Manual on conservation and utilization of crop residues as livestock feed

Weseh Addah[1] and Augustine Ayantunde[2]

Groundnut haulms | Rice straw | Cassava peels | Whole cotton seed

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The Africa Research In Sustainable Intensification for the Next Generation (Africa RISING) program comprises three research-in-development projects supported by the United States Agency for International Development (USAID) as part of the U.S. Government's Feed the Future initiative.

Through action research and development partnerships, Africa RISING is creating opportunities for smallholder farm households to move out of hunger and poverty through sustainably intensified farming systems that improve food, nutrition, and income security, particularly for women and children, and conserve or enhance the natural resource base.

The three regional projects are led by the International Institute of Tropical Agriculture (in West Africa and East and Southern Africa) and the International Livestock Research Institute (in the Ethiopian Highlands). The International Food Policy Research Institute leads the program's monitoring, evaluation and impact assessment.

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Executive Summary

The greatest challenge associated with the utilization of crop residues as livestock feed is not their unavailability but the application of appropriate forage conservation technologies that are socially and economically adaptive to local conditions to reduce nutrient losses while improving nutritional quality. Natural pastures are abundant during the rainy season, and bountiful volumes of crop residues exist during the harvesting season. Farmers are, however, often unmotivated or lack adequate knowledge for appropriately conserving these feed resources to close up the gap between feed availability and the nutrient requirements of ruminants, especially in the dry season. Crop residues left on the farm after harvest often lose their nutrients through leaching and mold infestation or are destroyed by wild bushfires. The main methods of conserving crop residues in a smallholder crop-livestock production system include drying of forages with a lower concentration of moisture (>40-60%) and ensiling those with a higher concentration of moisture (<60%) and soluble sugars (2-3%). Forages with less than 40% moisture content, such as cereal straws, should be conserved by chemical treatment with urea. Drying reduces crop residues' moisture content, thereby inhibiting mold infestation, but it has to be done rapidly. Fresh crop residues such as cassava peels and groundnut haulms are preferably conserved by fermentation in a silo. Apart from microbial detoxification of hydrogen cyanide, microbial protein from the proliferation of sugar-utilizing bacteria during ensiling of cassava peels increases the protein content of cassava peels silage compared to the unensiled peels. Ensiling groundnut haulms during the rainy season ensures that leaf and nutrient losses are minimized. Ammonification of cereal straws increases their digestibility and crude protein content and reduces the growth of spoilage yeasts and molds and the viability of obnoxious weed seeds. This manual presents step-by-step conservation methods for using locally available feed resources to adapt to the economic and social environment. It outlines appropriate procedures for preserving crop residues by drying, ensiling and chemical treatment. This manual is aimed at technical staff in experimental stations and extension agents.

Introduction

The poor quality of natural pastures constrains the productivity of ruminants in most tropical regions. This has economic implications for smallholder ruminant farmers because ruminants gain weight during the rainy season when prices are ironically low but lose weight during the dry season when the market value for meat is relatively higher due to increased social activities religious festivals during this time.

In the tropics, matching the growth requirements of ruminants with feed resources is challenged by deficits in the availability of quality forages due to lower concentration of digestible nutrients and the destruction of natural grasslands by wildfires. The decline in quality of natural pasture during the dry season reaches a point where it is no longer capable of adequately supporting animal growth without supplementation (Annor and Adongo, 1992). The menace of perennial food insecurity in most of sub-Saharan Africa makes it unethical to put productive land to the production of cultivated pasture or grain as supplementary feed for ruminants. Hence, only farming systems that incorporate dual-purpose crops that supply food for humans and residues as feed for animal production can consistently be relied upon to produce good forage for ruminants. Per unit area, these systems have been proposed to produce more high-quality forage than natural grasslands (Suttie, 2000) and planted pastures (Blümmel et al., 2005). Common crop residues fed to ruminants in northern Ghana include groundnut and cowpea haulms, rice straw, cottonseed, and cassava peels.

Despite many research efforts to improve the utilization of crop residues in Africa, they are still under-utilized because of the difficulties associated with production, transportation, conservation, and storage technologies (Jayasuriya, 1993). One of the conventional crop residue utilization methods by ruminants is to graze them *in situ* on the farm field. However, this system is associated with trampling, mold infestation, pests damage, and destruction by wild bush fires. Most crop residues' bulkiness also makes transportation and storage difficult, often resulting in farmers preferring to burn the farm field's residue. Continual removal of crop residues from the farm field reduces the amount of mulch that would otherwise be left on the farm field to improve soil fertility. However, manure from livestock fed on crop residues is a better option for improving soil fertility in integrated crop-livestock systems because manure can then be transported and applied on farm fields at a time when bush fires are less rampant.

This manual is a technical handbook on the collection, conservation methods, storage, and utilization of groundnut haulms, cassava peels, whole cottonseed, rice straw, or corn stover as feed for ruminants. This manual will be helpful to technical staff in experimental stations and extension agents.

Crop residues conservation and technology

As climate change impacts worsen, reliable strategies to increase livestock farmers' resilience must include those supporting crop-livestock integration, improved quality feed resources availability and diseases, and pest control. Economic returns to ruminant livestock production are often low because farmers cannot meet the nutrient requirements of ruminants for growth, especially in the dry season. Every year large volumes of crop residues are produced from crop production. Still, the lack of adequate knowledge on appropriate collection methods, conservation, and storage often leads to loss of nutrients and this feedstuff's inability to meet ruminants' nutrient requirements.

Methods of conservation of crop residues are influenced by the concentration of moisture in the residue. The most common way of conserving crop residues is drying. Field-curing is preferable during the dry season. However, groundnut and cassava tubers are usually harvested in the rainy season when the soil is still wet to aid uprooting of the pods and tubers from the ground. Drying groundnut haulms and cassava peels during this period reduces their nutritional quality due to leaching losses. Moisture-laden crop residues (> 60%) such as cassava peels and groundnut haulms are preferably conserved by ensiling, whereas those with moisture levels of 40-60% (rice straw) and <40% (corn stover) should be conserved as haylage and hay respectively. The traditional practice of allowing crop residues to dry on the field before transporting them by cart and storing them on sheds or rooftops before feeding them to livestock is associated with a mold infestation, more significant leaf loss, and leaching of nutrients (Apori, 1997; Antwi et al., 2010).

Legume crop residues, especially groundnut and cowpea haulms, constitute 40-60% of crop residues fed to small ruminants in most parts of West Africa (Larbi et al., 1999; Ayantunde et al., 1999). Harvesting of these crops, however, often occurs in the rainy season. Leaf losses associated with drying, transportation, legume storage, and cereal crop residues also significantly reduce their nutritional value. The leaves contain more nutrients than the stems (Larbi et al., 1999; Antwi et al., 2010). Also, heaps of cassava peels left on the farm field after peeling the tuber often go moldy if they are not collected and adequately dried.

