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Forage conservation in sub-Saharan Africa: Review of experiences, challenges, and opportunities

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Abstract

Forage conservation is an important potential solution to seasonal variation in feed quality and quantity and herder-farmer conflicts in sub-Saharan Africa (SSA). Considerable variations exist in the type of forages conserved and the preservation methods across SSA. Hay from cultivated forages is commonly made with mechanical mowers and balers by large-scale commercial farms. In contrast, smallholder farmers, who dominate farming on the continent, make hay from natural pastures and straw from crop residues or stockpiled forage. Mechanized harvesting and storing of silage are also practiced by commercial farmers in various countries including South Africa, Nigeria, and Kenya. Smallholder farmers rarely make silage, despite repeated recommendations about its potential to bridge the dry season feed gap. This is due to the limited resources, knowledge, and skills. Hay and silage produced by smallholders is typically poor in quality due to use of lower quality forages, improper storage methods, and lack of an economic incentive because feed prices do not reflect quality

Abbreviations: CP, crude protein; DM, dry matter; IVDMD, in vitro dry matter digestibility; ME, metabolizable energy; NIRS, near-infrared spectroscopy; SSA, sub-Saharan Africa.

in most regions. This paper discusses the status of forage conservation across SSA and recommends strategic interventions and technologies to improve the quantity, quality, safety, pricing, and utilization of preserved forages in SSA. Key deductions include the need to raise awareness about their role in bridging the feed gap, to build capacity and invest in appropriate technology, to optimize their production and use, to develop mechanisms to relate prices to quality, and to incentivize women and youth and the private sector to engage further in making and selling preserved forages.

1 | INTRODUCTION: THE NEED FOR FORAGE PRESERVATION IN SUB-SAHARAN AFRICA

The livestock sector contributes between 30 and 80% of the agricultural gross domestic product in African countries (AU-IBAR, 2016). It is central to the livelihoods of rural areas and important to the continent's food and nutritional security and economy. The demand for livestock products will increase two- to eightfold between 2030 and 2050 due to the increase in human population, urbanization, and increased incomes (Alexandratos & Bruinsma, 2012). Consequently, the current per capita annual consumption of meat and milk of about 14 kg and 30 L, are projected to rise to 26 kg and 64 L, respectively, by 2050 (AU-IBAR, 2016), which are below the recommended consumption levels of 33 kg of lean meat or 230 L of milk (FAO, 2014). However, livestock productivity is currently constrained by complex systemic challenges, of which the limited supply of quality feed is commonly cited as the greatest one in most African countries (Balehegn et al., 2020). The projected global increase in the demand for animal-source foods, which will mostly be concentrated in low- and middle-income countries (LMIC), may allow smallholder livestock producers to improve their livelihoods and food and nutrition security (Ritchie & Roser, 2017). However, across livestock production systems in many LMIC, limited supplies and high cost of good quality feed severely constrain exploitation of this opportunity.

In most sub-Saharan Africa (SSA) production systems, forage is abundant and may be even excessive and of sufficient quality during the rainy season but availability and quality declines rapidly during the dry season (Nyamukanza et al., 2008). For instance, in the southern Africa region, extreme seasonality of forage availability for livestock exists due to variability in climate (Batisani & Yarnal, 2010; Palmer & Ainslie, 2006), leading to inadequate forage quantities for ruminant livestock. A recent analysis of feed demand and supply in Burkina Faso revealed that at the national level there was a feed surplus of up to 6 Tg of dry matter (DM), yet there was a feed deficit of 2 Tg in the Sahel region, and lesser deficits in three other regions (Ayantunde, 2021). A preliminary feed supply-demand assessment in Ethiopia showed that the feed deficit was 10% when expressed as DM, but it was 45 and 42% when expressed as metabolizable energy (ME) and crude protein (CP), respectively (FAO, 2018). This data highlights the need for more forage conservation to ensure availability and quality across seasons and regions.

As an example of the loss in nutritive value towards the end of the dry season, the CP and ME value of forages in the western Usambra highlands of Tanzania, each decreased by 20% during the dry season, consequently milk yield by cows fed the forages was reduced by 40% (Maleko, Ng, et al., 2018). In southern Ethiopia, CP and in vitro dry matter digestibility (IVDMD) of natural pasture declined by 28 and 5%, respectively, during the dry season compared to the wet season (Abebe et al., 2012). Similar reductions in forage availability and forage nutritive value occur across the continent and limit supply of nutrients needed to optimize the growth and productivity of livestock (Abusuwar & Ahmed, 2010; Mayouf & Arbouche, 2015; Müller et al., 2019; Samuels et al., 2016). In addition to these factors, forage conservation is important to prevent forage losses in grazing systems due to trampling, diseases, and pest damage and wildfire (Ajayi, 2011). This further highlights the need to conserve feeds to address the quantity and quality deficits.

Climate change, manifested in unpredictable and extreme variations in rainfall in many African countries, is projected to continue (Batisani & Yarnal, 2010), leading to an even greater supply and demand imbalance in availability of forages for improved livestock production. To address the current feed deficits largely driven by dry season shortages as well as the predicted increases in such shortages due to climate change, appropriate forage conservation and preservation practices are critically needed to preserve quantities, reduce nutrient and energy loss, and minimize spoilage.

