Adapted from FUNCEME, DNOCS, SUDENE, INMET.

Productive systems in semi-arid regions face a significant challenge in realizing their production potential due to water limitations, particularly in rainfed (dryland) cultivation. According to Castro (2012), among the main obstacles to production in this region, there is the edaphoclimatic diversity and soil characteristics. Therefore, understanding the heterogeneity of soil types, often on the same farm, enables better crop targeting suiting the cultivation situation. Additionally, using applications to predict the risk of losses due to adverse weather events for the cultivation of forage plants is essential for the success of feed production in these regions. Thus, the use of crops more adapted specifically to edaphoclimatic conditions allows the expansion of the variety of silage produced on the farm.

Thus, we see that the semi-arid region, even with problems related to water scarcity, presents a vast variety of forage, which allows directing silage to different groups of animals and different harvesting strategies, based on the existing crops in the system. In this case, it is common to have annual periods where the climatic conditions favor the production of annual cycle plants, and others that favor perennial cycle plants. This type of situation regarding feed production is very common to be observed in the vegetation of the biomes existing in these regions, which, depending on the year, may favor a particular native forage plant compared to another (Araujo Filho, 2013).

Although several crops are used for ensilage, some stand out because of their greater fermentative capacity. Among them, corn, sorghum, and millet are the most common due to their productivity, dry matter content, carbohydrates, and mainly nutritional value, as they have grains rich in starch. However, these crops are highly demanding in fertility and, especially, in water availability, which can compromise crop production, mainly in semi-arid regions, where there are years of low rainfall (Santos et al, 2016; Silva et al., 2021; Nascimento et al., 2023). Study carried out by Pompeu et al. (2014) demonstrates the potential of using silage in animal feed. The authors reported that the production of natural matter silage from sorghum and millet was 22,855.6 and 16,586.8 kg ha^{-1}, respectively. This productivity allowed feeding 43 and 40 sheep, respectively, with an average body weight of 25.0 kg for 240 days (dry period), considering a dry matter consumption of 3.5% of body weight and a concentrate roughage ratio of 30:70. Other methods that enable the use of these crops in the semi-arid region are the use of genotypes adapted to the region's conditions, favoring cultivation and material harvest, with productivity and quality to be ensiled. An interesting alternative for semi-arid regions is the production of tropical grass silage.

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Forages in this group are rustic, show accelerated growth rate when water and nutrients are not limiting factors, and can provide good DM/hectare productivity during the rainy season (Rêgo et al., 2010; Dias et al., 2019; Furtado et al., 2019). This typically results in silage with a low cost per ton of DM.

Legume silages can also be an option for conserving this type of forage crop in the semi-arid region. Despite having lower productivity than grasses, this type of crop can be ensiled alone or associated with other feeds. The diversity of legumes presents in these regions, especially in the Brazilian semi-arid, makes it possible to conserve the moist plant in the form of silage (Voltolini et al., 2019).

Forage cactus is a crop commonly found in semi-arid regions due to its great adaptability to their climatic conditions. It is a feed that has low concentrations of dry matter and crude protein (on average 5 to 10%, respectively), thus being unable to fully meet the nutritional demand of the animal, as well as being responsible for metabolic disorders in ruminant animals (e.g. diarrhea). On the other hand, it has high biomass productivity per hectare and concentration of non-fibrous carbohydrates, making forage cactus a good option to be ensiled as total ration (Santos et al., 2006; Oliveira et al., 2010). In general, studies with forage cactus silages as total ration show various benefits, such as: improvements in the nutritional value and fermentative characteristics of the silages, feed acceptability, ruminal parameters, and animal performance (Silva et al., 2023).

Silages of native pastures appear as an option for storing feed and ensuring roughage stocks, especially during more critical periods of the year. This type of feed is characterized by heterogeneity in terms of quality, varying with the harvested floristic composition and the stage of growth/development of the crops. Depending on the composition and quality of fermentation, such feed can be offered to the most diverse species and categories of animals. It also has a low production cost, as it primarily involves the biomass accumulated in the natural pasture area (Campos et al., 2019).