The knowledge and practice of feeding crop residues to livestock are not new. Still, innovative methods of conserving these residues to reduce nutrient losses are not being practiced as the farmers continue to practice field-drying and storage on sheds or tripods (Fig.1). This has been identified as the leading cause of nutrient losses that account for these feedstuffs not meeting sheep and goats' nutritional requirements despite offering these residues as supplementary feed.

Cultivation of pasture for feeding livestock is not a sustainable practice for pro-poor farmers in Africa since pasture production is not directly linked with food production. In Africa, the introduction of innovations to smallholder livestock farmers is one of the most challenging research and extension tasks, even if the innovations can be demonstrated to be beneficial. Most farmers are reluctant to change their traditional practices, especially when the innovations introduced call for extra time and labor (Jayasuriya, 1993; Sumberg, 2005; Senyolo et al., 2018). When properly conserved, some crop residues' nutritional quality is comparable to natural grasslands or planted pasture. Jayasuriya (1993) outlined five major factors for the low farmer-uptake of new technologies associated with crop residues as animal feed in developing countries. These included: (i) the absence of detailed production patterns of crop residues; (ii) difficulties associated with transport and storage of crop residues; (iii) inappropriate technologies; (iv) absence of agricultural extension services; (v) insufficient on-farm research to demonstrate supplementation of crop residues on animal performance.

Figure 1: Women sitting underneath a shed while plucking groundnut from harvested plants. Storage of groundnut haulms atop a shed, as shown in this photo, serves the dual purpose of providing a shade and protecting the haulms from destruction by domestic animals. Photo credit: Addah Weseh/UDS.

Drying versus ensiling

Drying on the farm field (sun-curing) is the most typical crop residue conservation practice in the tropics. Other methods of conserving or treating forages include: (i) the use of hydrolytic chemicals like sodium hydroxide, urea, ammonia, propionic acid, (ii) use of biological agents such as *Lactobacillus spp*, fibrinolytic fungi, and enzymes, and (iii) physical alteration methods such as chopping and milling of the forage. Often, these treatments, such as urea application, may involve ensiling as well. After urea treatment, cereal crop residues such as rice straws and corn stover are usually ensiled to decompose urea into ammonia with the aid of urease enzymes. Jack bean meal can also be added as a urease source (Berger et al., 1994).

Drying/field-curing

In Ghana, most arable crops grown primarily for their seeds or tubers are typically harvested during the mid-to-late rainy season, making it challenging to dry/sun-cure the residues. Sun-curing on the field in the rainy season may reduce crop residues' nutritional value due to nutrient leaching, leaf losses, and the growth of spoilage microorganisms. Attempting to field-cure crop residues in the rainy season can reduce their digestibility by as much as 14% under temperate conditions (Minson, 1990). Field-curing increases mold infestation when humidity is high, causing mildew leaves, whereas rapid drying may also result in shattering and loss of leaves. Indoor drying reduces leaf losses, but forage dried indoor moisture content should be less than 60% to reduce mold formation and deterioration. Smallholder farmers' current practice is to field-cure crop residues (e.g., legume residues) to about 40% dry matter (DM) and then transport the residue to the homestead for storage on top of sheds or tripods where further drying of the haulms occur during storage. These sheds then serve as shelter from the scorching sun during harvest (Fig. 1). Storage of cowpea haulms outdoors reduces their nutritional quality, whereas storage under cover conserved the haulms' nutritional quality (Apori, 1997; Antwi et al., 2010). In general, field-curing has little or no effect on crude protein concentration in the dry and rainy seasons if there is no significant leaf loss (Minson, 1990).

Ensiling

Most crops are harvested during the rainy season when drying is difficult. Under this condition, ensiling the residue is the best alternative to drying. Ensiling crop residues is not common in sub-Saharan Africa, possibly because smallholder farmers find tropical forages more challenging to ensile due to their low concentration of soluble sugars (Yang, 2005).

The greatest challenge to ensiling crop residues is the concentration of water-soluble carbohydrates available for fermentation into organic acids such as lactic acid and volatile fatty acids such as acetic, propionic, and butyric acids. These acids are essential for preserving the silage as they inhibit the growth and proliferation of undesirable yeasts, molds, and *bacilli sp.*

Management factors that affect the production of good quality ensiled crop residues

Chop length is an important management factor that affects the quality of silage produced. Longer chop length impedes compaction in the silo resulting in pockets of air in the silo that encourage aerobic metabolism/deterioration of the silage. However, manual chopping crop residues to a shorter length is tedious and time-consuming (Fig. 2). The optimum chop length for ensiling groundnut haulm is about 3-5 cm (Fig. 2).

Figure 2: Women pluck off groundnut pods from harvested plants while men chop the haulms for ensilage. Photo credit: Addah Weseh/UDS.

Quick filling of the silo is also essential to reduce the plant's continual respiration and to reduce the growth of aerobic organisms. Silos should be sealed within 24 hours.

To ensure maximum anaerobic conditions in the silo, the bag silo is lined with a plastic sheet (see STEPS 5-6) before being filled with the chopped haulms. The silo should never be opened until the silage has "matured" and is ready for use. The ensiled material is ready for use only after the lowest possible pH has been attained (silage is matured). Mini silos can be constructed with plastic pipes (4 inches) and filled simultaneously with the big bag silos to monitor the trajectory of fermentation in the big bag silos. The mini silos are opened to monitor the trajectory fermentation in the big bag silos. Changes in the mini silos are considered to reflect changes occurring in the bag silos. The extent of pH decline in a fermentation dominated by Lactic Acid Bacteria reflects the degree of fermentation in a silo. In most forages, fermentation is completed after 60 days of ensiling. Perforation of the silo bag will allow infiltration of air that will cause proliferation of spoilage organisms. Rodents easily perforate the silo, and it is advisable to monitor the silos for such perforations and quickly seal them with adhesive tape.

Rice straw and corn stover

Collection and treatment/conservation of rice straw and corn stover

Rice straw is a crop residue obtained after the threshing of rice. It is often collected from farm fields after hand threshing or combine harvesting. Care should be taken to avoid collecting straw that is mixed up with soil.

As a significant cereal staple crop, rice production has been increasing steadily in Asia and Africa, with a concomitant increase in straw production. Rice straw has a lower nutritional value for animals. This limits its acceptability and intake. Various methods of treatment and conservation can enhance the digestibility and nutritional value of rice straws. These include (i)physical, e.g., chopping, grinding, and pelleting, (ii) use of steam, (iii) use of hydrolytic chemicals like sodium hydroxide, ammonia, and urea, and (iv) biological (microbial and enzymatic) treatments. In some cases, a combination of two or more of these treatments is used to conserve cereal straws.