Despite recommendations of forage conservation (mainly silage making) as a solution to the widespread problem of variability in feed quality and quantity (Tufail et al., 2020), awareness and adoption for forage conservation practices among smallholder farmers in SSA is low (Makau et al., 2019). In the semi-arid region of Kenya, only 5.1% of surveyed farmers made silage mainly for their dairy cattle but not regularly (Njarui et al., 2011). In a survey of 154 farmers in coastal Kenya, only 0.6% of them practiced silage making (Lewa & Muinga (2013). A survey of 181 farmers in coastal Kenya showed only one farmer practiced silage making (Muinga et al., 2015). Likewise, in Ethiopia silage is uncommon in Oromia, Southern Nations and Nationalities and Peoples Regional State (Tolera, 2007), and the Tigray regions (Tesfay et al., 2016), though its potential success has been demonstrated in several projects. Limited adoption of silage making is caused by factors including the novelty of forage conservation practices (Lukuyu et al., 2011), associated costs, poor fit into the prevailing farming systems, and lack of simple and appropriate technologies for ensiling (Tufail et al., 2020) among other factors (Table 1). The objective of this paper is to review the status of the practice of forage conservation in SSA, to identify factors that limit adoption of forage conservation technologies and management practices and to outline strategies to increase the practice across the continent.

Core Ideas

- Low forage availability and poor quality during dry season limit livestock productivity in sub-Saharan Africa.
- Improved forage preservation as silage and hay are recommended to meet this forage gap.
- Hay making, and crop residue preservation are practiced in sub-Saharan Africa, but need improved techniques.
- Silage-making is mostly limited to commercial farms, due to technical, financial, knowledge, and resource limitations.
- Improving awareness, knowledge, skills, and affordability of equipment can improve adoption.

2 | METHODOLOGY

A PRISMA diagram showing the manuscript selection process for the review is shown in Figure 1. Publications were identified from Web of science and Google scholar databases using searches for key words including silage, hay, forage conservation, and forage preservation in sub-Saharan African countries. All these terms in combination with names of African countries were used in the search. For instance, the search terms used included “silage OR ensiling AND [African Country]”, “Hay OR Hay making AND [African Country]”, “Forage conservation AND [African Country]”, “Forage Preservation AND [African Country]”. Papers reporting data or information on practices of forage preservation, adoption of forage preservation technologies, types of forages preserved, and experiments on forage preservation in any of the sub-Saharan African countries were included. In addition, pertinent information from the gray literature was included. Moreover, a general ad hoc search was also made to identify papers that provided pertinent information on general feed and forage issues in African countries. This review did not focus on a specific year of publication range, but in the presence of older publications with similar data, more recent publications were selected.

3 | COMMONLY PRESERVED FORAGES AND PRESERVATION TECHNIQUES

The commonly preserved forages in Africa can be grouped into three categories, namely herbaceous vegetation from natural pasture, crop residues, and planted forages (Ajayi, 2011). To some degree, forage from browse plants, agro-industrial by-products (Kebede et, al., 2020; Yonatan et al., 2011), and root crops and tubers (Anaeto et al., 2013; Mohammed et al., 2013; Njarui et al., 2011) are also preserved. The importance of these forage types and their conservation methods vary with the farming systems and socioeconomic status of the farmers. In many smallholder livestock systems, where crop residues are of high importance for animal nutrition, there are varied methods of conservation such as baled, stacked, or standing hay. By contrast, pastoralists usually set aside exclosures or forage reserves where grazing is excluded for certain periods to reserve “standing forage” for later use (Mwilawa et al., 2008).

The practice of growing improved forage species is increasing in peri-urban smallholder dairy production systems in the region and the preservation methods are mostly harvesting as hay and to a limited extent silage making (Millogo, 2010). Various “improved” forage species and cultivars have been introduced to East Africa (Mengistu et al., 2016; Muyekho et al., 1999), South Africa (Palmer & Ainslie, 2006), and West Africa (Elbasha et al., 1999; Tarawali et al., 2005). Nevertheless, forage production is primarily from a few grasses, legumes, cereals, and to a lesser extent native tree species (Madzonga & Mogotsi, 2014; Mapiye et al., 2011; Muller, 2017). Table 1 of Scholtz et al. (2009) provides a list of forage species and the commonly practiced conservation methods in different regions of SSA.

