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Silage for Climate Resilient Small Ruminant Production

Artabandhu Sahoo

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Abstract

Climate change impact on livestock, especially due to impact on agriculture and ensuing shortage of feed resources and its quality, will have a profound effect on growth, milk production, reproduction, metabolic activity and disease occurrence. Small ruminant feeding and nutrition research should therefore be tailored in line with climate resilient agriculture and farming systems. Seasonal feed scarcity is a concurrent problem that farmers usually face besides natural calamities like drought, flood, cyclone, earthquake, etc., and it has a significant impact on small ruminant productivity. Silage making is an effective and common method of forage preservation and also a form of treatment to occasionally retrieve the underutilized pastures for better acceptability, degradability and utilization. Demand for conventional crop (principally maize) outpaces its production, which stresses upon to find suitable, or even better, alternatives for silage making. This chapter deals with silage making from legumes, mixed forages, alternate forages and by-products from fruits and vegetable sector, TMR silage, phytochemicals role in silage making and livestock production, use of inoculants/additives in silages, the concept of therapeutic silage, novel microbial approaches to solving the problem of silage aerobic deterioration during the feed-out phase, animal and human health concern of deteriorated silages and production of designer animal produce from innovative silages.

Keywords: silage, small ruminant, feed scarcity, nutrition, productivity

1. Introduction

Seasonal shortages in feed supply are major constraints to increasing ruminant productivity in developing countries. Small ruminant feeding and nutrition research should therefore be tailored in line with climate resilient agriculture and farming systems. The calamity of

climate change should be converted into an opportunity for developing and spreading climate resilient small ruminant farming and production systems. Natural pastures, crop residues and indigenous fodder trees are the main feed resources for ruminant livestock. But, due to seasonal fluctuations in the availability and quality of these feed resources, intake of energy, protein and some essential minerals by most ruminant species fall below their maintenance requirements resulting in 'under-nutrition' and low productivity in most animal production systems [1]. The leftover natural pastures, particularly the abundantly grown monsoon grasses/herbages that get matured (lignified) and dried have limited intake and characterized by low nutritive value, digestibility and utilization. In dealing with the rainy season crop harvest, and due to the difficulties in hay storage, ensiling is considered as one of the preferable preservation techniques especially with the greatest potential for protein-rich foliage.

Silage making is an effective and common method of forage preservation and also a form of treatment to occasionally retrieve the underutilized pastures for better acceptability, degradability and utilization. It is universally agreed that silage making is one of the principal approaches if feed and nutrition is to be ensured round the year. In the rainy season, there is an abundance of grass, while it becomes scarce in the dry season, and therefore, silage production in the tropics has been established as a sustainable means of supplementing feed for ruminants in the dry scarcity periods. Maize is observed to be the major crop for silage making, but as the demand for maize/corn outpaces its production due to current changes in global energy system for the production of biodiesel, coupled with increasing competition between animals and humans for this major food/feed item; it has become imperative to research into suitable, or even better, alternatives to this conventional crop for silage making. Low cost unconventional plant biomass offering promising nutrients may serve as an alternative, because of changing climatic conditions and lack of opportunity to cultivate fodder due to shortage of water resources. Hence, the perennial forage surplus obtained when the weather is favorable is recommended for storage as silage in order to meet the animal requirements throughout the year [2]. Alternate forage resources (brownses and tree forages, field and crop wastes), succulent plant biomass (roots and tubers, cactus, fruits and vegetables co-products/wastes) and conceptualization of legume silage, mixed silage, total mixed ration (TMR) silage and their application would certainly expand the forage resource base and feed banking for ensuring nutritional input.

2. Climate resilient small ruminant production

Climate change leading to adverse changes in temperature, precipitation and sea level will disturb the food, water and livelihood security systems. The impacts of climate change on livestock are on its growth, milk production, reproduction, metabolic activity and disease occurrences. The indirect impacts include (i) scarce availability of water, pasture and other feed resources, (ii) health anomalies associated with modified/unknown vector-borne and parasitic diseases, (iii) competing environmental interaction with other livestock species. It is important to understand the small ruminant vis-à-vis other livestock responses to the changed

climatic environment and to analyze them in order to design modifications of nutritional and environmental management, thereby improving animal comfort and performance. In many countries, there is a scarcity of forage for ruminants feeding because of climatic conditions and shortage of water resources. The success of small ruminant rearing mostly depends on congenial macro- and micro-environments and the effectiveness of the ameliorating measures taken to reduce the stress factors. Adapting to climate change and reducing greenhouse gas (GHG) emissions may require significant changes in production technology and farming systems that could affect productivity. Globally, livestock contribute to 18% of the human-generated greenhouse gases, and the main components include methane (CH_4) produced by the belching of animals (25%), carbon dioxide (CO_2) by uses of land due to decomposition of organic substances (32%) and nitrous oxide (N_2O) due to spreading of manure and slurry over land (31%) [3]. One of the best ways of mitigating enteric methane emission could be improvement of the feed and forage of the ruminant animals to enhance the feed-conversion efficiencies in the production of a unit of milk or meat.

3. Silage making

Ensilage of forage crops has been practiced in one form or another for more than 3000 years. Several technical advances in silage making, such as multiple application of forage harvester, rapid and efficient silo packing, effective exclusion of air from silos, control of undesirable bacteria and use of silage additives (e.g. formaldehyde, glutaraldehyde, sodium hydroxide, sodium acrylate, urea, formic acid, etc.), and their application have expanded production and application of silage in livestock feeding. Emphasis has also been given on its qualitative enhancement due to increase in its usage in dairy and other ruminants. Ensiling forage enables preservation of succulent nature besides converting it to a form considered more utilizable by the ruminant livestock. Good silage is light brown in color, has a sour taste and pleasant acidic smell due to its lactic acid content, which make the product stable and can be kept for 6 months to 1 year, if required. This technology can be practiced round the year as and when any surplus plant biomass is available and yield better quality conserved forage to feed during scarcity.

Ideally, crops for silage are harvested at right stage, i.e. at 50% flowering, and then chopped into 2–5 cm pieces and left for wilting if needed to have moisture content not more than 60%. It is important to note that the influence of forage characteristics (epiphytic lactic acid bacteria (LAB), buffer capacity and sugar: buffer capacity ratio) on treatment effectiveness varied with DM content. Any additives (molasses, probiotic culture, etc.) can be added and mixed uniformly by spreading the chopped materials on a pucca (concrete) floor or polythene (plastic) sheet and then transferred to polythene lined silo pit (**Figure 1**) or plastic bags (**Figure 2**)/drums (**Figure 3**) and compressed tightly in order to make it air free. It is kept anaerobically away from direct sunlight under the shade for 55–60 days under anaerobic condition. To make good quality silage, one must have quality assessment of the plant, microbial and environmental factors that influence the fermentation process and, ultimately, the nutrient value of the silage. It is essential to harvest forage at the right time, from the point of view of nutritional



Figure 1. Silage pits lined with plastic sheet to prevent seepage.