Ammonia and urea treatment of straws for ensiling increased crude protein concentrations, decreased proteolysis and reduced the population of spoilage organisms such as molds and yeasts (Berger et al., 1994). Hydrolytic chemicals such as urea and ammonia disrupt fiber's physical integrity by increasing the solubility of hemicelluloses and hydrolyzing ferulic acid esters.

Improvements in digestibility of crop residues treated with ammonia are not as dramatic as sodium hydroxide. Still, ammonification is an effective means of increasing the intake of corn stover and other cereal crop residues (Berger et al., 1994). Greater DM intake associated with the extra-ruminal treatment of crop residues with hydrolytic agents such as urea and ammonia is attributed to the increased hydration rate of residues treated with these agents. This reduces the lag time in the rumen, increases the rate of bacterial attachment and colonization of fiber in the rumen, and ultimately increases passage rate and DM intake (Allen and Martens, 1988; Berger et al., 1994). Ammonification of crop residues has been shown to increase dry matter intake. Ammonification of crop residues mediates fiber digestion improvements by hydrolyzing bonds linking lignin to cellulose and hemicellulose. This kind of hydrolysis is found to increase the digestibility of straws by 20-22% and crude protein concentration by 1-2 times with other benefits such as reducing mold and other parasitic infestation (Zhishan and Qiaojuan, 2002). Berger et al. (1994) reported a 22% increase in dry matter intake due to ammonification in twenty-one experiments, whereas, in thirty-two experiments, ammonification increased digestibility by only 16%.

The bag and pit silos for ensiling urea-treated stover or straws

Rice straw and corn stover can be treated with 5-8% urea without adverse effects on intake and growth performance. The technical challenge of urea treatment of straw by farmers with no formal education is the arithmetic calculations of the correct straw: water: urea ratio. A pre-weighed quantity of urea of 0.5 or 0.7 kg can be transferred to standard containers whose volume is equivalent to 0.5 or 0.7 kilograms (Fig. 6). Subsequently, these calibrated containers are used to measure urea without weighing with a scale and then used for treating 100 kg of corn stover or rice straw (STEPS 2-3). The required water needed to treat 100 kg corn stover or rice straw is similarly determined using a graduated plastic bucket with the 100 L point marked by an indelible marker. A sack calibrated for weighing

100 kg of straw or stover can subsequently be used for quantifying the required amount of straw needed without weighing. The procedure for preparing a 100-kg 5% urea-treated straw is outlined in STEPS 1-8. Our field studies indicate that farmers with minimum or no formal training or education could follow these instructions for treating 100-kg rice straw with ease (STEPS 1-8).

Stover or straws with a 40-60% moisture content are most preferable. For 5% or 7% urea treatment, the rice straw or corn stover obtained from the farm field is chopped to a theoretical length of 5-10 cm and divided into two equal portions of 100 kg. Each 100-kg treated straw is put on a plastic sheet spread on the concrete floor. Urea solutions (5% or 7%) are prepared by dissolving 0.5 kg or 0.7 kg of urea in 100 L each of water measured with a graduated plastic bucket or drum (STEPS 4-5). The stover or straw is then sprayed with 5% and 7% urea solution before being ensiled. The straw is turned over and evenly spread before it is collected into a plastic-lined bag or sack set in place on stones or wood in a cool, dry place. The bag is then compressed and fastened. Loads of rocks and other heavy objects are placed on the bag to expel pockets of air. The bag is then stored for 14-40 days before use. For ensiling in pit silos, the ends of the sheet are rolled over to cover the pile, compressed, and then transferred to a dug-out pit where heavy stones are placed on it before being covered with soil. Care should be taken to avoid soiling the treated straw.

Upon opening, a well ensiled urea-treated forage should have a yellowish color with friable and soft forage particles compared to the pale color of the untreated material. The treated stover or straw should be air-dried for a day before being fed to animals.

Preparation of 100-kg 5% urea-treated straw

1. Weigh 100 kg of rice (see STEP 1).
2. Where possible, chop the straw into 5-8 cm.
3. Weigh 0.5 kg of urea and transfer the weighed quantity into a bucket of water (see STEPS 2-3).
4. Measure 100 L of clean water into the bucket using a graduated bucket or drum and stir to dissolve the urea entirely into a solution (see STEPS 4).
5. Spread out straw on a plastic sheet on a flat cemented floor and spray with urea solution. The straw should be turned while spraying to ensure the application's uniformity (see STEP 5-6). The use of rubber gloves is encouraged. Urea is corrosive.
6. Collect the treated straw, compress it into the rubber-lined silo bags, and store for a minimum of 7-14 days (see STEPS 7-8). Bag silos are constructed by lining the inner surface of sacks with a polyethylene or plastic sheet.

<u>STEP 1:</u> Weigh 100 kg straw before treatment.

Weighing of rice straw for urea treatment at Gia in the Upper East region of Ghana. Photo credit: Addah Weseh/UDS.

<u>STEP 2:</u> Measuring 0.5 kg of urea.

A farmer weighs urea (left) and calibrating the quantity using tin containers (right). The use of tin containers is mainly helpful in situations where farmers do not have weighing scales or are illiterate. Photo credit: Robert Niayeli /UDS.

STEP 3: mixing urea in water.

Pouring and mixing 0.5 kg urea in 100 L of water with a graduated bucket (for 100 kg of a straw) and dissolving it in the water bucket. Mix thoroughly by stirring. Photo credit: Addah Weseh/UDS.

STEP 4: Transfer urea solution into knapsack sprayer

A farmer transferring urea solution into a knapsack sprayer for treatment of rice straw at Zanko in the Upper West Region of Ghana. Photo credit: Addah Weseh/UDS.

STEP 5: Spraying rice straw with 5% urea solution while being turned over.

A farmer sprays urea solution to rice straw while his colleague turns the fodder to ensure an even spray in Upper West Region of Ghana. Photo credit: Addah Weseh/UDS.

STEP 6: Filling the bag silo with treated rice straw

Farmers filling a silo bag with treated straw at Zanko in Upper West Region of Ghana. Photo credit: Addah Weseh/UDS.

STEP 8: Compress treated straw into a silo and store for a minimum of 14 days.

Manual compression of straw into bag silos lined with plastic lining at Zanko Community in the Upper West Region. Photo credit: Addah Weseh/UDS.