4 | SILAGE MAKING

Silage is a product of fermenting high-moisture forages after chopping and compaction under acidic and anaerobic conditions in structures called silos. Good quality silage (well-preserved silage that is not prone to deteriorate) can be

TABLE 1 Commonly preserved forages, techniques for preserving them, and constraints and opportunities associated with the technique

Type of forage or forage component	Species	Production system	Type of preserved forage/forage component	Challenges	Opportunities	Reference
Planted grasses	Nile grass (*Acroceras macrum* Stapf), weeping love grass [*Eragrostis curvula* (Schrad.) Nees], tef [*Eragrostis tef* (Zuccagni) Trotter], Rhodes grass (*Chloris gayana* Kunth), buffel grass (*Cenchrus ciliaris* L.), guinea grass [*Panicum maximum* (L.) Willd.], elephant grass (*Pennisetum purpureum* L.), congo grass (*Urochloa ruziziensis*, formerly *Brachiaria*).	Mixed crop livestock and commercial large scale.	Hay, straw, and silage.	Limited arable land, insufficient water for forage production, financial constraints, limited access to appropriate infrastructure, equipment, and high costs of forage seeds; use of forages species not adapted to the agroecological region.	Development of improved cultivars specific for the marginal agroecological conditions.	Maphane & Mutshewa (1999), Van der Stoep & Tylcoat (2014), Muller (2017), Trytsman et al. (2020)
Cereals/grains and their by-products	Red oat (*Avena sativa* L.), barley (*Hordeum vulgare* L. subsp. *vulgare*), bajra (*Pennisetum typhoideum* L.), pearl millet [*Pennisetum glaucum* (L.) R.Br.], Sudan grass [*Sorghum sudanense* (Piper) Stapf], wheat (*Triticum aestivum* L.), maize (*Zea mays* L.).	Mixed crop-livestock urban and peri-urban and commercial.	Hay, straw, stover silage, densified forage, sometimes with urea treatment.	Ensiling stovers results in poor-quality forage, especially if commercial silage additives and proper ensiling facilities are not available; loss of nutrients through aerobic respiration and leaching; labor and resource intensive processes. Food/ grain is usually the priority, so forage from cereal grain crops usually available only as low-quality straw.	Increased resource access for cultivation by, for example, emerging farmers in South Africa; improvement of dual-purpose cultivars for both forage and grain. Increased availability of supportive technologies such as choppers, densifiers, pelleting machines.	Maphane & Mutshewa (1999)

(Continues)

TABLE 1 (Continued)

Type of forage or forage component	Species	Production system	Type of preserved forage/forage component	Challenges	Opportunities	Reference
Browses	Sweet thorn [*Vachellia karroo* (Hayne)], gum arabic [*Vachellia nilotica* (L.) P.J.H. Hurter], and babul [*Acacia nilotica* (L.) Del.], umbrella thorn [*Acacia tortilis(Forssk.) Galasso & Banfi]* or *Vachellia tortilis* (Forssk.) Galasso & Banfi], sickle bush (*Dichrostachys cinerea* Wight et Arn.), *Tapinanthus lugardii* (N.E. Br.) Danser, *Erianthenum ngamicum* (Sprague) Danser, red-berry mistletoe (*Viscum rotundifolium* L.f.), *Viscum verrucosum* Harv., *Ficus thonningii* Blume. *Acacia grewia* species, desert date [*Balanites aegyptiaca* (L.) Delile].	Pastoral, mixed crop livestock.	Leaf meal, dried pods, and fruits.	High concentrations of secondary metabolites like tannins that reduce their quality; encroachment on valued areas from species like Vachellia species and sickle bush; low biomass production; labor intensiveness of foliage and pod collection.	More and more information is made available on the storage of browse as a leaf meal, pods etc.	Hintsa et al. (2015), Balehegn (2017)
Natural pasture grasses and legumes	Bermuda grass (*Cynodon dactylon* (L.) Pers.], star grass (*Cynodon nlemfuensis* Vanderyst), giant star grass [*Cynodon aethiopicusClayton & Harland]*, Masai love grass (*Eragrostis superba* Peyr.), jaraguá [*Hyparrhenia rufa* (Nees) Stapf].	Mixed crop livestock, pastoral, pastoral urban and peri-urban commercial systems.	Harvested hay, standing hay, silage.	Variable quality depending on botanical composition and soil fertility. Low nutritional quality.	Good adaptation to marginal agro-ecological regions.	Muller (2017), Trytsman et al. (2020)

(Continues)

TABLE 1 (Continued)

Type of forage or forage component	Species	Production system	Type of preserved forage/forage component	Challenges	Opportunities	Reference
Legumes	Groundnut (*Arachis hypogaea* L.) haulm, cowpea [*Vigna unguiculata* (L.) Walp] haulm, Pigeon pea [*Cajanus cajan* (L.) *Huth*] residue, lab (*Lablab purpureus* (L.) Sweet), alfalfa (*Medicago sativa* L. subsp. *sativa)*, siratro [*Macroptilium atropurpureum* (DC.) Urb.], garden pea (*Pisum sativum* L.), red clover (*Trifolium pratense* L.), cow pea (*Vigna unguiculata* (L.) Walp.] cheesytoes [*Stylosanthes hamata* (L.) Taub], and Townsville stylo (*Stylosanthes humilis* Kunth.)	Mixed crop livestock, urban and peri-urban commercial, and large-scale intensive commercial systems.	Conserved alone or in mixtures with grasses as hay or silage.	Significant leaf losses during sun-drying and storage; lack of knowledge to make legume silages; low input availability.	High demand for legumes due to their relatively high concentration of crude protein and low concentration of anti-nutritional factors.	Manyawu et al. (2016)
Roots/tubers	Cassava (*Manihot esculenta* Crantz), sweet potato [*Ipomoea batatas* (L.) Lam.] peels, enset [*Ensete ventricosum* (Welw.) Cheesem.]	Mixed crop livestock, urban and peri-urban commercial systems.	Sun-dried, pelleted, chopped, or ensiled roots and tubers	Loss of nutrients through aerobic respiration and leaching by rainfall, lack of inputs and technical knowledge to make silage, low adoption of silage making, anti-nutritional constituents (e.g. hydrogen cyanide).	Processing of cassava peels into high quality feed products, good market demand, high concentration of water-soluble carbohydrates for ensiling.	Njarui et al. (2011), Anaeto et al. (2013), Hadgu et al. (2015)
Byproducts	Wastes and agro-industrial by-products from sugar, fruit, brewery, vegetable, slaughterhouses, fisheries, etc.	Urban and peri-urban commercial production systems, large-scale intensive commercial systems.	Ensiled or dried by-products	Highly perishable and susceptible to spoilage when fresh, may be only available in localized areas near agroindustry.	Potential to increase availability, new treatment, and preservation methods.	Yonatan et al. (2011), Kebede et al. (2020), Mekuriaw et al. (2020)