The difficulty in feed producing leads to the necessity for systems that exploit maximum production efficiency in the semi-arid region. In many semi-arid regions of the world, the use of grains imported from other regions results in high grain prices. This means there is a need to improve the purchasing strategy at the correct times and process the grains for use. The use of ensilage in this case is an alternative to increase the efficiency of grain utilization, as fermentation increases the digestibility of starch and, consequently, the dry matter digestibility of grain (Silva et al., 2018).

In addition to the aforementioned feeds, conservation through silage can also be applied to alternative feeds and derivatives of some agricultural crops produced in the region. This is the case of crops such as cassava, pornunça, and sesame (Voltolini et al., 2019; Pitirini et al., 2021; Amorim et al., 2022).

Harvest

The availability of machinery for silage production revolves around some aspects, such as: producer demand, availability of machines by sales companies and the outsourcing of operations involving the production and use of silage. The selection of this equipment, in turn, depends on the production scale, the type of feed to be harvested/processed, access to the area, machines availability during the harvest period, and the acquisition cost (Yezekyan et al., 2020). However, the choice of machinery may not fully correspond to the producer's needs, which can bring in poor results and generate economic losses (Yezekyan et al., 2020).

Before focusing on specific machinery for harvesting forage plants, it is important to highlight that in a small and medium scale, harvesting is done manually with processing (particle reduction) carried out in stationary machines powered by electricity or diesel (such as tractors). Likewise, in the ensiling of other feeds, such as dry grains or agro-industry derivatives, processing is an operation carried out using mills, which are stationary equipment.

The mechanization of forage harvesting in ensilage requires the use of agricultural machines in the field, which are divided into tractor-drawn or trailed harvesters and self-propelled harvesters. Historically, in Brazil, the use of tractor-drawn machines compared to self-propelled machines is very common, both in meat and milk production systems (Silvestre and Millen, 2021; Bernardes and Rêgo, 2014). This occurs mainly due to the acquisition cost of this second type of machinery. With the expansion of the market for companies that provide harvesting services, there has been an increase in the frequency of self- propelled machines used, especially in larger properties. It is worth noting that this type of trend has already been observed in other countries (Bietresato et al., 2013).

The forage harvesting efficiency, the chopping pattern, and the grain processing can be identified as the biggest differences between this type of machinery in relation to tractor-drawn harvesters, especially when considering grain crops, such as corn and sorghum. On the other hand, tractor-drawn machines have the advantage of price in acquisition, maintenance, and ease of operation. Therefore, when choosing a harvester, the following must be considered: the type of forage/feed, the acquisition or outsourcing of the operation, availability in the region, and the cost-benefit for the adopted production system.

Considering that the vast majority of self-propelled machines are imported and consequently have prices linked to the international market, domestic demand has exerted pressure and directed the national industry of tractor-drawn harvesters to make adjustments in the configuration of this type of machinery. An example of this is that the increase in demand for grain processing technology in crops like corn and sorghum probably caused the national machinery industry to incorporate grain processors into tractor-drawn machines. Furthermore, there was a demand for more robust machinery, with greater harvesting capacity. Companies like JF Má´quinas currently have tractor-drawn harvesters that do not depend on planting lines to harvest and are equipped with a grain processing system (e.g. model 1300 AT). This reinforces the increase in the diversity of grain processing machines in the country, bringing the possibility of more adjusted feed processing and consequent exploitation of the grain fraction (Table 1).

In semi-arid regions, the use of perennial forage crops has been preferred by producers to the detriment of annual crops grown in rainfed areas. Unlike regions with edaphoclimatic conditions that provide greater security for the cultivation of short-cycle annual crops, silage production in the semi-arid region must be rigorously planned.

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Table 1. Summary of some tractor-drawn forage harvesters machines in Brazil.