Figure 2. Packing of fodder in plastic bag for silage making.

quality, quantity available and climatic conditions, and then to store it properly to reduce losses. Silage made from grasses and cereals is dark yellowish green in color, while it is blackish green when made of legumes. A good silage is friable, non-sticky and free from mold/fungal growth and should have an acceptable and pleasant aroma (fruity odor) and mild acidic taste. It should have a $\text{pH} < 4.5$; the lactic acid should be higher than other acids with a low butyric acid content (0.2–0.5%) and ammoniacal N not higher than 9–15% of total N.

Farmers' friendly ensiling process has been developed in many countries for its wider adaptation, which is relatively simple, can be performed manually, is flexible in handling and feed-out according to needs and does not require much input. Dry tree forages, less palatable fallen tree leaves, less preferable stovers and mature crop residues can be mixed with high moisture



Figure 3. Silage making in plastic drums.

containing cactus, azola, residual/leftover vegetables and fruits to prepare mixed silage of desired quality with proper balancing for appropriate moisture, degradable and water soluble carbohydrates (WSC) and N-fractions. The preservation of forage crops as silage depends principally on the production of sufficient acid to inhibit activity of undesirable microorganisms under anaerobic conditions [4].

3.1. Suitable crops for making silage

Forage crops should be harvested for silage making from flowering to milk stage of the crop. Forage characteristics, viz. type of forage, maturity, DM and WSC content, at the time of ensiling influence the ease of ensiling and ultimately the quality of silage. Cereals, in general, are easier to ensile than legumes or grasses, because of their lower buffering capacity and high WSC content. As forage matures from the vegetative stage into reproductive stage (i.e. heading for cereals; flowering for legumes), stems and leaves become more lignified, and the digestibility of these plant components declines. Several factors influence the rate of maturation of a crop including variety, moisture level, temperature, nutrient stress and time of season. Thus, optimal timing of harvest usually encompasses a compromise between DM and nutrient yield. DM content of forage tends to increase with advancing maturity, but silage DM can also be increased by wilting a less mature forage in the field prior to ensiling. Grass family crops are more suitable for making silage because of higher sugar and WSC, e.g. jowar (*Sorghum bicolor*), bajra (*Pennisetum glaucum*), maize (*Zea mays*), guinea grass (*Panicum maximum*), cenchrus grass (*Cenchrus ciliaris*, *C. setigerus*), sudan grass (*Sorghum sudanense*), oats (*Avena sativa*), barley (*Hordeum vulgare*), napier (*Pennisetum purpureum*), etc. [5]. Making silage only from leguminous crops like berseem (*Trifolium alexandrinum*), Lucerne (*Medicago sativa*), soybean (*Glycine max*), lobia/cowpea (*Vigna unguiculata*) is not advisable since they contain high moisture and less carbohydrate. Hence, they are mixed with grasses for making quality silage.

3.2. Ensiling legume crops/fodder

Current restrictions on the use of animal-based protein supplements coupled with increasing demand for soya protein concentrates put pressure on the livestock farmers and researchers to

consider alternative home-grown protein-rich forage crops as supplements to grass silage for sustaining production. Ensiling legumes is a good way of providing a cheaper, non-animal-based and traceable home-grown protein that may improve the efficiency of production system in any livestock farms. Also, legume silages with low DM and WSC contents are generally more resistant to aerobic deterioration than cereal silages [6]. There are also some unidentified microbial inhibitors that prevent the growth of spoilage microorganisms [7]. But, most legumes undergo butyric acid fermentation when ensiled without additives at low DM content due to low WSC and high buffering capacity [8]. Furthermore, severe degradation of proteins may devalue the protein quality due to inefficient N utilization.

Besides, stage of maturity and DM content of the crop at ensiling, wilting and rate of drying markedly reduce proteolysis in the silo [9]. Rapid and extensive wilting (DM > 500 g/kg) improved protein value and reduced CP degradability. Moreover, due to the reversible protein-binding properties of tannin, species containing tannin have shown to undergo less protein degradation during ensiling than that do not contain tannin. Since protein degradation in the silo is widely recognized to be the most limiting factor in legume silage, intrinsic protein protection by mixing tannin-containing forages may contribute to reducing the rate and the extent of NPN formation in silages, thereby improving N usage. Fraser et al. [10] compared the nutritive value of a range of ensiled forage legumes from late second-cut lotus (*Lotus corniculatus*), first-cut sainfoin (*Onobrychis viciifolia*) and both early and late second-cut red clover (*Trifolium pratense*) and lucerne and found high intake potential of all the legume silages. The tanniferous lotus silage recorded higher intake and N utilization compared to less/non-tannin legumes, clover and lucerne, while low N digestibility appears to limit the nutritional value of sainfoin. In silages made from the beginning of ripening stage, where most of the protein was localized in the seed, the level of proteolysis was reduced and a good fermentation was observed in peas ensiled after a short wilting period [11]. Possible approaches include the adoption of harvesting techniques that reduce field wilting time, the use of protein protection agents during ensiling such as tannins or the choice of natural tannin-containing legume species.

3.3. Alternate plant biomass for silage making

Industrialization of food production has produced large quantities of food wastes, viz. (i) crop waste and residues, (ii) grain and legume by-products; (iii) distillery and brewery by-products; (iv) fruit and vegetables by-products; (v) sugar, starch and confectionary industry by-products and (vi) oil industry by-products. Fruit and vegetable processing by-products/co-products are promising sources of valuables such as phytochemicals (carotenoids, phenolics, flavonoids), antioxidants, antimicrobials, vitamins or dietary fats that have favorable technological activities or nutritional properties and have traditionally been used as feed ingredients, and their effect on animal performance has been extensively studied [12–14].

Key determinants while selecting unconventional resources: Moisture content is the most important factor in silage making, with a recommendation at 65–75% [15] depending on the means of storage, the degree of compression and the amount of water that will be lost in storage. Effluent is produced when moisture is above 75%, with the amount of effluent increasing with increasing silo height due to increasing pressure. In general, forage with high moisture

content makes sour silage. Additionally, the critical pH value for clostridial growth varies directly with the moisture content of the plant material, and unless WSC levels are exceptionally high, ensiling wet crops encourages clostridial fermentation, resulting in high losses and reduced nutritive value. Moreover, many high CP legume foliages can be difficult to ensile successfully, because they tend to have low WSC, high buffering capacity and low DM content when directly harvested [8].