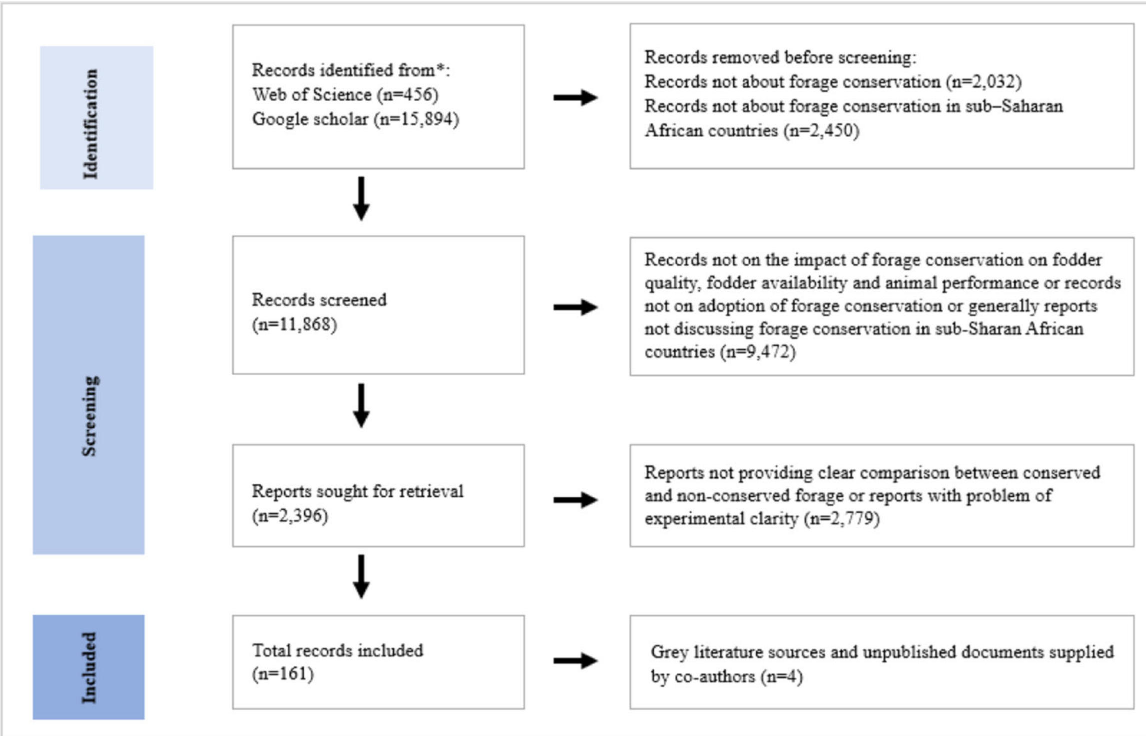

FIGURE 1 The PRISMA flow diagram from initial search and screening to final selection of studies included for the review of experiences, challenges and opportunities for forage conservation in sub-Saharan Africa

produced from most grass, cereal, and legume crops. Silages generally have a higher moisture concentration of about 650 g kg^{-1} compared to that of hay, which can range between 8 and 150 g kg^{-1}, because they are preserved without drying and sometimes at an earlier growth stage than hay (Müller et al., 2017).

In sub-Saharan African countries, silage is mostly made under experimental conditions at research centers or on large commercial farms and it is rarely produced by small-scale farmers in rural areas due to lack of awareness, inputs, and technical knowledge (Supplemental Table S1). In Kenya, about 25% of farmers who received silage-making training and extension support adopted the technology attracted by the increased animal productivity that resulted from feeding silage during the dry season (Makori, 2007). A relatively high level of adoption of 48.2% was recorded among 100 surveyed farmers in three subcounties in the Tana Catchment of Kenya (Oguntoye et al., 2018). Consequently, silage making is increasingly becoming common in urban and peri-urban and large-scale commercial farms (Aranguiz & Creemers, 2019a). Commercial farms primarily make silage from forages such as elephant grass (*Pennisetum purpureum* Schumach.), maize (*Zea mays* L.), sorghum [*Sorghum bicolor* (L.) Moench], oat (*Avena sativa* L.), triticale (X *Triticosecale*), and barley (*Hordeum vulgare* L.), which are mostly ensiled in large bunkers (Muller, 2017) and tubes, whereas urban and peri-urban farmers mainly make small bag or pit silos from various forages (Table 1). Lukuyu et al. (2013) reported that in Kenya, Uganda, and Rwanda, silage is mainly made in pits (51%), followed by plastic tubes (27%; Figure 2), aboveground piles (16%), and plastic bags (12%).