Utilization of rice straw or corn stover

The treatment of straws with urea increases the crude protein content of the treated rice straw due to the residual nitrogen from the ammonification processes during ensiling of the treated straw (Amaning-Kwarteng et al., 2010). Sheep fed on 5% urea-treated straw had a higher intake than those fed on 7% urea-treated or untreated straw (Kabiru et al., 2015; Table 1). However, the lower intake by sheep fed on 7% urea-treated straw was not evident in their growth performance.

Urea is converted to microbial protein and ammonia in the rumen-by-rumen microbes. The microbial protein flows past the rumen for digestion and absorption, mainly in the small intestine. The ammonia is absorbed in the rumen, reticulum, and omasum. It is carried in the portal vein to the liver, where it is detoxified to urea and recycled into the mouth through saliva.

Oral urea poisoning is harmful due to excessive ammonia production in the rumen. Normal ammoniacal nitrogen levels are 60-680 mg/L in rumen fluid and 0.8-2.5 mg/L in blood. When ammonia levels in rumen fluid exceed 500-800 mg/L, ammonia levels increase in the peripheral blood (Rogers, 1999). Cattle can tolerate up to 5%, whereas sheep on a good diet can tolerate urea up to 6% of urea in feed dry matter, provided it is well mixed with forage and is fed over the whole day (Rogers, 1999).

Intake of urea-treated forage is lower for younger animals because urea utilization is less efficient in younger animals and may cause poisoning when its concentration is greater than 8%. Severe signs of urea poisoning include cyanosis, severe respiratory distress, decumbency, and death. However, sub-clinical poisoning may show no apparent signs of adverse effects on production except brownish mucosae (Kabiru et al., 2015).

Table 1: Effect of varying levels of urea inclusion on feed intake and growth performance of sheep[1]

Item	Urea treatment		
	0%	5%	7%
Feed intake (g/day)	64.5	47.8	40.2
Average daily weight gain (g/day)	25.8	43.7	28.8

[1] *Kabiru et al. (2015)*

Groundnut haulm

Groundnut haulms, obtained after harvesting and extracting the main food product or seed, have become the mainstay of the smallholder small ruminant industry in sub-Saharan Africa. Haulms from annual groundnut (*Arachis hypogaea L.*) harvest is the commonest leguminous crop residue for feeding ruminants in sub-Saharan Africa (Apori, 1997; Larbi et al., 1999), in more arid parts of Asia (Suttie 2000) and some parts of the USA (Johnson, 1979; Foster et al. 2011). The haulms, which include the leaves, stems, and roots, are obtained after harvesting the groundnuts and field-drying. The crude protein content (134 g kg-1 DM) and yield (4547 kg DM ha-1) of groundnut haulms are high (Larbi et al., 1999), with their content being comparable to temperate legumes such as full-bloom alfalfa hay (Yang, 2005). The crude protein content of groundnut haulm during the late dry season is 2.2% compared to 15% for full bloom alfalfa (Table 3).

Table 2: A comparative composition of groundnut haulms, rice straw, and natural pasture during the dry season

Item (% DM)	Groundnut haulm[1]		Rice straw[2]		Heterogeneous natural pasture[3]		Full bloom Alfalfa hay[3]
	Early	Late	Early	Late	Early	Late	
CP	9.8	12.2	5.5	-	6.3	6.1	15
NDF	4.3	5.2	72.0	-	6.8	6.8	50
ADF	4.3	4.9	39.8	-	4.7	5.0	37
ADL	9.6	8.7	4.6	–	1.0	8.6	10
IVOMD	52.8	64.7	-	-	40	38.8	–

[1]Konlan (2017; 2018); [2]Sarnklong et al. (2010); [3]Almonari et al. (2014)

[1]Heterogeneous natural pasture was composed of Pennesitum pedicellatum, Sida acuta, Digitaria ciliaris, Andropogon gayanus.

CP: Crude Protein; NDF: Neutral Detergent Fiber; ADF: Acid Detergent Fiber; ADL: Acid Detergent Lignin; IVOMD: In Vitro Organic Matter Digestibility.

The traditional groundnut haulm storage practice is to sun-cure them on the farm field before they are transported and stored on sheds to provide shade in the dry season (Fig. 1). Because harvesting occurs in the rainy season, field-drying before transportation and storage often results in the leaching of nutrients due to rainfall. Leaf losses associated with drying, transportation, and storage of dry legume crop residues also dramatically reduces their nutritional value, given that the leaves contain more nutrients than the stems.

In the traditional conservation method of crop residues, moisture is not a desirable quality trait in the storage of crop residues. However, crop residues with residual moisture (<60%) can be collected immediately after harvest when they have not yet become moldy on the field, chopped, and ensiled for feeding in the dry season. This reduces losses of nutrients and improves digestibility and animal performance.

Sun-curing on the farm field is the primary method of conserving crop residues in Ghana. Still, groundnut grown primarily for the seed is typically harvested during the mid-to-late rainy season, making it a challenge to sun-cure the haulms. Given that groundnut haulm has a high leaf: stem ratio (34:1) and that the leaves contain more crude protein that is more digestible than the stems (Larbi et al., 1999), sun-curing on the field may reduce the nutritional value of haulms due to nutrient leaching, leaf losses (Fig. 4) and the growth of spoilage microorganisms. Field-curing forage in the rainy season (> 100 mm) can reduce organic matter digestibility by as much as 14% (Minson, 1990) in the temperate region.

Ensiling groundnut haulm may help lessen the nutritional losses associated with attempting to field-cure groundnut haulm during the rainy season. Previously, ensiling was found to improve the DM digestibility of groundnut haulm by 4–8% compared to sun-drying but with no effects on heifers' growth performance (An, 1998).

Yeasts and molds can reduce the nutritional quality of both dried and ensiled haulms during storage. Storage of cowpea haulms outdoors reduced their nutritional rate (Antwi et al., 2010), whereas storage under cover conserved the haulm's nutritional quality (Apori, 1997). Hay stored outside suffers at least a 10–15% loss in DM than hay stored undercover for the same period (Rotz and Muck, 1994).

Figure 3: Leaf losses associated with mildew caused by molds during field-curing groundnut haulms on the farm field at Nyangua in the Upper East region. Photo credit: Addah Weseh/UDS.

Characteristics of a good groundnut haulm for ensilage

Moisture is an essential factor in fermentation. Bacteria needs moisture to ferment sugar. Too much moisture impedes the fermentation process.

Higher dry matter impedes exclusion of trapped air and achievement of higher packing density during silo-filling. This leads to a lower lactic acid bacteria population because lower water activity reduces bacterial growth (Whiter and Kung, 2001). To ensure that the ensiled material has a higher density, the haulms are chopped to ~3-5 cm (Fig. 1) before filling and compaction in the silo.