The characteristics of good silage should have pH values of 4.2 or less, $\text{NH}_3\text{-N}$ contents <100 g/kg DM and high lactic acid contents. Legumes that have low WSC and high buffer capacity do not produce good quality silage [8]. High N-containing leguminous fodder also includes tree forages and browses that are rich in plant secondary metabolites (PSM). Many times these phytochemicals may become adverse to fermentation process (e.g. antimicrobial effects of alkaloids, essential oils, etc.) and put forth additional challenges to step up microbial fermentative activity. Further, degradation of protein during ensiling process produces volatile organic acids with higher pKa values, and thus, the silages may have higher pH, unfavorable aroma, less aerobic stability and greater spoilage. Further, the relationship between weekly growth rate and change in quality parameters is differed among species and functional groups, i.e., grasses and legumes, and therefore, quantifying the impact of delaying the harvest date of grass-legume mixtures and assessing the relationships between productivity and components of feed quality are important.

3.3.1. *Phytochemical-rich forages*

Tannins in ruminants can induce beneficial effects attributable to tannin-protein complexes, which lead to increased rumen escape of dietary protein and increase in microbial protein outflow. High N fertilized grasses are more degradable, which are hydrolyzed extensively during ensiling and are rapidly degraded in rumen resulting in more excretory loss. Decreased proteolysis and slower fermentation of proteins and NPN are particularly important in silages for uniform N availability to ruminal microbial synthesis and thus optimizing its usage. Forage legumes with PSM are considered to be less susceptible to proteolysis than other legumes, which improve silage quality. The legume sainfoin has been shown to contain tannins of particularly beneficial composition for ruminant nutrition. Adding tannins during ensiling holds key both at ensiling and at rumen level to check N degradation and decrease its excretion.

Plant phenolic compounds and flavonoids are the largest and best-studied natural phenols that possess a series of biological properties and act on biological systems, such as antioxidants, antimicrobials and immunostimulants, which in turn, are associated with a reduction in the incidence of various human diseases. The shift in research to feedstuff endogenous factors, which influence proteolysis and lipolysis, may have a significant contribution on ruminant products (meat, milk) and their transmission to human food chain. Any qualitative variation in ruminant food products with naturally rich conjugated linoleic/linolenic acid (CLA) and other $\omega 3$ fatty acids (FA) can thus be influenced by animal's diet. Ruminal biohydrogenation is heavily influenced by PSM, which includes polyphenol oxidase (PPO), FA oxidation and tannins, and the effect is a complex set of mechanisms directly affected by PPO or indirectly by passage rate, lipid encapsulation, shift in the ruminal microbial population,

modulation of protein and fiber degradation and interactive effect of other PSM [16]. The animal performance with silages from PSM-rich forages attributed not only to differences in their nutritive value but also to interactive effects impacting differently on feeding motivation and digestive efficiency [17].

Usefulness:

- **Reducing nutrient drainage:** Decrease in protein and N compound degradation during ensiling and rumen fermentation.
- **Improving nutrient use efficiency and enhancing P:E ratio:** Efficient use of N in grasses by ruminants decreases its excretion, reduces requirements in diet and increased net return per cow.
- **Protecting environment:** Reduces environmental pollution thereby promoting environment-friendly livestock production.
- **Improving livestock products quality:** Alters ruminal biohydrogenation process and improves FA profile of milk and meat.

Possible outcome: Research outcome will help identify tannins and other phytochemicals which can be used as silage additives. Tannins shift N excretion from urine to feces and from soluble to insoluble N forms in feces. This undigested form of N from plant residues mineralizes more slowly than microbial and endogenous N, and these shifts in N forms could reduce ammonia and nitrate losses from ruminant production system and thus contribute to reducing the protein and NPN supplements in the animal feed. Besides improving N usage and aerobic stability of silages, the ingested phytochemicals also have significant role on improving ruminant livestock products and their shelf life [18]. This will augment “Green Consumerism” and the naturally improved products could be placed on the market at higher prices with the brand name of “environment-friendly products.” Ultimately, farmers will feel encouraged to adopt bioactive forage-enriched feed for livestock feeding.

3.3.2. Use of phytochemical-rich plants and nutrient usage

The use of phytochemicals in ruminants can induce beneficial effects, most-importantly, the role of condensed tannins on retention of dietary N (reduced urinary output) and its overall usage vis-à-vis efficiency of energy utilization. Ensiling of N-rich forages (e.g. alfalfa/lucerne, berseem, cowpea, etc.) transformed majority of protein N into non-protein N (NPN), which can be inhibited to some degree by accelerating the rate of pH decline during silage fermentation, but compared to cereal forages, structural difference in leaf: stem ratio and its physicochemical characteristics, low WSC content and high buffering capacity make it difficult to ensile resulting in proteolysis. Forages containing condensed tannins (CT) undergo less proteolysis during ensiling, and transformation of their plant protein N into NPN is inhibited compared to forages without CT [10, 19, 20]. Therefore, adding tannins during ensiling holds key both at ensiling and at ruminal level to check N degradation and decrease its excretion to the environment. High level of tannins may adversely affect the activities of silage bacteria [21]. Co-ensiling

sainfoin and alfalfa improves fermentation in silos and increases total tract digestibility, suggesting positive associative effects of the two forages [20]. The optimal ensiling and ruminal fermentation for alfalfa and sainfoin were observed at approximately 60:40 ratio (DM basis). It also reduces proteolysis and preserves the nutritive value with sainfoin relative to alfalfa alone. Both total phenol and total tannin contents contributed to the decrease in lactic acid production. Fasuyi et al. [22] found 4% molasses and 14 to 21 days ensiling period optimum and most suitable for effective ensiling of *Tithonia diversifolia* leaves. They also observed a gradual decrease in major anti-nutrients (phytin, tannins, oxalates, alkaloids, flavonoids) with lengthening duration of ensiling. However, there are reports that tannins suppress the production of lactic acid during ensilage [23]. A number of additives that include chemical inhibitors, such as acids, formaldehydes, and various salts, and biological stimulants (LAB and other bacteria) expedite lactic acid production to support ensiling process [24]. The resistance mechanisms of *L. plantarum* include the ability to degrade phenolic compounds [25] such as tannin, by the action of novel tannin acylhydrolase [26] and gallate decarboxylase enzymes [27].

3.4. Concept of mixed silage

The concept of mixed silage has widened the scope of incorporating grains, protein concentrates, leguminous forage crops, tree forages and other conventional and unconventional tanniniferous forage crops with the conventional one for silage making. Making of mixed silage involving seasonal availability of feed resources allows the farmers to opt for a variety of forages, for example monsoon herbage, tree forages and browses, including that of conventional grasses and cultivated fodder. It also widens the scope of incorporating non-conventional fodder resources like cactus, thorny non-toxic plants/weeds and phytochemical-rich plant resources. Corn and legume silages are commonly fed together in rations for dairy cattle, one complementing the other for the deficit N and energy sources, respectively. Thus, the fermentable carbohydrates in corn silage may complement the rumen degradable N (RDN) in legume silage, which may decrease ruminal N losses. Above all, the N intake affects the amount of N excreted via manure, whereas types of carbohydrate (starch in corn silage vs. sugars in grass silage) and forage species (legume vs. grasses) have greater impacts on the route (fecal or urinary) of excretion. Besides agronomic benefits of grass-legume mixtures, there are positive associative effects contributing to voluntary intake due to a greater motivation of animals to eat mixtures along with decreased urinary N excretion and increased N retention [28]. Thirumurugan et al. [29] evaluated cereal-legume mixed silage to combat feed and water scarcity and sustaining production during hot summer in semi-arid regions of India. Total mixed ration (TMR) silage is a way forward in this direction.