In East African countries, napier grass (*Pennisetum purpureum* Schumach.) and maize are the main ensiled forages for dairy production (Creemers & Aranguiz, 2019). In southwestern Uganda, where most of the dairy farming is concentrated, 76% of silage-producing farmers used napier grass and 24% used maize (Ntakyo et al., 2020). In the semi-arid region of Kenya, ensiled forages were limited to napier grass and maize (Njarui et al., 2011). In the central highlands of Kenya where dairy farming is highly commercialized, ensiling of maize, napier grass, and forage sorghum in plastic tubes has been widely adopted as a result of promotion by the government and other development agents (Tufail et al., 2020). Maize stalks are either ensiled without or occasionally with ears (grain-plus-cob) (Ntakyo et al., 2020). Likewise, in many parts of the continent, farmers harvest maize ears for human consumption and ensile the remaining stover. Sweet potato [*Ipomoea batatas* (L.) Lam.] vine silage is also common for pig rearing in the central region of Uganda (Dione et al., 2015).

In southern African countries, silage making is not common among smallholder (emerging native black farmers who recently returned to farming after centuries of displacement (Zantsi et al., 2019) farmers who generally prioritize

FIGURE 2 Plastic tube silage from Kenya (Photo: Farm Kenya [https://www.standardmedia.co.ke/farmkenya/])

production of grain crops over forage crops. However, on most commercial farms such as those in the eastern Cape, round bales of silage are common for dairy production (Meeske et al., 2002). When smallholders make silage, it is mostly produced in drums/plastic bags or small bunkers (Nkosi et al., 2009) using maize, pearl millet (*Pennisetum glaucum*) or sorghum stover and agro-industrial by-products such as potato (*Solanum tuberosum* L.) wastes.

In West Africa, guineagrass (*Panicum maximum* Jacq.) and napier grass are the most common grasses used for silage production, particularly in Ghana (Okantah et al., 2007) and Nigeria (Babayemi, 2009; Lamidi & Ojo, 2018; Olorunnisomo, 2011). However, due to the costs and technical challenges, silage making has mainly been on experimental farms of universities and research institutes. Common types of silos used in West Africa include aboveground piles (Okantah et al., 2007), plastic barrels/containers (Babayemi, 2009), pits lined with single to multiple sheets, or bags made of polyethylene or plastic.

With the exception of molasses and perhaps bacterial inoculants used on few commercial farms, additives are rarely used in silage making in SSA. Molasses is commonly used in east African countries including Kenya (Snijders et al., 2004) and Ethiopia (Kebede, 2019). In a survey conducted in the southwestern Uganda, the most widely used additives were molasses (70%), maize bran (18.3%), microbes (6.8%), and MolaPlus (2.3%, MOLAPLUS, Ltd.) (Ntakyo et al., 2020). Examples of different fodder types ensiled using various treatments and the quality of ensiled product are in Supplemental Table S2.

4.1 | Ensiled by-products

Fruit, vegetables, and root crops are important components of the multi-culture farming systems in SSA and by-products from agro-allied industries are also becoming increasingly available (Chedly & Lee, 2000; Machin, 2000). These include wastes and by-products from industries that produce sugar, fruits, vegetables, and beer like brewer's spent grains, banana by-products, root crops such as cassava (*Manihot exculenta* Crantz), taro [*Colocasia esculenta* (L.) Schott], sweet potato, yams, wet pulps, grape mare as well as others like slaughterhouse waste, and fishery and poultry litter, etc. In addition, sugarcane (*Saccharum officinarum* L.) tops, coffee (*Coffea arabica* L.) pulp, khat [*Catha edulis* (Vahl) Forsk. ex Endl.], and enset [*Ensete ventricosum* (Welw.) Cheesem.] are ensiled in Ethiopia (Mekuriaw et al., 2020; Yonatan et al., 2011). Cassava peels are also ensiled in Ghana and Nigeria (Anaeto et. al, 2013).

4.2 | Silage quality

The quality of silage in SSA is dictated by various factors that are typical to production systems on the continent. While silage quality is high in certain commercial systems with appropriate equipment and expertise, other systems are characterized by medium to low quality silages due to several reasons. These include ensiling of high moisture, low quality tropical grass forages harvested at advanced maturity stages and inadequate chopping, compaction and sealing due to lack of appropriate machinery or skills. Additional reasons include ensiling of high moisture forages (>60%) that lack of sufficient water-soluble carbohydrates (2.5–3.7% DM) for a good fermentation (Haigh, 1990; Piltz & Kaiser, 2004). Factors such as advanced maturity at harvest, associated high lignin and cell wall concentrations, and bulkiness of the forage impede compaction in the silo and prevent the proper exclusion of oxygen necessary for an ideal fermentation (Yang, 2005). Further, DM and quality losses for most storage methods, partly due to improper sealing of silos, can foster oxygen ingress and rainwater seepage into the silos (Bareeba, 1992; Ntakyo et al., 2020). Consequently, silage quality is often suboptimal in many production systems.