Figure 4: Preparation of 1% glucose solution for treating groundnut haulms before ensiling at Tibali in the Northern Region. Photo credit: Addah Weseh/UDS.

Figure 5: Preparation of 1% glucose solution for treating groundnut haulms before ensiling at Tibali in the Northern Region. Photo credit: Addah Weseh/UDS.

Figure 6: Mixing groundnut haulms and 1% glucose solution thoroughly before ensiling at Tibali in the Northern Region. Photo credit: Addah Weseh/UDS.

The next most important factor to consider is a substrate for the lactic acid bacteria to ferment. The most readily available source of substrate for microbial growth is glucose or water-soluble carbohydrates. The higher protein in groundnut haulms (Table 2) buffers the rapid decline in silage pH. Very dry/matured haulms can be treated with glucose (1%) (Fig. 3) to provide enough moisture and substrate for optimum fermentation. The efficiency of silage fermentation depends on the concentration of humidity and fermentable substrates. Salt should never be added because it inhibits bacterial growth and will reduce the lactic acid bacteria population during ensiling.

Preparing groundnut haulm silage

1. At harvest, most groundnut vines contain 60% moisture. This should be wilted to about 40%
2. The wilted haulm is then chopped to 3-5 cm and stored in rubber-lined bag silos.
3. The appropriate moisture content can be determined by squeezing the chopped haulms in the palm. The presence of moisture on the palm after squeezing indicates the haulm has too much moisture. The haulm particles' quick return to their original length after squeezing indicates the haulm is too dry. Its gradual return to its original size indicates optimum moisture.
4. The bag's content is compressed to expel pockets of air, and loads are placed on the bag to remove the air further.
5. The ensiled material is then stored in a cool, dry place, preferably under a shed. The bag should be placed on a wood pallet or stony platform before filling. Once filled, it becomes difficult to leave unto a stone/wooden base.
6. The bag silo should occasionally be inspected for perforations caused by rodents.
7. After about 60-120 days, the silo is opened, and the silage is used for feeding.
8. Several small bag silos are required to reduce aerobic spoilage compared to one large bag to reduce the length of time the silo will be exposed to air. When one small bag is fed out, another is opened.
9. Where large silos are used and opened, the silage can then be dried and stored before feeding. This practice similarly reduces aerobic spoilage during feed-out.

Lower concentrations of water-soluble carbohydrates for fermentation into lactic acid (Yang 2005; Thom et al. 2012; Addah et al., 2018) appear to be the main limitation to high-quality conservation groundnut haulm into silage. Higher crude protein concentration of groundnut may further buffer the decline in pH during ensiling. It has been hypothesized when lactic acid concentration is satisfactory, higher silage pH should be considered a consequence of higher buffering capacity and moisture concentration that will require even more lactic acid to further depress pH (Yang 2005).

Preparing groundnut haulm hay (the innovative method)

1. Fresh groundnut haulms after harvest are chopped to 3-5 cm and sun-dried on concrete floors
2. The chopped haulm is dried (where possible, rapidly on a concrete floor) to a dry matter of 72-80%. Care must be taken to collect all shattered leaves.
3. The dried haulm is then packed into bags and stored in a dry, cool place or barn for later use (Fig. 3).

Figure 7: A haulm trader in northern Ghana collecting groundnut haulm into a sack after drying. Rapid drying of haulms on concrete floors reduces mold infestation but is associated with brittleness and increased leaf shattering. Photo credit: Addah Weseh/UDS.

Preparing groundnut haulm hay (the enhanced farmer-practice method)

1. At harvest, most groundnut vines contain 40% DM. After plucking the nuts, the haulms are allowed to cure on the field. To reduce spoilage, the haulms should be spread out on the field to minimize heap spoilage caused by molds and yeasts.
2. The haulms are then field cured for 1-2 weeks (40% DM), depending on the moisture content.
3. The haulms are then collected from the farm field, chopped to 3-5 cm, and stored in bags or on top of sheds. Leaf loss and leaching due to early or late rainfall may cause a significant loss of leaves and nutrients if storage is done on rooftops or sheds.
4. The haulms are offered as supplementary feed.

Cassava peels

Conservation and utilization

Leaching losses are more significant in cassava peels when the peels are allowed to dry on the farm. Absorbent materials such as whole cottonseed and *Cajanus cajan* residues are added at ensiling when moisture levels are greater than 60%. This has the additional advantage of increasing the crude protein content of cassava peels.

Cassava peels are by-products of cassava tuber processing. The peel accounts for 11% (Tewe et al., 1992) to 20.1% (Ifut, 1992) of the whole tuber. The peels are readily and cheaply obtained from almost all the agro-ecological zones of West Africa, where ruminants are also reared. Cassava peels are, therefore, a major supplementary feedstuff for feeding cattle, sheep, and goats in Ghana. However, they are often either underutilized or underexploited. Production estimates of cassava in 2010 indicated that Ghana is ranked sixth in the world and fourth in Africa in cassava production (FAO, 2013).

Their lower crude protein content limits cassava peels' utilization by ruminants, hydrogen cyanide (HCN) concentration, and poorer methods of conservation and storage that further reduces their nutritional quality. Hydrogen cyanide imposes bitterness on the peel and thereby reduces its palatability and intake. Hydrogen cyanide is toxic and can depress growth performance (Okafor, 2004) and interfere with functions of metal-containing enzyme systems responsible for cell respiration and function (Enneking and Wink, 2000), and cause death (Tewe and Iyayi, 1989).

Even though ruminal microbes can detoxify hydrogen cyanide, the peel's bitterness can be a significant constraint to intake. Primary methods of reducing the hydrogen cyanide concentration and improving cassava peels' intake by ruminants include soaking, boiling, sun-drying, ensiling, and sulphur. However, in Ghana, the commonest method of preserving cassava peels as feed for ruminants is sun-drying. Reduction in hydrogen cyanide concentration of cassava peels through ensiling is 10% higher than reduction through drying. The decrease in hydrogen cyanide by ensiling compared to drying has not been consistent in all studies. Ensiling also increases the protein content of the peels, increases their digestibility, and improves the growth rate of sheep. Other methods of reducing the effects of HCN on livestock include dietary supplementation with sulphur. However, cassava peels cannot be fed alone because their lower crude protein content (4.5-6.0% dry matter) cannot support rumen microbial growth, thereby warranting supplementation with other protein-rich feedstuffs as whole cottonseed or cake. Even though cassava peels are commonly fed to ruminants in the dry form in Ghana, the peel is more effective at enhancing its nutritional value than other preservation methods (Oduguwa et al., 2013; Niayeli et al., 2020).