3.4.1. Why mixed silage?

Monotonous use of a single fodder (e.g. maize) in silage making limits the farmers to adopt the technologies, particularly in unfavorable geographical and climatic regions (semi-arid and arid regions). Therefore, combination of grasses and legumes is an alternative solution to the success of the ensiling process. The purpose of the addition of legumes to silage is to supply N/protein for microbial protein synthesis, reduce protein degradation in the rumen and

increase amino acid absorption in the intestinal tract. The combination of grasses and legumes in ruminant feed is very effective for a highly nutritious diet. This allows the farmers to use its surplus or seasonal plenty or available at hand plant biomass resources to preserve as silage to feed during scarce or unavailability. Successful ensiling can be evaluated by determining the relationships between fermentation characteristics and microbial diversity in silages. Reducing the moisture content of the crops through substitution with other high DM forages could be another approach. Moreover, nutrient composition analysis following up with palatability study can very well evaluate the combinations of different silages involving local grasses, tree forages, browses and monsoon-favored less/non-tested abundantly grown plant biomass. This versatility allows the farmers to use their wisdom to choose and harvest the available forage biomass at hand for preserving as silage. Above all, year-round feed and nutrient supply to the livestock can certainly enhance per animal/whole farm productivity, thereby enabling the livestock husbandry sustainable and profitable. Some of the questions that continue to be answered for harnessing possible beneficial effects of plants rich in phytochemicals as a part of silage are

- Can mixed silage concept is more versatile, if at all, the effect of high N containing feed-stuffs on silage quality and preservation process?
- Tannins/polyphenols that are suitable for adding during ensiling need to be identified based on their chemical characteristics, affinity to form complexes during ensiling and rumen fermentation and release of tannin-protein complexes at different pH of stomach and intestine, and also keeping in view their toxic and anti-nutritional effects.
- Comparing results from simulated rumen *in vitro* system studies for stability of complexes and release of bound N from rumen of silage with tannins added during ensiling, can help evaluate efficacy of tannins for utilization of N in grasses and leguminous forages by ruminants.
- Feeding trials in different ruminant species fed on grass silages with or without tannins and the effects of supplemental tannins pre- and post-feeding on excretion of N and N-metabolites for evaluating efficacy of tannins on overall N economy.
- Effect of other plant phytochemicals on ensiling process and post-consumption effect on ruminal N and energy use efficiency both *in vitro* and *in vivo*.

3.4.2. Competing conventional silage

The plant, microbial and environmental factors that influence the fermentation process determine the nutrient value of the mixed silage. These factors must be considered as an integrated package to facilitate optimum forage preservation process. Moreover, it is now observed that the use of ensiled alternative forages have positive influence on voluntary feed intake (VFI), nutrient use efficiency and productivity of livestock systems [2, 30]. This would encourage the livestock farmers to preserve nutrients for future use and sustain whole farm productivity. A list of mixed silage evaluated in various countries in the feeding of native ruminant livestock is detailed in **Table 1**.

Silage types			DM	OM	CP	NDF	ADF	Citation
Local name	Region/Country	Botanical name*						
Cholai* (100)	India	<i>Amaranthus</i> sps	22.8	87.2	8.80	55.5	49.6	[30]
Bajra* (100)	India	<i>Pennisetum typhoides</i>	36.9	87.8	8.18	65.8	46.7	
Cholai + Bajra (50:50)	India	–	28.6	87.5	8.54	60.3	47.8	
Cholai + Cenchrus* (50:50)	India	<i>Cenchrus</i> sps	26.9	86.2	7.32	55.2	41.5	
Jojhru* + Cholai (50:50)	India	<i>Crotalaria medicaginea</i>	30.6	87.4	10.28	52.2	38.5	
Jojhru + Cenchrus (50:50)	India	–	27.8	87.0	8.76	58.8	42.5	[2]
Jojhru + Bajra (50:50)	India	–	32.7	87.0	9.88	59.2	41.5	
Cactus* + Ardu ¹ * (80:20)	India	<i>Opuntia</i> sps + <i>Ailanthus excelsa</i>	25.8	85.1	8.70	51.7	35.0	[30, 31]
Cactus + Gram straw* (80:20)	India	<i>Cicer arictinum</i>	28.6	82.9	8.36	54.5	38.6	
Cholai + Moringa ¹ * (80:20)	India	<i>Moringa oleifera</i>	32.2	86.1	12.22	52.5	34.2	[2]
Moringa + Bajra ¹ (70:30)	India	–	37.2	88.3	12.56	55.4	38.2	
Cholai + Ardu ¹ (80:20)	India	–	30.8	86.8	9.28	53.8	41.5	
Oat* + Ardu ¹ (75:25)	India	<i>Avena sativa</i>	35.8	88.2	8.22	58.6	44.8	
Barley* + Ardu ¹ (75:25)	India	<i>Hordeum vulgare</i>	36.2	87.9	8.02	59.5	44.2	
Oat + Lucerne* (75:25)	India	<i>Medicago sativa</i>	32.6	87.3	10.51	52.8	39.5	[29]
Oat + Lucerne + Ardu ¹ (75:12.5:12.5)	India	–	36.0	87.8	10.24	53.6	39.2	
Cactus + Acacia* (67:37)	Zimbabwe	<i>Acacia angustissima</i>	38.0	81.6	25.0	63.4	57.4	[32]
Cactus + Leucaena* (67:37)	Zimbabwe	<i>Leucaena leucocephala</i>	44.0	82.4	20.0	57.3	52.3	
Cactus + Calliandra* (67:37)	Zimbabwe	<i>Calliandra calothyrsus</i>	41.0	84.1	21.9	72.2	55.4	
Cactus + Siratro* (67:37)	Zimbabwe	<i>Macroptilium atropurpureum</i>	42.0	85.3	12.5	65.7	58.8	
Pennisetum* (100)	Indonesia	<i>Pennisetum purpureum</i>	31.2	87.5	5.6	66.6	34.4	[23]
Pennisetum + Calliandra (75:25)	Indonesia	–	33.6	89.7	10.6	59.7	25.4	
Pennisetum + Calliandra (50:50)	Indonesia	–	37.0	90.9	14.2	56.0	26.1	
Pennisetum + Calliandra (25:75)	Indonesia	–	40.7	92.4	17.3	54.4	17.5	
Calliandra (100)	Indonesia	–	46.5	93.4	20.2	53.8	13.4	