Many laboratories in SSA lack functioning equipment especially those for measuring specialized attributes such as fermentation characteristics like concentrations of organic acids and ammonia nitrogen, spoilage indices like yeast and mold counts or types, or aerobic stability (Dube, 2009; Ludgate et al., 2020). Therefore, silage pH and chemical composition is more frequently reported. Kung and Shaver (2001) recommended that good tropical silages should have a pH of 4.3–4.7. A minimum pH of 4.4 has been also used as a benchmark for good cassava peel silage (Asaolu, 1988). However, such pH values are challenging to obtain with tropical crop residue silages, which often have high stem/leaf ratios, low water-soluble carbohydrates, and high cell wall concentration.

5 | HAY MAKING

Preservation of forages as baled, loose or stacked or standing hay is widely practiced among smallholders and commercial farmers in many countries in Africa. With increasing climate variability, even pastoralists are now practicing storing grass in the form of hay (FAO, 2013). In Ethiopia, hay contributes up to 8% of the overall feed resources in the country (Aranguiz & Creemers, 2019b) and is mostly prepared from natural pastures (Feyissa et al., 2013). The contribution could be higher in some places depending on the availability of pasturelands. For example, hay provides close to 80% of feed source in one district in Oromia (Duguma et al., 2012) and another district in the Amhara region of Ethiopia (Mekonnen et al., 2010). In many places in the northern and central highlands of Ethiopia, lowland pasturelands are protected from grazing during the growing season and harvested for hay making. The common grasses used for hay making in such lowland pasturelands are Andropogon, *Festuca* (tall fescue), *Eragrostis* (love grass), *Hyparrhenia* (giant thatching grass), *Themeda* (kangaroo grass), *Setaria* (green foxtail), *Brachiaria* (palisade grass), *Pennisetum* (napier grass), *Cynodon* (Bermuda grass), *Sporobolus* (smut grass), and *Phalaris* (reed canarygrass) (Suttie, 2000). Making hay from cultivated perennial forage is increasing but is still uncommon, mostly on smallholder farms (Aranguiz & Creemers, 2019a). The quality of hay in SSA is usually very low due to the use of native poor-quality forage, late harvesting (Kitaba & Tamir, 2007) and improper storage (Feyissa et al., 2013). For instance, most farmers in northern Ethiopia store hay in open fields, which causes a loss of up to 70% of CP due to leaching (Yayneshet et al., 2009a). Baling is only practiced by retailers and only in specific regions of the country (Aranguiz & Creemers, 2019a). In the northern region of Uganda where pastoralism is dominant, the natural pastures such as giant thatching grass [*Hyparrhenia rufa* (Nees) Stapf], *Urochloa* spp., red oat grass (*Themeda triandra* Forssk.) and Rhodes grass (*Chloris gayana* Kunth), are preferred pasture species for standing hay (Roschinsky et al., 2012). A review of reports from Kenya, Uganda, and Rwanda indicated that the common methods of hay making are loose hay (53%), box baling (47%), and machine baling (6%) (Lukuyu et al., 2013). In wet and cold environments, such as the eastern African highlands, hay making with thick-stemmed and succulent grass species such as napier grass, Guatemala grass (*Tripsacum laxum* Nash), and maize is challenging, consequently silage making is preferred (Maleko, Msalya, et al., 2018).

In Kenya, a wide range of perennial grasses are stored as hay. These include red oat grass, buffel grass (*Cenchrus ciliaris* L.), common star grass (*Cynodon dactylon* Pers.), maasai love grass (*Eragrostis superba* Peyr.), guinea grass (*Panicum maximum* Jacq.), *Urochloa*, horse tail grass (*Chloris roxburghiana* Schlult), and wild rye grass (*Enteropogon macrostachyus* Munro ex Benth.). In southern African rangelands, the main method of conservation is to leave the natural grass species standing in the fields, harvesting and placing them in tree branches, on wooden racks or in small home granaries (Ndathi et al., 2012), which makes them subject to rapid deterioration due to weather-related conditions (Koech et al., 2016).

In the southern Africa region, hay is reported to contain moisture concentrations between 8 and 150 g kg^{-1} (Muller, 2017). In Kenya, the moisture concentration of hay varies between 52 and 185 g Kg^{-1} depending on the date after baling and storage conditions (Koech et al., 2016). The nutritional quality of the hay differs significantly between different forage species and harvesting times (Muller, 2017). Legume hay produced in South Africa is generally of higher quality in terms of CP concentration, which ranges between 130 and 210 g kg^{-1}, while that of grasses and cereal hay ranges between 40 and 100 g kg^{-1}(Muller, 2017). In the winter rainfall zone of South Africa, specifically the Western Cape province, hay is mainly made from oat, barley, triticale, and to a lesser extent serradella *(Ornithopus sativus* Brot.), vetch (*Vica sativa* L.), and lupines (*Lupinus polyphyllus* Lindl.). In the summer rainfall areas, hay is made from alfalfa as well as various grass types such as African lovegrass [*Eragrostis curvula* (Schrad.) Nees] and teff [*Eragrostis tef* (Zucc.)], and in some cases sorghum (Dugmore, 1995). Alfalfa (*Medicago sativa* L.), however, remains the premier hay crop in South Africa primarily due to its high quality, depending on the phenological stage at which the forage is harvested (Muller, 2017; Scholtz et al., 2009).