Company	Model	Processor	TDP power (cv)	Chopped size (mm)	Rotation at power take-off (rpm)
Nogueira*	FTN 1150	Yes	85 to 130	3 to 22	540
Nogueira	FTN 1000 Power	Yes	65 to 95	2 to 36	540
Nogueira	FTN 1000 Super	Yes	85 a 125	2,5 to 18	540
MTW Máquina	FH - 65100	Yes	> 50	2 to 36	540
MTW Máquina	FH - 1200 AT	Yes	> 55	2 to 36	540
Menta¢	Robust ATM 1.3	Yes	>125	2 to 36	540
Menta	Robust ATM 2.6	Yes	200 - 250	2 to 36	1000
JF Máquinas#	JF C120 S3	Yes	55 to 90	3 to 36	540
JF Máquinas	JF 3200 AT S2	Yes	200 to 240	2,5 to 43	1000
Combine	Combine 60 Master	Yes	75 to 100	2 to 36	540
Combine	Combine 50 Super	No	75 to 100	2 to 36	540

* All current machines from the Nogueira company contain a grain processor; ¢ Other machines from the Menta company do not contain a grain processor; # Most JF company machines contain a grain processor, except the JF 1600 AT PS.

This premise seeks to guarantee long-term feed stocks (silos stocked for years) to meet the demands of livestock. This scenario also contributes to increasing the demand for forage harvesters in years that are more favorable to forage cultivation. This trend requires even more planning and property management regarding the use and hiring of service providers.

Silo types

The choice of silo on the property is linked to several factors, such as: financial resources, feed planning on the property, available material for ensilage, technology available in the region, and others. Based on these considerations, it is possible to make decisions and opt for more viable choices for the rural producer.

'Cincho' and 'rapadura' silos (common in Brazil) are variations of traditional pile silos with an easy and more practical handling, as well as low cost, which are characteristics preferred in semi-arid regions, where livestock farming still has many family properties. To use 'cincho' and 'rapadura' silos, frame structures without a bottom are required in the form of a hoop or rectangle, respectively.

The rapadura format has the advantage of promoting silage exposure minimization during feed-out of silo, when compared to the traditional cylindrical cincho silo. The frame for the rapadura silo can be of 3.0 m length by 1.0 m width and 0.5 m height; while the cincho frame may have a diameter of 2.50 m and a height of 0.50 m (Pereira et al., 2011). The rapadura type silo is an adaptation of the cincho type, aiming to facilitate the daily supply and removal of slices in an efficient and more uniform way.

The use of precast concrete in the construction of silos is a technology that, despite being well-established in other countries, is still limited in Brazil. This technology involves the use of heavy precast concrete blocks to build silos. Its main advantages are the practicality in construction, material mobility, which enables transportation from one area of the property to another, as well as adjusting the silo according to the storage need of feed. However, despite these advantages, the cost of manufacturing/acquiring these panels is high, making them less competitive when compared to conventional silos (bunker, pile, etc.). Furthermore, there are few companies willing to invest in the commercialization market for these blocks. These are limited to companies that specialize in the production of concrete products for livestock. Therefore, the demand for private investment emerges as a prospect, along with the conduct of research aimed at developing technologies suited to the region's demands.

Plastic films

The management of the silo sealing can be considered crucial in the ensilage process as it will be responsible for the formation and prevalence of the anaerobic environment for the fermentation of the ensiled feed. In the sealing stage, the use of plastic films (e.g. double-sided) is essential, ensuring the restriction of atmospheric air into the silo, thus maintaining the stabilization of the anaerobic environment (Borreani et al., 2007).

The plastic films must possess certain characteristics for use in the sealing stage, such as: porosity, protection against ultraviolet rays, and the type of material used in manufacturing. However, tropical conditions can negatively affect the physical properties of plastic films during storage (Bernardes et al., 2018). Paillat and Gaillard (2001) reported that tropical climatic conditions increase porosity and reduce the resistance of plastic films to solar radiation and high temperatures. As previously highlighted in the text, in semi-arid regions it is common to store silage for periods that exceed even one year, due to feed production restrictions in some years. Additionally, the Brazilian semi-arid region is characterized by high solar

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radiation and high temperatures (Alvares et al., 2013), which can compromise the durability of the plastic films in silos. These factors may contribute to reducing the efficiency of this input during silage storage in Brazilian semi-arid regions.