Silage types			DM	OM	CP	NDF	ADF	Citation
Local name	Region/Country	Botanical name*						
Aruana grass* (100)	Brazil	<i>Panicum maximum</i>	28.2	–	8.95	67.1	41.3	[33]
Aruana grass + Gliricidia (75:25)	Brazil	–	28.3	–	10.07	60.9	40.1	
Aruana grass + Gliricidia (50:50)	Brazil	–	28.1	–	11.06	53.7	37.2	
Aruana grass + Gliricidia (25:75)	Brazil	–	27.5	–	12.0	46.5	30.4	
Gliricidia* (100)	Brazil	<i>Gliricidia sepium</i>	27.6	–	12.83	39.5	25.6	
Gliricidia (100)	Vietnam	–	21.7	92.9	20.3	52.7	35.4	[34]
Mexican sunflower	Nigeria	<i>Tithonia diversifolia</i>	17.6	–	17.00	–	–	[22]
Moringa (100)	Nigeria	–	31.9	97.9	18.45	11.2	11.1	[35]
Moringa + Wheat* offal (50:50)	Nigeria	–	36.2	90.9	14.35	12.1	9.95	
Moringa + Guinea* grass (50:50)	Nigeria	<i>Panicum maximum</i>	32.1	97.9	8.25	12.3	11.1	
Moringa + Guinea* grass + Wheat offal (50:10:40)	Nigeria	–	32.1	97.5	10.48	11.2	9.16	
Moringa + Guinea* grass + Wheat offal (50:20:30)	Nigeria	–	32.3	97.6	12.27	11.0	9.16	
Moringa + Guinea* grass + Wheat offal (50:30:20)	Nigeria	–	33.5	97.5	13.13	10.9	8.90	
Moringa + Guinea* grass + Wheat offal (50:40:10)	Nigeria	–	35.9	97.6	13.40	10.7	8.54	
Amaranth	Iran	<i>A. hypochondriacus</i>	48.8	91.8	14.70	30.0	17.2	[36]
Fruit* byproduct silage	Greece	<i>Punica granatum</i>	29.2	95.9	12.00	21.8	16.9	[37]
Cassava	Vietnam	<i>Manihot esculenta</i>	26.7	92.8	21.70	51.4	37.2	[34]
Cassava leaf	Indonesia	–	30.7	92.9	16.20			[38]
Cassava leaf	Nigeria	–	30.4	97.8	15.46	–	–	[39]
Cassava peel	Nigeria	–	29.2	97.8	5.72	–	–	

*Forages used in silage display botanical names.

[†]Forages in dry form.

DM, dry matter; OM, organic matter; CP, crude protein; EE, ether extract; TCHO, total carbohydrates; NDF, neutral detergent fiber and ADF, acid detergent fiber.

Table 1. Dry matter and nutrient composition (% DM basis) of different types of unconventional silages.

3.5. Silage from alternate forages

3.5.1. *Amaranthus silage*

Amaranth is a dicotyledonous species and commonly considered as a pseudo-cereal, which has a good yield performance up to 86.4 t fresh forage/ha [40] with promising nutritive value [30, 41–43] and CP up to 285 g/kg DM with useful minerals including Ca, Fe, Zn, Mg and P. It is adaptable to varying climatic and agronomic conditions, tolerance to drought as well as a low water requirement [44]. The use of *Amaranthus* silage in the diet of fattening Moghani lambs up to 300 g/kg of dietary DM improved total gain and carcass weight without any adverse effect on lean-to-fat ratio and animal health and demonstrated its replacement value for maize silage [36]. A small bag ensiling technology is being promoted as a useful and low cost tool to improve production in smallholder livestock farms [45].

3.5.2. *Moringa silage*

Moringa oleifera has attracted the attention of researchers in recent times, and its intensive cultivation with the application of fertilizer and water supply gives a DM yield up to 120 tonnes/ha, with 7–8 cuttings in a year [46]. *Moringa* leaves are high in CP and phytochemicals that reported to have a positive influence on lactation performance [47, 48]. Sole *Moringa* silage, or in combination with fresh *Panicum maximum* in equal proportion, may not be promising dry season feed conservation strategies for ruminants, while silage mixtures of 50% *Moringa* +10–30% Guinea grass and 20–40% wheat offals showed great potentials [35]. It should preferably be ensiled in mixtures with conventional and/or unconventional forages to increase the VFI and nutritive value of the silage. This is often considered as a perennial forage surplus to preserve as silage to meet round the year feed requirements.

3.5.3. *Cactus silage*

Cactus, particularly the *Opuntia* species, is grown in semi-arid regions of many tropical countries and is often fed to livestock during summer to provide both feed and water [31]. However, the excess biomass during other season can be preserved suitable as silage for feeding during scarcity [30]. It was observed that mixing cactus and browse in silage making improved both DM and N content in the product. Similarly, it can be mixed with legume forages and hays by supplying a degradable source of organic matter. The cactus + browse or cactus + legume silages improve microbial protein flow to the lower gut for digestion and supply of amino acid for maintenance, growth and production. These silages could be used in livestock feeding to improve livelihoods in drier and resource constrained farming communities by providing opportunities for conservation of forage and maintaining their animals in periods of feed scarcity. The nutritive value of silage from cactus cladodes was evaluated and found acceptable quality silage based on pH, organic acids contents and voluntary intake. It might be advantageous to ensile cactus mixed with other ingredients and improving utilization of poor quality roughages with the addition of cactus-browse silages as supplements [31]. Abidi et al. [49] ensiled fresh cactus cladodes with olive cake and wheat bran and found no adverse effect on

digestible nutrient intakes by replacing with oaten hay. In addition to feed shortage, water scarcity compromises livestock performances in dry areas. Because of its succulence, cactus could overcome this constraint as ruminants do not need to drink water when receiving cactus cladodes (35 g DM/kgW^{0.75}) [50]. It is reported that ensiled mixture of spineless cactus, olive cake and wheat bran could be used to replace totally or partially oaten hay without affecting lamb performances and meat quality [49]. It is thus advocated to go for mixed silage with cactus and protein-rich dry forages (e.g. Ardu leaves, gram straw, pea crop residues), so as to balance the minimum moisture content (i.e. 35–40%) in making of good quality silage [31]. A reasonable intake of 3–4 kg cactus silage in adult sheep was recorded that meet 900–1200 g DM and enough nutrients to support minimum production during scarcity.

3.6. Silage from by-products

3.6.1. Silage from fruit and vegetable co-products

Utilization of fruit and vegetable co-products, such as grape, tomato, olive or citrus pomace that are voluminously produced and have an important impact on the environment, in the animal feed holds promise in expanding the forage biomass, thereby meeting the increasing demands of feeds and fodder. Besides the fact that fruit and vegetable co-products are good sources of phenolic constituents [12, 51] that act as natural antioxidants, and research emphasis has now been directed at use of these co-products in improving products' quality [14]. They evaluated pomegranate byproduct silage supplementation to growing lambs and found improved nutritional and functional qualities as indicated by the increase in essential FA, intramuscular fat, total phenolic content and antioxidant activity.