Sun-drying

Sun-drying can detoxify cassava peels to tolerable levels (Ahamefule et al., 2003). Tweyongyere and Katongole (2002) examined three hydrogen cyanide detoxification methods of cassava peels; sun-drying, fermentation, and soaking. It was concluded that sun-drying was the most effective and resulted in a rapid reduction of hydrogen cyanide by more than 82% in 48 hours. Hydrogen cyanide was reduced to safer levels of <50 mg/kg in 72 h. Sun-drying resulted in a more significant loss of total cyanide than laboratory oven-drying at 60°C for 48h (Tewe and Kasali, 1986). More than 86% of HCN in the peel is lost by sun-drying. Sun-drying on sloped trays effectively removes much of the soluble cyanide compounds due to the slower breakdown and less denaturation of the linamerase enzyme that destroys the cyanogenic glycosides (Gomez et al., 1984). Sun-drying cassava leaves reduced HCN content to 22.5 mg/kg compared to 147 mg/kg for the ensiled material (Phuc et al., 1996). Indeed Phuc et al. (1996) concluded that drying might be more effective at removing HCN than ensiling. Other studies, however, showed that ensiling reduced free HCN of the peel by 36% (Gomez and Valdivieso, 1988) to 98% (Tewe, 1992) compared to 82% (Tweyongyere and Katongole (2002) to 85% (Gomez et al., 1984) by sun-drying.

Sun-drying is cost-effective since it requires less capital expenditure and labor as compared to the other methods. However, sun drying is slow depending on the time of the year. It often encourages mold growth and other spoilage microorganisms such as Aspergillus flavus, which can be pathogenic (Clerk and Caurie, 1968). Microbial growth exposes the consuming animal to aflatoxicosis and mycotoxin infection (Lukuyu et al., 2014). Drying can also result in the loss of volatile nutrients such as vitamins. To speed up the drying process, the material is first chopped to 3-5cm, which allows for quicker evaporation of moisture and subsequent release of volatile toxic substances such as hydrogen cyanide. Not only is sun-drying cost-effective compared to ensiling, the slower rate of drying, especially in the rainy season, results in a more significant loss of bound hydrogen cyanide, increases the contact period between the glucosidase and the glucoside in the aqueous medium, which causes hydrolysis of cyanogenic glucosides by linamarase (Tewe, 1992; Famurewa et al., 2014; Lukuyu et al., 2014). Data from the University for Development Studies indicated that sun-drying effectively reduced hydrogen cyanide than ensiling (Niayeli et al., 2020; Table 3).

Table 3: Comparison of sun-drying and ensiling methods[1]

Item	Dried	Ensiled	SEM
pH	6.2	4.2	0.029
Ammonia Nitrogen (mg/kg DM)	0.48	1.12	0.365
Hydrogen cyanide (mg/kg DM)	18.02	25.01	0.145

[1] *Niayeli et al. (2020)*

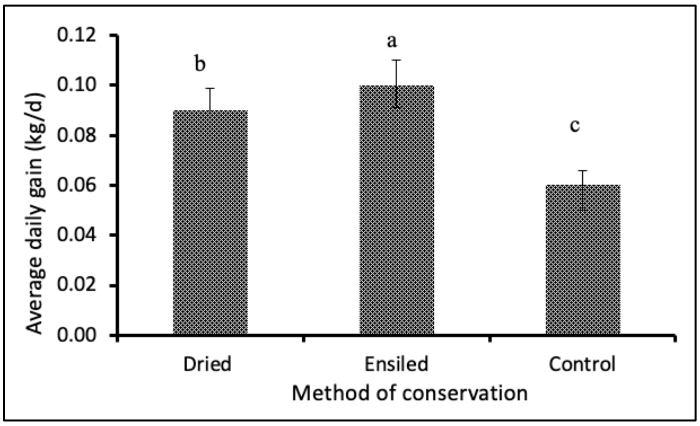

Figure 8: Effects of different conservation methods on the average daily gain of sheep (Niayeli et al., 2020).

Ensiling/fermentation

The ensiling process causes disintegration of intact glucoside through cell disruption, a drop in pH of the ensiled medium, and intense heat generation and reduces mold infestation (Lukuyu et al., 2014). Gomez and Valdivieso (1988) also reported that ensiling cassava chips reduced the cyanide content to 36% of the initial value after an ensiling period of 26 weeks. Fermented cassava peels could be considered safe if hydrogen cyanide concentration is below the deleterious 30 mg/kg (Tweyongyere and Katongole, 2002). The microorganisms produced during fermentation can produce linamarase that hydrolyze the glycosides, reducing the cyanide content (Okafor, 1998).

Ensiling/fermentation also helps to improve the crude protein content of cassava peel silage. During the fermentation period, the increased growth and proliferation of fungi or bacterial complexes can increase the protein content (Oboh, 2002). Indeed, the average daily gain was improved for sheep fed on an ensiled cassava peels diet than dried cassava peels diet (Fig. 8) even though hydrogen cyanide was lower in the dried cassava peels than ensiled cassava peels that were used to formulate these diets. Fermentation of cassava peels with the pulp juice has shown to increase crude protein in peels from <2% to 13-26% of dry matter while lowering crude fiber values by one-half (Adamafio et al., 2010; Obadina et al., 2006), thus, further enhancing potential feeding value of the product. Ensiling has cost implications compared to drying of the peels as more labor is required to chop, packing, and compact the silage and the additional cost incurred in acquiring or constructing a silo.

Table 4: Sensory characteristics of cassava peel silage after 45 d of ensiling in large bag silos in the Northern region[1].

Item	Description	Score[1]
Colour (1-15)	Light brown	9.22±2.24
Smell (1-15)	Very pleasant	10.50±2.46
Texture (1-10)	Firm	8.00±2.10
Grade	Good	27.72±0.72
pH	Lower	4.12+0.03

[1] *Niayeli et al. (2020)*

[1] *Values are means of three large silos (n = 3)*

The silages were graded by summing the scores for color (1-15), texture (1-10), and smell (1-15) as excellent grade (40-31), good grade (30-21), general grade (20-11) and low-grade (≥10). (Jian et al., 2015; Jianxin, 2002).

Soaking

Soaking provides a suitably more effective medium for fermentation which converts or hydrolyses cyanogenic glycosides to cyanide and allows extraction of the soluble cyanide into the soaking water. Soaking removes about 20% of free cyanide in fresh cassava chips after 4 h (Tewe, 1992). Cooke and Maduagwu (1978) reported that bound cyanide begins to decrease only after the onset of fermentation during soaking. A very significant reduction in total cyanide is achieved if the soaking water is routinely changed over 3 to 5 days (Tewe, 1983). The process is reported to be the best for cyanogen removal (Cardoso et al., 2005). Soaking has the combined effect of allowing cyanogenic glycosides to contact linamarase (Westby and Choo, 1994) that initiates the hydrolysis of cyanogenic glycosides to form hydrogen cyanide, which is toxic. Water-soaking fresh peels for 1 to 5 h followed by sun-drying also significantly reduced cyanogenic glycosides in amounts proportional to the soaking duration (Shoremi et al., 1999).