In Botswana, lablab bean [*Lablab purpureus* (L.) Sweet] production and utilization as hay has been adopted by both small-scale/emerging dairy and small ruminant farmers (Madzonga & Mogotsi, 2014). However, local production is still relatively low because most farmers buy alfalfa from

South Africa (Mogotsi et al., 2020). Eighty percent of farmers surveyed (Madzonga & Mogotsi, 2014) plant lablab for feeding their own livestock while 20% produce and sell hay to other farmers as a means of income generation. The adoption of buffel grass in Botswana, though recommended by research (APRU, 1980), has been hampered by the fact that it forms permanent pasture and farmers who practice arable-livestock mixed farming do not want to commit large areas for pasture.

Generally, grass hay, either from natural or planted pastures is characterized by low protein (40–70 g kg^{-1} for natural and 70–100 g kg^{-1} for planted pastures), which is inadequate for maintenance and production of ruminants (Madibela et al., 2002). Napier grass recently attracted the attention of farmers in Botswana, but has not been widely adopted (Mogotsi et al., 2020), with farmers experiencing a myriad of challenges including unavailability of water for irrigation, shortage of labor and planting material for propagation, as well as limited technical knowledge on the management. *Urochloa* grass spp. has emerged as an alternative forage and has been extensively cultivated in East Africa with preliminary data showing 15–40% increase in milk production in Kenya and 36% in Rwanda among farmers who planted *Urochloa* spp. compared to those who did not (Ghimire et al., 2019).

Standing hay is common among the pastoral communities as it is an easier conservation method, and it fits the mobile nature of pastoralists. Degraded rangelands in many areas have also been spared from grazing and are used as standing hay for cut and carry systems (Tesfay, 2008). Digitgrass (*Digitaria eriantha* Steud.) and kikuyu grass (*Pennisetum clandestinum* Chiov) are the most commonly used species of the summer growing/winter dormant grasses in southern Africa and guinea grass (*Panicum maximum* Jacq.), Rhodes grass, and Nile grass (*Acroceras macrum* Stapf) are also regarded as good candidates under these conditions. Temperate grasses (i.e., spring, winter, and autumn growing species such as tall fescue [*Festuca arundinacea* Schreb.] and orchard grass [*Dactylis glomerata* L.]) are also good for standing hay for the winter rainfall regions in Saharan Africa (Hardy, 1995). Standing hay conservation in "exclosures'' is common in Ethiopia and this entails excluding pasturelands from grazing for some time. Dried grass is then either grazed in situ or harvested and carried to the barns (Yayneshet et al., 2009b). In Ethiopia, the main purpose is to allow overgrazed pasturelands to regenerate and recover to a more productive state. The quality and biomass of standing hay in exclosures depends on various factors including the age of exclosures (time since exclosure was constructed), species composition of the forage and soil physical and chemical characteristics (Mekuria et al., 2011).

In general, hay making is less popular in West Africa (Kima et al., 2015) compared to East and southern African regions. In West Africa, natural pastures (both annual and perennial species) are mainly used for hay making as they are harvested manually when green, then dried and stored in sacks for feeding the animals or for sale. However, in many cases the natural pastures are left in the field to dry (i.e., standing hay) before they are harvested (Amole & Ayantunde, 2016). The dried grass can also be grazed in situ by the animals. Planted forage species such as ruzi grass [*Urochloa ruziziensis* (R. Germ. and C.M. Evrard) Crins], lablab bean, and monkey tamarind (*Mucuna pruriens*) have been promoted for hay making in Mali, Nigeria, and Burkina Faso with limited success in peri-urban areas where smallholder dairy production and animal fattening are dominant (Amole et al., 2015; Amole & Ayantunde, 2016). In the Inner Delta of River Niger in Mali and Niger, bourgou [*Echinochloa stagnina* (Retz.) P.Beauv.] is a widely planted grass used to make hay (Djibrina, 2015). The grass is normally cut at least 10 cm above the ground with a machete (to allow for regeneration) when it has reached above 80-cm height. It can be harvested between five and seven times in a year. The common method of hay making in West Africa is loose hay.

Natural pasture hay, the most common type of hay in SSA usually has lower quality compared to hay from improved forages, probably because natural pasture hay is a combination of various herbaceous vegetation with varying degrees of forage quality and the practice of outdoor stockpiling leads to nutrient loss due to leaching (Feyissa et al., 2013). A study in Ethiopia comparing the quality of natural pasture hay with napier grass hay and *Urochloa* hybrid indicated that the latter two, when fed to lactating cows, increased milk yield by 53 and 73% compared to natural pasture hay (Mekuriaw et al., 2020). Similarly, in a study in Ethiopia goat kids supplemented with vetch (*Vicia* spp.) hay had significantly higher body weight gain compared to those browsing in rangelands (Berhane & Eik, 2006).