3.6.2. Pineapple fruit residue silage

National Institute of Animal Nutrition and Physiology (NIANP), Bengaluru (India), has developed a silage technology to preserve pineapple fruit residue (PFR) and use it as fodder for livestock [52]. More than 70% of pineapple fruit is wasted during processing in industry, and there is potential availability of PFR to the tune of 1.35 million tonnes per year in India. PFR is high in moisture and sugars and thus can suitably preserved in the form of silage, which otherwise become a waste in processing industries. Nutritionally, PFR silage is demonstrated as a valuable fodder resource comparable to maize green fodder and increases milk yield and quality.

3.6.3. Cassava silage

Cassava (*Manihot esculenta*) is known as a highly productive tropical crop that is traditionally cultivated to produce roots for human consumption or for starch production. The yield of cassava leaves is recorded as much as 4.6 thousand tonnes of DM/ha when taken as a by-product at root harvesting. Cassava leaf silage was successfully introduced to small holder farmers in Indonesia [38]. The chemical and microbiological composition, silage preparation and the effects of LAB inoculants on silage fermentation of cassava residues including cassava leaves, peel and pulp were studied to effectively use in livestock diets [53, 54]. They found improved fermentation quality with lower pH, butyric acid and higher lactic acid when the residues were ensiled with LAB inoculants.

3.7. Ensiling on nutrient composition and utilization

Differences in WSC and protein (particularly, the A and B fractions) contents and fermentative characteristics between plant parts and plant species contribute to the differences in ensiling process, be it lactic acid production, pH reduction and modification/reduction in the phytochemical constituents. The use of molasses has been in practice for stepping up the initial fermentation process during ensiling. It is suggested that a critical WSC concentration in herbage for successful preservation as silage without additives is 30 g/kg DM. Sugars, such as fructosans, starch, pectins and soluble fiber content, greatly decline during the fermentation process [55]. A part of the OM gets lost in the initial phase owing to respiration of plants and during fermentation to CO₂ and other fermentation products and storage of silage by microbial activity. Total DM losses for optimal lactic acid fermentation are relatively low and should range between 2 and 6%. The proteolytic activities are restricted when the pH of the silage is ≤ 4.3 [56], and in good silage, the process will stop earlier and limit the loss of protein. Tannin might limit the proteolytic activities and reduce the loss of silage CP (soluble NPN) [19]. Different ratios of grass to red clover silage in TMR demonstrated improved performance when they were offered as a mixture than when fed alone [57]. Red clover contains PPO, which binds protein and it tended to reduce whole body N balance at higher inclusion levels due to increased partitioning of N into urine and feces. Legumes that contain CT also have the potential to reduce the degradation of plant protein to NH₃-N in the rumen, thereby releasing proteins in the abomasum, leading to improvements in feed efficiency and reduction of N excretion. Research emphasis should therefore be needed to explore the interactions of CT-containing legume feeds with other dietary components, fiber digestion and the consequential N partitioning effects, thereby reducing N excretion and improving efficiency and environmental quality.

3.8. Ensiling effect on phytochemicals/anti-nutritive factors

Phytochemical determination showed that ensiling reduces the presence of some anti-nutritional factors such as tannins, phytic acid and trypsin inhibitors [58]. A low pH, which is critical to make good silages from wet crops, also dissociates tannin-protein complexes and may compromise formation of rumen escape protein that can improve protein utilization. Invariably, ensiling of tannin-rich, legume, cereal or mixed forages shows a pH decline not beyond 4.0, and hence, any possibility of dissociation of tannin-protein binding complex does not arise, which requires pH of 2–3 [59]. Increase in ensiling duration also reduces tannin concentration. At pH range 3.5–5.5, insoluble tannin and plant leaf protein complex was established [60]. A reduction of 25 and 42% in the tannin content of fresh cassava and *Gliricidia* tops, respectively, was found after ensiling [34]. This phenomenon can be correlated to hydrolysis of hydrolysable tannins. Moreover, diets containing 2–4% of CT reduce proteolysis during ensiling and rumen fermentation by up to 50% [61]. Similarly, a continuous decline in HCN to the tune of 68 and 43 % was found in ensiled cassava and *Gliricidia* tops, respectively after 2 months of ensiling [60]. Handling and ensiling process and the initial environment of the aerobic phase created favorable environment for reducing the HCN. A rapid reduction in pH restricts the enzyme activities that reduce the speed of HCN elimination during storage. Pyrrolizidine alkaloids remain unaltered in silage and are not toxic [62]. The PPO activity, associated predominately with the detrimental effect of browning fruit and vegetables,

showed potential to inhibit proteolysis that draws interest to improve animal forage quality through greater N utilization [63]. The mechanism for PPO protection of plant protein in the rumen is a consequence of complexing plant protein, rather than protease deactivation, and these complexed proteins reduce protein digestibility in the rumen and subsequently increase undegraded dietary protein flow to the intestine. It catalyzes the conversion of phenols to quinones, which are extremely reactive and bind with cellular nucleophiles such as proteins to form protein-bound phenols. Red clover and cocks foot (*Dactylis glomerata*) showed high PPO activity compared to other forages [64]. There are several reports on the positive effect of PPO on preserving polyunsaturated FA (PUFA) within rumen simulation models [17] and limiting post-harvest proteolysis [64, 65]. The effect of PPO on inhibition of ruminal proteolysis and biohydrogenation is reported at 25 and 11%, respectively [66]. Thus, the benefit of red clover silage is attributed to a reduction in lipolysis in silo and an increase in beneficial C18 PUFA in animal products. A number of factors, e.g. cultivar, growing season, stage of maturity, sward management including forage conservation method and cell damage, play a role in the extent of enzyme activity.

3.9. Total mixed ration (TMR) silage

Ensiling TMR allows preservation and saves labor at the farm as it saves daily preparation cost of TMR with succulent fodder. This concept of silage making is aimed at ascertaining nutritional adequacy to livestock for maintenance and/or production. Production of TMR silage and feeding to production stock in a livestock farm are gaining rapid acceptability. However, the fermentation process of the substrates during ensiling may influence various nutritional components, and therefore, the loss should be kept minimum for easy adoption and maximize nutrient utilization efficiency. Balancing CP and total carbohydrates content with respect to concentration of fermentable N and sugars would provide a desired reducing environment for anaerobic degradation to lactic acid and rapid drop in pH. Brewer's grains are found to be a suitable by-product for ensiling as it improved aerobic stability when ensiled with various feeds as a TMR [67]. Five different silage types with cassava by-products (peel and pulp at different ratio) (40%) with corn husk (42%), Brewer's grain (14%) and molasses (3%) were evaluated and recommended as a useful energy source in Thailand during the dry period [54].