Possible problems may arise with the shorter durability of plastic films in semi-arid regions. The increase in the porosity of the plastic films can allow gas exchange between atmospheric air and gasses (e.g. CO_2) formed inside the silo, compromising the stabilization of the anaerobic environment, and leading to possible cases of silage deterioration. Additionally, the lower physical resistance may result in minor physical damage to the plastic film (e.g. tears), creating microenvironments along the silo surface.

Considering these possible scenarios, alternatives should be applied in the sealingstage, concomitantly with the use of plastic films, especially in semi-arid regions characterized by high temperatures. Oxygen barrier films are recommended as an alternative for silo sealing, acting specifically on oxygen permeability in the interior of the silo. It is used in conjunction with conventional double-sided films, promoting better forage conservation and reducing lossesof the nutritional value of the feed, especially in the peripheral regions of the silo (Lima et al., 2017). However, there is currentlylimited availability of this type of material on the market in Brazil, with a predominance of conventional plastic films (Table2).

Table 2. Characteristics of plastic films sold in Brazil.

Company	Width (m)	Length (m)	Microns
Negreira Lonas Plásticas e Filmes Agrícolas	4 – 8	50 – 100	150 – 200
Paperplast	4 – 12	25 – 100	150 – 200
AMC Telas Agrícolas e Decorativas	6 – 12	50 – 100	150 – 240
Tropical Insumos	8	5 – 30	200
Campo Online	8 – 12	5 – 50	150 – 200
Lonas e Lonitas	8	5 - 100	150

After sealing, it is essential to protect the plastic film in semi-arid regions due to the climatic characteristics. The distribution of a thin layer of soil over the plastic film is still the conventional method adopted to guarantee such protection. Despite the reduced cost, this practice has made it difficult to manage silo feed-out and often leads to contamination. This management must be carried out carefully to avoid silage loss and harm to the herd. Currently, companies are looking for silo sealing options that protect the plastic films against physical damage and the negative effects of excessive exposure to high temperatures.

The use of protective covers on the pile silo has been made available in the market to producers as a complementary sealing option to the plastic films. These covers ensure maximum physical protection to the plastic film against various physical damages, whether they are caused by animals, weather conditions, human activity, or ultraviolet rays, eliminating holes and the need for weights on the silo surface. The emergence of these new technologies in response to the challenges presented, especially in semi-arid regions, can be an alternative in the sealing process, ensuring better preservation of the plastic films and, consequently, promoting better conservation of the feed produced. However, in order to make this technology affordable, several challenges must still be faced to make it a viable option for frequent use in these regions.

Additives

Over the years, the diversity of additives available on the market has gradually increased to help in conservation silage. Secondary fermentation stimulators and inhibitors, aerobic and nutrient deterioration inhibitors, and moisture scavengers are the main categories of the different additives (Muck et al., 2018). Among the different types of additives (e.g. chemical, biological), bacterial inoculants are the most used for silage production (Bernardes and Rêgo, 2014).

Silage is one of the feeds that make up the ruminant diet, but it can be highly unstable in the presence of oxygen (Woolford, 1984). Aerobic deterioration during silo feed-out can be identified as the main cause of loss of DM and nutritional value of silage (McDonald et al., 1991) prompted mainly by yeast metabolism and non-controllable factors related to climate (e.g. temperature) that can positively affect the deterioration process, intensifying the reduction in the nutritional value of the feed (Bernardes et al., 2018). Ambient temperature can act as a catalyst for enzymatic reactions involved in the metabolism of microorganisms, accelerating their growth (Madigan et al., 2016).

Properties located in hotter regions (e.g. Brazilian semi-arid region) may present more frequent and intense problems with deterioration compared to colder regions. The Brazilian semi-arid region is identified as a region with high temperatures (> 34 °C) and higher normal solar radiation (1864.4 $KWh.m^{-2}$) compared with the Southeast and South regions of Brazil (1650 and 1428 $KWh.m^{-2}$, respectively), which may contribute to higher aerobic deterioration of silage in these regions. According to Ashbell et al. (2002), higher aerobic deterioration can occur at 30 °C due to greater yeast growth. Additionally, McDonald et al. (1991) reported that the yeast's growth range is remarkably variable (between 5 and 50 °C), with the optimal growth of most species at 30 °C. Therefore, it is plausible that silages produced in semi-arid regions may have lower aerobic stability and consequently higher nutritional losses compared to those produced in colder regions.