Boiling

Boiling is very drudgery and labor-intensive. This method is only recommended when cassava peels are to be fed to pigs. Boiling was able to remove about 90% of free cyanide within 15 min. compared with 55% of bound cyanide after 25 min. of boiling (Cooke and Madunagwu, 1978). A 25-75% reduction of cyanide was achieved by cooking/boiling, which depended on cooking time and chip size, with the highest HCN losses recorded in chips with smaller sizes (Nambisan and Sundaresan, 1985). Aalberberg and Limalevu (1991) also reported a reduction of 50-60% cyanide by cooking/boiling. However, boiling has been said to destroy the linamarase enzyme (Tewe, 1992). Prolonged boiling has also been reported to denature or destroy the linamerase enzyme at a temperature of 72°C, leaving the glycosides and HCN intact. Boiling also has a disadvantage of nutrients lost during the nutrients' leaching into the cooking medium (FAO, 1990). Boiling resulted in a 20-30% loss of vitamin C from unpeeled roots and tubers (FAO, 1990). Boiling is not cost-effective in large-scale applications due to the time and the resources involved.

Sulphur in hydrogen cyanide (HCN) detoxification

Although the precise level of HCN that causes toxicity is not known, levels below 50mg/kg have been reported to be harmless, and acute hydrogen cyanide toxicity is not common (Smith, 1992). Sulphur-containing amino acids accomplish detoxification of hydrogen cyanide to non-poisonous thiocyanate (e.g., cysteine) that are synthesized in the rumen (Iyayi and Tewe 1992) and/or ionic and elemental sulphur by the liver (Smith, 1992). The latter found that 1.2 mg of sulphur is required to detoxify 1.0 g HCN and recommended sulphur licks as adequate protection against chronic cyanide toxicity. Cassava contains cyanogenic glucosides, made up of 95% linamarin and 5% lotaustralin (Conn, 1994). Cyanogenesis is initiated when cassava tissue is physically cyanogens, and cyanogenic enzymes (linamarase) are located in different cell compartments (Conn, 1994). Linamarin, the major cyanogenic glucoside, is present in all tissues of the cassava plant and is synthesized from the amino acid valine (Balagopalan et al., 1988). Detoxification of cyanide can be achieved by converting it to a relatively non-toxic product readily eliminated from the body. Exogenous supplementation of rhodanese, a sulphurtransferase, in sulphur donors has been reported to accelerate cyanide transsulphuration to thiocyanate (Cannon et al., 1994). This detoxification requires sulphur donors, provided from sulphur-containing dietary amino acids, cysteine and methionine, and elemental sulphur (Rosling, 1994). The requirement for a sulphur-containing amino acid is for use in the rhodanese detoxification pathway. Therefore, the detoxification of hydrogen cyanide is influenced by the nutritional status, such as B vitamins (B12, folic acid) and essential sulphur-containing amino acids provided by dietary good quality protein (Bradbury and Holloway, 1998). Agency for Toxic Substances and Disease Registry (1997) reported that the major reactions involved in detoxification of ingested cyanide includes reaction with cysteine to form iminothiozilidine compound that is excreted through saliva and urine, conversion of cyanide to formic acid, and excretion through urine and cyanide combining with hydroxyl cobalamine and excreted in urine and bile.

The use of sulphur-containing amino acids to detoxify cyanide to less toxic thiocyanate causes an increased demand in the diet (Maner and Gomez, 1973). Therefore, protein deficiency may result in a low intake of methionine and cysteine used for the detoxification of the HCN in diets containing cassava (Osuntokun, 1981). Therefore, excessive consumption of the main cassava source of dietary energy and protein can expose animals to cyanide toxicity. Supplying sulphur licks to ruminants effectively protected them against chronic cyanide toxicity (Wheeler et al., 1975) as sulphur was reported to stimulate the rate of HCN detoxification by rumen microbes (Promkot et al., 2007). Injection of thiosulfate (which makes sulphur available to the body) was found to detoxify HCN by converting the poisonous cyanide into less toxic thiocyanate (FAO, 1990). A low protein diet deficient in sulphur-containing amino acids may decrease the HCN detoxification capacity and make a person or animal consuming it susceptible to cyanide's toxic effect (Oke, 1978).

Therefore, HCN toxicity should not constitute a major limitation to using cassava products and by-products to feed livestock. This is because the simple provision of sulphur in the form of sulphur-containing amino acids (methionine and cysteine) and elemental sulphur in diet will protect the animals from HCN toxicity (Table 5).

Table 5: Effects of dietary sulphur level on growth performance and some metabolic indices of sheep and goats fed cassava/urea based diets[1]

Parameters	Dietary sulphur (%)			
	0	0.25	0.50	0.75
HCN (mg/kg)	247.0	246.0	248.0	247.0
Body Weight Change (%)	-75.0	-25.0	83.34	68.34
Ruminal NH_3N (mg/100 ml)	2.45	2.40	0.75	1.05
Ruminal thiocyanate (mg/100 ml)	4.01	3.10	3.60	2.80
Serum Thiocyanate (mg/100 ml)	0.035	0.073	0.060	0.073

[1] *Tewe (1992)*

Effect of different methods of conservation on intake, digestibility and growth of ruminants

Dried cassava peel and rice-straw fortified with urea as a dry season supplementary feed was fed to grazing sheep. It was observed that whereas sheep supplemented with rice straw and cassava peel gained weight, sheep used as control lost about 15% of their body weight during the dry season (Otchere et al., 1977). Akinsoyinu (1992) combined dried cassava peels with poultry litter as a nitrogen source and used to replace maize in diets of goats at 0, 50, or 100%. No effect on dry matter intake was noted across the treatments. However, digestibility reduced with increasing levels of replacements. Substitution of maize cobs with cassava peels (20%) in sheep-fed pangola grass (*Digitaria eriantha*) has improved digestibility, body weight gain, and rumen function (Smith, 1988). Adebowale (1981) also fed fermented cassava peels to sheep at 0, 20, 40, and 60% levels of inclusion to replace equivalent amounts of maize in the control diet and recorded growth rates of 60, 38, 31, and 67 g/d and feed/gain ratios of 7.8, 10.9, 11.8 and 7.4 kg feed/kg gain respectively. Poor performance of ruminants fed cassava products has sometimes been attributed to chronic toxicity, although other reasons such as deficiency in dietary nitrogen could also be responsible (Smith, 1992). Depressing weight gains were, however, obtained when fermented cassava peels were fed to sheep. Formunyan and Meffeja (1987) explained that such depressed growth rates might be due to fermented cassava peels' depressant effects on rumen function.