3.10. Aerobic stability of silage

It is a key factor in ensuring that silage provides well-preserved nutrients to the animal with minimal amounts of mold spores and toxins. When silage is exposed to air on opening the silo, fermentation acids and other substrates are oxidized by aerobic bacteria, yeasts and molds, and the stability is thus dependent principally on following factors [68]:

- i. **Biochemical and microbiological factors:** Development of yeasts and molds during plant growth and during field wilting or storage and concentration of undissociated acetic acid in silage.
- ii. **Physical and management factors:** Silage density and porosity are key physical factors that affect the rate of ingress of O₂ into the silage mass during the feed-out period. A target for potential silage aerobic stability is generally 7 days including the time in the feed

trough. Speed of harvest needs to be coordinated with packing to achieve a minimum silage density of 210 kg DM/m³ by the time of feed out and a rate of silage removal to match or exceed the depth of air penetration into the silo.

- iii. **Type of additives:** Use of additives is advisable when there is risk of meeting these objectives.
- iv. **Silo sealing:** Post-exposure sealing of silage pit/bags/drums helps prevent aerobic exposure and infestation of bacteria, molds and yeast/fungal growth.

3.11. Spoilage and fungal contamination

The epiphytic microbial populations are the starter culture and the survival and activity of these populations are also among the factors influenced by the characteristics of the crop at the time of ensiling and often contribute to spoilage and could be a potential health risk. Therefore, the types of LAB rather than the total numbers of bacteria present in the epiphytic populations may be more important in determining the efficiency of the fermentation process. Manuring onto forage prior to ensiling increases numbers of epiphytic enterobacteria (e.g. *Bacillus* and *Clostridium* spp.) and contact of the forage with soil can also increase yeast and mold counts in the silage [69]. Although these microorganisms are usually inactivated during ensiling, they can become active and contribute to accelerated spoilage when the silage is exposed to air upon feeding. Well-preserved silages are dependent on appropriate fermentation after storage, which results in low pH and production of sufficient acid to inhibit the growth of undesirable microorganisms. Lactate-oxidizing yeasts are generally responsible for the initiation of aerobic spoilage, and the secondary aerobic spoilage flora consists of molds, bacilli, listeria and enterobacteria [70]. The activity of harmful microorganisms not only reduces the silage quality (e.g. formation of butyric acid) but also increases the losses of energy and DM [71]. Hexoses are fermented to carbon dioxide and hydrogen, and subsequent decarboxylation and deamination of amino acids by these bacteria contribute to a decrease in the quality and quantity of forage. Yeasts also ferment sugars to ethanol and carbon dioxide with higher fermentation losses. Spoilage after opening the silage pit or bags seems to be concurrent problems faced by many farmers because LAB typically reduces the concentration of acetate, which is strongly antifungal, and increases concentration of lactate, which is a growth substrate for spoilage yeasts [6]. When silage is exposed to air during storage or at feeding, aerobic spoilage leads to increase in pH and losses of DM and nutrients [72] due to lactic acid degradation by mainly the lactic acid-utilizing yeasts (e.g. *Pichia*, *Candida*) [73]. Difference in anaerobic degradation of cereal and legume forages during silage making leaves more residual WSC than do legume silages, which is a readily available source of energy for the animal. But, upon exposure to air, these WSC are readily utilized by spoilage microorganisms and often become more prone to aerobic deterioration than legume silage.

Growth of spoilage fungi in baled silage is not of random occurrence but is facilitated where in-bale environments allow the fungi to survive, colonize and reproduce. Visible fungal growth was observed on baled grass silage during the winter feeding season [74]. The factors analyzed are the concentrations of ethanol and lactic acid, DM content, bale tying, month of bale feed-out, age of bales, polythene film damage, ryegrass dominance, bale storage location

and volatile FA concentrations. Besides, the environmental factors inside the silo, e.g. moisture content, pH, acid and gas composition, are likely to influence the species composition of the fungal population and the extent to which mold colonization occurs. Oxygen ingress causes excessive moisture or dryness, condensation, heating, leakage of rainwater and insect infestation of the silo, leading to undesirable growth of microaerobic acid-tolerant fungi, which may lead to mycotoxins production in this substrate [75]. Mycotoxin-producing molds, *Bacillus* sps and *Listeria monocytogenes* in aerobically deteriorated silage form a serious risk to the quality and safety of milk and to animal health. An average of 32% positive cases observed with most frequent fungal species from *Aspergillus*, *Penicillium* and *Fusarium* in pre- and post-fermented sorghum silage samples [76]. Thus, periodic monitoring is essential to prevent the occurrence of mycotoxicosis particularly in countries with hot and humid climates.

3.11.1. Controlling spoilage

Addition of high levels of propionic acid is effective against aerobic spoilage, but its use has been restricted because of its corrosive nature, relative expensiveness, involvement in VFI depression and variable sensitivities of yeast [77]. Control of silage fermentation by microorganisms seems to be a safe and inexpensive alternative, and in this line, LAB inoculation has been recommended to improve the aerobic stability of silage [8]. Killer yeasts (e.g. *Kluyveromyces lactis*) are known to secrete a killer protein that is lethal to specific yeasts (e.g. *Saccharomyces cerevisiae*) in a model of silage fermentation [78]. Genetically modified killer strain of *K. lactis* constructed to avoid dependence on substrates of lactose/lactic acid, a principal product of silage fermentation, which reduced aerobic spoilage.

3.11.2. Microbial inoculants

The mechanisms by which the inoculants alter silage fermentation and potentially improve animal performance are numerous. It supports accelerated post-ensiling decline in pH enabling quality silage production, improves stability and DM preservation, conserves nutrients, enhances aerobic stability and improves voluntary intake, nutrient utilization and efficiency of production. There may be increase in lactic/acetic acid ratio and reduction in proteolysis and protein deamination, thereby allowing better utilization of WSC and increase in DM recovery [79]. The problem of aerobic instability could be prevented by the use of microbial inoculant *L. buchneri*, a heterofermentative LAB, which could improve the aerobic stability of silages through the production of acetic acid from lactic acid during the anaerobic phase of silage conservation [71, 80, 81]. The natural populations of LAB in fresh crops are often heterofermentative and low in number, and thus homofermentative bacteria are used as inoculants to improve silage preservation. This accelerates the initial phase of the fermentation process via anaerobic degradation of WSC into lactic acid with a rapid decrease in pH and thereby preventing growth of spoilage microbes, molds and other contaminants and supporting preservation and storage without further deterioration in quality. Usually, selected homofermentative LAB have been used to improve the efficiency of the fermentation process to minimize DM and nutrient losses over conservation [82]. To prevent the aerobic deterioration of silage, heterofermentative LAB species, such as *L. brevis* and *L. buchneri*, have been developed as silage

additives [6, 83–85]. Dual-purpose inoculants containing both homo and heterofermentative LAB have recently been developed and the beneficial effects on aerobic stability have been reported [86]. Some isolates of *L. buchneri*, besides producing acetic acid can produce ferulate-esterase enzyme, which hydrolyses feruloyl ester linkages between lignin and hemicellulose, and thus advocated to potentially improve fiber digestibility of forages during ensiling [87]. The diversity of LAB species inhabiting silages stabilizes its fermentation quality and supports preservation. LAB inoculants (viz. *L. plantarum*, *L. rhamnosus*, *L. acidophilus*, *Pediococcus acidilactici*, *P. pentosaceus*, *Enterococcus faecium*, *Lactococcus lactis*, etc.) are safe and easy to apply, non-corrosive, do not pollute the environment and are regarded as natural products.