Reducing the negative impact of deterioration in silages is routinely a challenge for producers and the use of bacterial inoculants composed of lactic acid bacteria (LAB) meets this demand. Since the introduction of the strain of *Lentilactobacillus buchneri* (syn. *Lactobacillus buchneri*) as the main strain responsible for controlling silage deterioration by Muck (1996), several studies have reported the efficiency of this bacterium in preserving the nutritional value of silages. Subsequently, other LAB strains such as *L. diolivorans* (Kroneman et al., 2002) and *L.*

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reuteri (Sriramulu et al., 2008) were also presented as possible inoculants that control the deterioration process. Currently, a new strain known as L. hilgardii has been presented as a new heterolactic microorganism with antifungal effect in silages, improving silage stability; however, few studies have been carried out to evaluate this strain as an inoculant. Therefore, the emergence of products with more efficient LAB in controlling deterioration could be an alternative to the Brazilian semi-arid region.

In general, the availability of these products by companies has gradually increased over the years with the discovery and subsequent combination of new LAB strains. Until the year 2023, it was observed that 16 companies have a total of 138 inoculants for silage registered on the Ministry of Agriculture and Livestock web page (Table 3). Of these, only 11 have a single type of microorganism in their composition.

Table 3. Strains of lactic acid bacteria most common in inoculants and products registered in Brazil

Most common strains	Registered products
Lactiplantibacillus plantarum	40
Lentilactobacillus buchneri	36
Pediococcus acidilactici	18
Propionibacterium acidipropionici	15
Lactobacillus acidophilus	9
Enterococcus faecium	9
Pediococcus pentosaceus	8
Lactobacillus delbrueckii subsplactis	7
Latilactobacillus curvatus	5
Bacillus subtilis	5
Lacticaseibacillus rhamnosus	4
Pediococcus ociditoctid	2
Lacticaseibacillus paracasei subsp. *paracasei*	1
Levilactobacillus brevis	1
Lentilactobacillus diolivorans	1

Feed-out management and silage use

Silo feed-out is one of the main aspects to be observed to reduce silage losses on the farm. It is important to emphasize that adequate management should be carried out to minimize losses during the silo feed-out. Adequately sizing a silo according to the herd's consumption is a crucial factor in ensuring minimum advance and reducing losses due to excessive exposure to oxygen. It is worth mentioning that this exposure should be considered as the time in which the silage is exposed on the silo panel until it is ingested by the animal via diet consumption.

During silo feed-out, it is first necessary to establish a feeding plan to determine the amount of feed that needs to be removed per day, as to avoid waste. Bernardes et al. (2021) evaluated several farms utilizing silage and analyzed silage loss as slices were removed from the silo. The authors observed that slices that represent an advance of at least 250 kg m^2 per day result in lower silage losses, since there is less deterioration caused by microorganisms.

The time that the silage remains exposed after silo opening contributes to the deterioration of the ensiled mass on the silo wall. When the feed-out time is slow, the entry of oxygen takes longer, compromising the ensiled mass. According to Okatsu et al. (2019), a slower feed-out rate causes an increase in the pH of the silage exposed on the wall, as well as in the count of aerobic microbiota, and a decrease in the lactic acid content present in the silage, a result of oxygen reactivating aerobic communities, which begin the process of consumption of lactic acid present in silage.

The elevated temperature of the silage is one of the factors that can cause feed refusal by ruminants (Gerlach et al., 2013; Borreani et al., 2018). This occurs due to aerobic deterioration caused initially by the consumption of lactic acid by yeasts. Therefore, in semi-arid regions, where temperatures are higher, the possibility of reducing feed consumption by ruminants may increase. Based on this, the use of additives that control the growth of microorganisms should be considered with greater attention in this region, as already mentioned in the previous topic.

In this stage, the use of machinery can facilitate the silos feed-out on a medium and large scale. In the market, there are already multifunctional machines that not only help in silo feed-out, but also with mixing diet ingredients. The use of such machinery will be justified by the gain in practicality and logistical ease.