Sheep fed a diet containing 80% ensiled cassava peels had a higher daily gain of 81g/d than those provided sun-dried peels that gained 59 g/d (Heuzé et al., 2012). Supplementing with ensiled cassava peels increased the average daily gain of grazing crossbred cattle from 0.07 kg/d to 0.33 kg/d compared to 0.29 kg/d to for the dried peel (Larsen and Amaning-Kwarteng, 1976). However, Abate (1981) noted a decrease in beef calves' growth rate offered a concentrated diet containing cassava peels as the main energy source. Fomunyan and Maffeja (1987), in a study, reported that sheep fed 0, 35, and 70% cassava peel-based diets in addition to elephant grass and using cottonseed cake as the protein source gained 45, 106.7, and 227.1 g/d, respectively. The conclusion was that live weight gains of sheep increased with increasing cassava peel intake levels and that the peels show promise as dry-season feed for sheep. Guimarães et al. (2014) also recorded average daily gains of 154, 153, and 153g/d after supplementing lambs with 10, 20, and 30% dried cassava peels concluded that cassava peel could be included in the diet up to 30% with no change in intake and animal performance. Ensiling cassava peels with *Pennisetum purpureum* had beneficial effects on silage properties, intake, and digestibility in Red Sokoto goats. It was concluded that adding cassava peels to form at least 30% of silage made from Pennisetum purpureum improved productivity during the dry season (Olorunnisomo, 2011).

Sun-dried cassava peels have been used to improve sheep's reproductive and total productivity compared to sheep offered a control diet (Addah 2005; Table 6). In that study, sheep showed cassava peels diets also had lower mortality rates and had higher pre-weaning growth rates, but prolificacy rates were similar.

Karbo et al. (1997) reported that Sahelian and Djallonké crosses with cassava peels improved the average daily gain of sheep compared to supplementation with pigeon pea (130g/d vs. 87.9 g/d). Asaolu (1988) fed two sheep groups with 80% each of dried or ensiled cassava peels supplemented in each case with 20% Gliricidia leaves. Sheep from both groups were compared to a control group fed 100% Gliricidia. It was observed that sheep fed mainly Gliricidia performed better than those on the cassava peel diets. However, those on ensiled cassava peel group performed better than those on the dried cassava peel diet in terms of dry matter intake (0.7 vs. 0.6 g/d), average daily gain (81vs. 59 g/d), and dry matter digestibility (76 vs. 72%).

Table 6: Effects of dried cassava peels on birth weight and pre-weaning growth performance of sheep1

Item	Birth weight (kg)	Pre- weaning growth rate (g/d)	Total[2] Productivity
Cassava peels	1.54	77.3	6.3
Control	1.18	30.4	0.72

[1] *Addah (2005)*

[2] $Total\ productivity\ = \frac{Total\ no.of\ lambs\ weaned\ x\ mean\ weaning\ weight}{Total\ no.of\ ewes\ mated}$

Whole cotton seed

Cottonseed is a by-product obtained from the ginning of cotton. Whole cottonseed (WCS) is often fed to farm animals without the cost of treatment. Cotton is a common oilseed grown, especially in Ghana's savannah zones and in almost all sub-tropical areas. The composition of the whole cottonseed is quite variable depending on the ginning process and the crop variety. This explains the wide variation in the composition of the by-product (Charray et al., 1992). Whole cotton seed has a relatively high crude protein content (15-25%), fat (10-33%), cellulose (25-30%), and an average of 14.52 ME (MJ/kg) (Charray et al., 1992). Scarr (1987) similarly reported an energy level of 11.0 ME (MJ/kg). Wide (1987) also documented CP (crude protein) content of 18.5% and CF (crude fibre) content of 16.9%. Whole cotton seed has safely been integrated into ruminant diets at a level of 25% dry matter (Arieli, 1992). Whole cotton seed has an apparent digestibility of 72.4% and low energy loss in the form of methane gas because of its minimal rumen methane gas generation of about 4.3% (Arieli, 1994).

Replacement of commercial concentrate with the whole cottonseed in sheep diets did not show any significant difference in growth performance (Arieli, 1992).

Whole cotton seed has experimentally been demonstrated as a useful source of dietary fat for modifying metabolism, modulating ovarian follicular recruitment and luteal activity, and enhancing reproductive potential in ruminants (Ryan et al., 1992). Salting of the whole cottonseed improves intake but mixing the whole cottonseed with other by-products results in the best intake and growth performance (Charray et al., 1992).

WCS and other cotton products may contain gossypol, a yellow pigment (*polyphenolic binapthyladehyde*) toxic to pre-functional ruminants and non-ruminants. Gossypol is, however, absent in glandless cotton varieties. It has little effect on adult ruminants because the rumen microbes can inactivate gossypol in the rumen (Church, 1991). Whole cotton seed has been reported to contain free dietary gossypol content of 4 -17 g/kg DM (McDonald et al., 1995). Gray et al. (1993) found that an extremely high level of dietary free gossip of more than 10g/animal/day did not reduce fertility in heifers, nor did it produce any detrimental effects during pregnancy or any detrimental effects on growth rate and body condition score.

Another factor limiting the inclusion of the whole cottonseed in ruminant diets is the high lipid content. Lipids are not utilized for rumen microbial synthesis; hence the organic matter available for rumen microbes will be low at high whole cottonseed feeding levels (Arieli, 1992).

About 250-400g/head of the whole cottonseed combined with molasses in a ratio of 1:1 has been recommended for West African Dwarf ewes depending on the ewe's physiological status (Charray et al., 1992). Charray et al. (1992) reported a daily weight of 87g/d when the whole cottonseed inclusion level was 35%. The feeding of the whole cottonseed to lactating ewes may not be recommended because milk protein production may be reduced with diets containing whole cottonseed or oilseeds due to ruminal and extra ruminal effects (Arieli, 1992).

Excessive quantities of gossypol may escape rumen detoxification and produce toxicosis in functional ruminants (Gray et al., 1993). In pre-functional ruminants and non-ruminants, symptoms of gossypol toxicity include depressed appetite, weight loss, labored breathing, cardiac irregularity, and extensive oedema in body cavities. This indicates an effect on membrane permeability during post-mortem inspections. Death is usually caused by the reduced oxygen-carrying capacity of the blood, hemolytic effects on erythrocytes, and circulatory failure (McDonald et al., 1995).

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