3.12. Therapeutic silage

Phytochemicals have antimicrobial properties against *E. coli*. The use of a high-quality PSM-containing forage may have the dual benefit of being a good-quality forage and reducing *E. coli* shedding [88]. Significant potential to use plants rich in bioactive compounds (saponin and tannin) for enhancing animal health and productivity that include reproductive efficiency, milk and meat quality improvement, foam production/bloat control, methane production [89] and Nematode control [90] has now been realized. The physicochemical structure and concentration of the phenolic compounds in the diet modulate the beneficial effects, and therefore, conceptualization of producing “therapeutic silage” involving forages rich in desired bioactive components would harness clinical and health benefits, besides modifying the yield and quality of meat and milk.

4. Protecting environment: green livestock production

Rapid breakdown of herbage proteins in the rumen and inefficient incorporation of herbage N by the rumen microbial population are major determinants of N (and C) loss and pollution in pasture-based livestock production system. Thus, when livestock are given fresh forages, they can waste 25–40% of the forage protein-N during ruminal fermentation. An increase from 23 to 34% in rumen N use efficiency through feeding higher WSC containing grasses could result in a 30% reduction in N_2O and NH_3 emissions [91]. Similarly, increasing the digestibility of cell walls in forages has been practiced to lower CH_4 losses, but in fresh grass and grass silage, the scope of this approach seems limited. CH_4 production in ruminants tends to increase with maturity of forage fed, and CH_4 yield from the ruminal fermentation of legume forages is generally lower than the yield from grass forages [92]. Shifting the animals from grass to legume plant species tends to decrease the enteric emission due to lower proportion structural carbohydrates and faster rate of passage which shifts the fermentation pattern towards higher propionate production. Further, enhancing N use efficiency in the rumen may also contribute to a reduction in the amount of C (both as CO_2 and CH_4) excreted. The concept of mixed or TMR silage may certainly address these concerns and enable eco-friendly livestock production. The impact of the form of C relative to N and the effect at different C:N ratios in terms of rumen function and conversion efficiency is an area of considerable promise that requires further detailed research.

4.1. Eco-friendly silage

The use of home-grown protein-rich feeds (e.g. forage legumes) with multiple positive effects associated with their role in N_2 -fixation and lower protein degradation emanated from tannin-protein interaction, thus contributing to nutrition and the environment. The PSM in forage silage can have positive effects on animal nutrition in terms of (i) improved N utilization; (ii) animal health (e.g. tannin-parasite interaction) and (iii) the environment through reduction of CH_4 and N emission. Enhanced in vitro DM digestibility and low methane production observed in vegetable residue silage inoculated with *L. plantarum* [92]. Inclusion of red clover in silages is found to be a promising strategy to bring in combined effect of improved animal performance with reduced environmental pressure [17] due to the presence of active POP in chaffed forages that act on exposed plant cell contents [63]. There is thus a need to go for selective plant breeding to develop tropical forages with decreased plant fiber and lignin content, increased WSC, increased content of S-amino acids, desired phytochemicals, etc.

4.2. Managing silage effluent

In some intensive agricultural areas, silage effluent may be one of the commonest forms of agricultural pollution contaminating water bodies. Sealing of silos with cement or lining with plastic sheets, and use of plastic bags/drums preserves the leachate that usually contains high amounts of nitrates. Harvesting forage for silage making at the correct moisture content and proper storage will reduce the volume of leachate from the silo. Silos and trenches should be located away from wells/water bodies to reduce the possibility of effluent polluting ground-water sources. A vegetated area between the trenches will be of greater usage to utilize the N-rich leachate or it can be applied to land as a source of crop nutrients.

5. Forage banking and meeting feed scarcity

Preservation of forage as hay and silage is intended at banking during surplus to meet the scarcity during unavailability or natural calamities. In other words, these technologies would evenly and adequately supply the bulk of feeding to livestock, thereby insulating any drop in production. Feeding hay or silage to livestock helps reduce the amount of concentrate feeding and thereby the cost of feeding. The concept of haylage, mixed silage and TMR silage has widened the scope of feed banking and nutritional optimization for higher productivity. Silage making is not only a process of feed preservation but it also preserve nutrients, phytogenic substances, succulence and completeness of a ration, thereby further the scope of feed and nutrient banking.

6. Conclusion

Seasonal feed scarcity is a concurrent problem that farmers usually face besides natural calamities like drought, flood, cyclone, earthquake, etc., which has a significant impact on sustaining animal agriculture and guaranteeing profitability. Ensiling of surplus forage biomass will

ensure round-the-year feed supply and safeguard production decline in times of feed scarcity and also could be able to make ready the animal for the next production year, thereby enhancing per animal productivity/whole farm output. Some of the inherent problems associated with ensiling are decline in the feeding value due to protein and amino acid breakdown and concomitant accumulation of ammonia. Assessment of the likely importance of microbial inocula and enzyme additives for stimulating various stages of ensiling process (e.g. separation of lingo-cellulose), likely impact of microbial origin formic acid vs. petrochemical sources and interactive function of microbial communities in ensilage are some of the areas of concurrent and ongoing research. Newer research areas include silage with herbal additives, phytochemical-rich plant biomass, therapeutic silage that promises veterinary health care (e.g. parasite control, control of bloat, acidosis), antioxidant-rich silage, high-moisture silage, etc. There is always animal and human health concern pertaining to consumption of deteriorated silages due to secondary aerobic spoilage by molds, bacilli, listeria and enterobacteria. Novel microbial approaches to solving the problem of aerobic deterioration during the feed-out period are needed. Silage inoculants can facilitate the ensiling process, but they can never be a substitute to the fundamental factors (plant maturity, DM content, oxygen exclusion) that are keys to making good quality silage. Utilization of agroindustrial by-products/co-products, including fruit and vegetable processing co-products, can be effectively used in mixed silage or TMR silage, which seems to be an underexploited source of dietary supplementation to farm animals with functional compounds and the production of value-added products. A challenge in the future is to complete studies on plant lipid fractions in conjunction with PSM and PPO in order to discriminate between effects of plant lipids on FA biohydrogenate intermediates. This may become the basis for achieving more sustainable, less expansive and healthier ruminant-derived human food.

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Author details

Artabandhu Sahoo

Address all correspondence to: sahooarta1@gmail.com

ICAR – Central Sheep and Wool Research Institute, Avikanagar, India

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