Silage monitoring by sensors

Respiration is the main cause of silage quality losses and depends on the supply of oxygen (O_2), heat, and water (McDonald et. al., 2002). Initially, the temperature of the ensiled material increases due to plant cell oxidation and fermentation, but this temperature decreases and stabilizes after the initial fermentation period. Significant increases in the temperature of silages in closed silos are associated with aerobic deterioration, most probably caused by disturbances in the silos. These problems result from failures in the covering material or cracks in the walls of bunker silos. However, monitoring oxygen levels, carbon dioxide, pH, and the internal temperature of the silo during storage allows monitoring the quality of the stored feed (Pippard et al., 1996), in addition to creating perspectives for managing silage production more accurately. This monitoring is even more important in animal production systems that work with the concept of guarantee by storing feed for the long-term. In the literature, there are already works concerning the development of the aforementioned sensors capable of detecting silage parameters. Shan et al. (2021) created an equipment called Mini-Sensor Multi-Bioreator (MSMB) to facilitate the selection of inoculants for silage, obtaining good performance during the acidification and fermentation process of LABs through in situ measurements of pH, CO_2, and ethanol. Bauerdick et al., (2022), proposed a sensor capable of detecting negative impacts in silos. The authors emphasize that this type of technology is still in the improvement phase, and special attention should be given to the durability of sensors against, for example, the oxidative environment of silage. Furthermore, it is necessary to improve the detection limits of sensors.

The infrared thermography technique is a more common and usual technology for monitoring the temperature of silage directly in the silos, where minimal increases in temperature can be readily detected. In practice, it is observed through this equipment that the lower compaction intensity on the sides and top of the silos tends to present stronger and more uniform color patterns, normally related to higher temperatures due to aerobic deterioration. This situation is quite evident in bunker silos, because of the difficulty of compacting these regions of the silo. The results of infrared thermography by Junga and Trávnícek (2015) showed a high relationship with chemical and microbial properties, where surfaces with higher temperatures showed significant changes in pH, yeasts, and filamentous fungi. In bagged silages, the use of thermographic cameras (Figure 2) can enable the understanding of the fermentation process inside the

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silo and assist in decision-making about the use of the silage.

Higher temperatures (in red) inside this type of packaging indicate that fermentation may be associated with a deteriorated layer silage. Therefore, regions that have higher temperatures during the stable phase of silage may present problems with yeasts and molds (Junga and Trávnícek, 2015; Queiroz, 2020). It is important to consider that thermographic cameras may have some limitations, as they can be influenced by external agents and the environment.

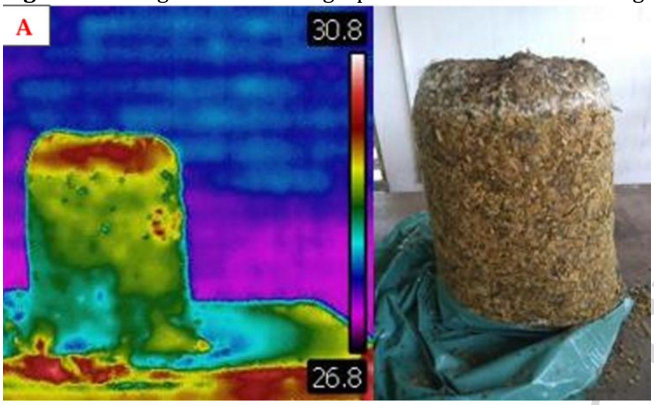

Figure 2. Image of a thermographic camera used on silage stored in bags. Source: Queiroz, (2020).

Technological innovation is ensuring the prediction of crop productivity through monitoring via satellite or drone monitoring (Figure 3). The technology is based on the use of equipment that evaluates the vegetation index (NDVI) applied to machine learning mathematical models. From this, it is possible to estimate the mass of forage available to be ensiled (Almeida et al., 2023).

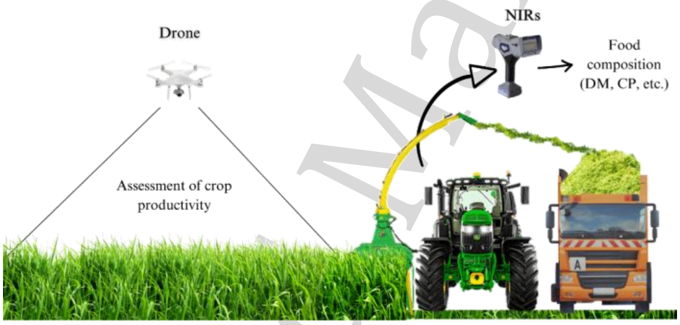

Figure 3. Use of technologies linked to harvesting in the ensilage.

In addition to the productivity analysis method, silage quality prediction is increasingly being used during the ensiling process. The use of Near Infrared Spectrometry (NIRS) is being used in conjunction with machinery during the harvest of the crop for silage production (Figure 3). From the fresh sample, it is possible to predict the parameters of the mass after fermentation, enabling to make strategic decisions to improve the silage quality (use of additives) and make estimates of the use of concentrate for the animal, even during ensilage (Restaino et al., 2009; Serva et al., 2021). The use of modeling is also a tool to help adjust feed production to the herd's demand, considering crop productivity, the fermentation process, and losses as factors. With easier access to monitoring technologies for silage production, it is possible to work with more rational and controlled management of production processes.

Relocation and commercialization

The relocation and/or commercialization of silage is something that is part of the routine of many producers, whether due to a lack of planning, water scarcity in the region, pest attack on the crop, diseases or other adverse events (Michel et al., 2017). Furthermore, the lack of labor, machinery or space can make silage production unfeasible (Dos Anjos et al., 2018). Under said perspective, the acquisition of balled silage or the acquisition of silage from other producers for the relocation process is a recent technology that has encouraged this sector of conservation feeds.

The silage relocation process consists in the feed-out of the silage, transporting it to the location, compacting the mass again and sealing the silo (Queiroz et al., 2021). This process needs to be carried out quickly, in order to avoid losses of the transported mass due to aerobic deterioration that begins after silo opening (Robinson et al., 2016). According to Santos et al. (2023), relocation and storage time are important factors during the process, as exposure tends to dehydrate the material, which can make it difficult to compact the relocated mass. However, the storage time of this mass favors silage, especially after the second opening, increasing the aerobic exposure time.

Sugarcane silage, when relocated, tends to have higher losses than other crops, due to the consumption of lactic acid present in the silage, which favors the proliferation, mainly of yeast. When studying the effect of sodium benzoate on relocated sugarcane silage, Souza et al. (2022) observed a reduction in losses due to the fungicidal effect of the applied salt, controlling the mold population and decreasing the yeast growth rate. Regarding feed consumption, sheep fed with relocated whole corn plant silage have similar intake to those fed with non-relocated corn silage (Queiroz et al., 2021). The same was observed with the feeding behavior of these animals, which did not vary regardless of the diet used (Cardoso et al., 2022).

The use of relocated silage is expanding into other scenarios, such as the use of partial or total diet silage. The ensiling of feed in partial or total mixture allows the commercialization of moist and fermented feeds, which is one of the major challenges currently faced by the feed manufacturing industry. Among the various benefits of total mixed ration ensiling, one notable advantage is the ability to include moist by-products (Nishino et al., 2003) and cactus (Rodrigues et al., 2023; Silva et al., 2023) in the production of this product. It also increases the ensilability of forage crops (Gusmão et al., 2018), achieving a uniform composition of the formulation and improving the nutritional value with storage. Additionally, it causes an increase in the aerobic stability of diets (Bueno et al. 2020), enabling the commercialization of moist feeds, mainly roughage. The relocated silages can be interesting ingredients to enable the production flow required by the feed manufacturing industry (Santos et al., 2021). Therefore, in the semi-arid region, due to climate uncertainties and the higher feed production risk, the commercialization of preserved moist feeds has intensified every day.

Environmental perspectives

In addition to strategies to maintain silage quality and processes that favor silo feed-out, it is important to observe environmental characteristics associated with silage production. Factors such as greenhouse gas emissions (carbon dioxide [CO_2], methane [CH_4] and nitrous oxide [N_2O]), volatile organic compounds (VOCs), and effluent production tend to have a negative impact on the environment, causing often irreversible losses to the system (Bleakley and Tiedje, 1982). Among the VOCs produced, alcohol is the one that most affects the ozone layer. Furthermore, other compounds such as alkenes, alkynes and aldehydes can compromise air quality, especially in near agricultural areas (Mitloehner, 2015).

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Greenhouse gasses are accumulated during the fermentation process of silage, being emitted shortly after opening in an instantaneous release process (Krommweh et al., 2020). Approximately 50% of these gasses are emitted in the first 36 hours after silo opening, including CO_2, CH_4, N_2O, ethanol, and methane. According to Jungbluth et al. (2017), the gas concentration in silage increases according to temperature. This factor can intensify the emission of these gasses, especially in semi- arid regions, where average annual temperatures are 25 to 30 °C (Alvares et al., 2013).

However, some research has demonstrated the possibility of the silage fermentation process producing lower concentrations of CO_2 (Krueger et al., 2023). These responses depend on the inoculant strains used, as homofermentative bacteria perform feed fermentation without the formation of CO_2 (Muck et al. 2018). Studies to identify the bacteria that perform this process more efficiently still need to be developed, to benefit the production sector and improve silage quality from a nutritional and environmental perspective. In the context, research should be developed to consider total emissions in the production system and from there, calculate the emissions from silage.

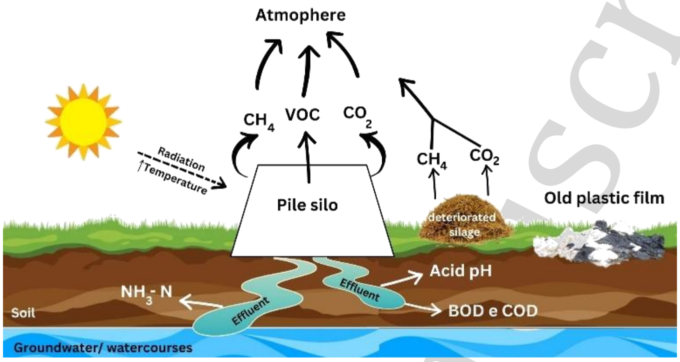

Figure 4. Environmental problems arising from improper silage use.

Another important point to be observed during the process is losses due to silage effluents. Effluents have a high biochemical demand for nitrogen, oxygen, and phosphorus, and they also have a low pH, thus direct contact with the soil can cause contamination of groundwater. Furthermore, the effluent can cause deterioration of concrete, which is a structure used in the construction of silos, mainly of the bunker type.

The moisture content of the ensiled crop is one of the main factors to be observed to avoid loss through effluents. The application of moisture-sequestering additives is a commonly used technology to combat this problem (Schimithausen et al., 2022). In the semi-arid region, extensive research has been conducted by various groups, focusing on utilizing fruit industry residues (Rêgo et al., 2010; Silva et al., 2011), biodiesel residues (Furtado et al., 2019), and other derivatives from agricultural crops (Dias et al., 2019; Amorim et al., 2023). It is important to note that silage is just one part of the production system, and all components must be balanced to mitigate the environmental impacts effectively.

Final Considerations

It should not be overlooked that there is still much to advance and improve in the basic conditions of the ensiling process. Despite the considerable variation in production systems in the semi-arid region, silage production somehow manages to meet producers' demands, but these can be propelled with the creation of new technologies. However, the difficulty in accessing new technologies is still a challenge, as both are designed for regions other than the semi-arid one. Minimizing the availability of these technologies in the semi-arid region causes logistic problems. In addition to this, their recent development and high acquisition costs make them less competitive compared to older and conventional technologies currently available. On the other hand, promoting research and access to lines of credit are fundamental to promoting new technologies applied to the silage production destined for the semi-arid regions.

An important point is that many of these new technologies are still in the development phase (e.g. sensors for silage) and need to be improved and perfected, but they show promising results when applied to ensilage. Nonetheless, it is relevant to emphasize that such technologies can contribute to more rational management of rural properties, increasing the efficiency of inputs utilization within them, reducing losses in the feed production process, and ensuring better sustainability of the system, especially from an environmental perspective in semi-arid regions.

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