Storage conditions are important determinants of quality of hay. A study in Kenya comparing hay quality under six drying conditions with drying room having different roofing (Translucent, Green, Zinc, Black, Canopy, and Traditional) with five storage lengths (0, 2, 4, 6, and 8 wk) indicated that hay from green color roofing had highest color profile score, indicating a better quality (Koech et al., 2016). Storage duration of 0–2 wk also resulted in 67 and 66.5% IVDMD values, respectively, indicating that quality declines with time of storage (Koech et al., 2016). The same study indicated that storage period of more than 12 wk adversely lowered digestibility and color profile rating (Koech et al., 2016).

Several interventions aimed at improving the quality and storability of hay have been suggested and recommended. For instance, to improve the quality of hay in Ethiopia Suttie (2000) suggested encouraging farmers to harvest hay earlier, that is, before complete maturity. Proper drying and storing off the ground or on a platform, made of wood or stone to avoid spoilage, shade for protection from sunlight, and legume–grass mixture instead of just natural pasture.

6 | PRESERVING FORAGE AS STRAW AND STOVER

Crop residues are an important source of feed across SSA, particularly in mixed crop livestock systems. Straw remaining after threshing of cereals is collected and dried for feeding livestock. In many sub-Saharan African countries, crop residues or straws contribute to a significant amount of the feed for livestock. For instance, in Ethiopia, 95% of livestock feed is from crop residues (FAO, 2018) like teff, barley, and wheat. In South Africa, crops like wheat, barley, triticale, and oat are the most common sources of straw (Muller, 2017), while in Botswana maize, sorghum, and millet are more common (Ntokome, 2019). In Kenya, instead of burning paddy rice (*Oryza sativa* L.), the large feed demand has led to rice straw marketing in the expansive Mwea irrigation scheme covering close to 10 thousand hectares under paddy rice.

Maize, sorghum, and millet straws are obtained after the crop is harvested and the dried stalks and husks are collected and further dried. These forages are often harvested when they are fully matured, dried, and senesced on the field and then stored on sheds or roof tops for drying and feeding to livestock. Storing stover in this way is associated with mold infestation, leaf loss, and leaching of nutrients (Antwi et al., 2010). Greater leaf losses are associated with sun-drying, transportation, and storage of legume crop residues, which greatly reduces their nutritional value (Antwi et al., 2010). Such losses also vary with storage methods. For instance, in Ghana more DM losses (830 vs. 380 g kg^{-1}) were reported when cowpea [*Vigna unguiculata* (L.) Walp.] haulms were stored on rooftops instead of sheds (Antwi et al., 2010). However, a survey in Ethiopia, reported that 90% of farmers leave straw in the open (Tesfaye & Chairatanayuth, 2007). These studies highlight the considerable need for training farmers on ideal storage methods.

As in other parts of the world, straw in SSA is generally very low in quality, with CP concentration typically below 50 g kg^{-1}, DM digestibility mostly below 600 g kg^{-1}, high fiber concentrations due to the advanced maturity of the forage and low concentration of minerals and vitamins (Muller, 2017). Therefore, preservation of straw is mostly done for handling, management, and avoiding wastage rather than preserving quality, and relatively little research and investment has been directed towards these areas (Baltenweck et al., 2020) or to improving the nutritive value.

7 | BROWSE PRESERVATION

Browses are important sources of livestock feed, especially in the arid and semi-arid rangelands in SSA, which account for about 43% of the land area of the continent (Tjelele, 2007). At least 75% of the shrubs and trees of Africa serve as browse plants and many of them are leguminous (Tjelele, 2007). While trees and shrubs are mostly browsed by animals in situ, harvesting browse forage (leaves, twigs, and pods) for feeding occurs in a few instances. Browse leaf meal is produced from harvested seed pods and leaves of trees that naturally occur within rangelands. These pods and leaves are air-dried (primarily in a shade) and ground or fed as is to livestock (Brown et al., 2018; Mapiye et al., 2009). This conservation method is common under extensive and communal/subsistence farming systems where the lack of suitable or available land for forage production, as well as financial constraints are key limitations to forage production and conservation. In the highlands of northern Ethiopia, farmers harvest green leaves of Chinese banyan plant and store them for use in the dry season (Balehegn et al., 2015).

Foliage and seed pods from several browse plant species have relatively high nutritive value with a CP concentration ranging between 10 and 210 g kg^{-1} (Macala et al., 1995) and IVDMD values ranging between 400 and 800 g kg^{-1} (Balehegn et al., 2015), making them good sources of protein for maintenance of livestock throughout the dry season. In drylands of the eastern Africa including in Ethiopia, Sudan, and Kenya, pastoralists collect pods of various *Vachellia* (previously known as *Acacia*) species and long-thorn kiawe [*Prosopis juliflora* (Sw.) DC.] and store them for use during periods of food scarcity (Hintsa et al., 2015; Mahgoub et al., 2005; Sawal et al., 2004). The use of these browse plants as feed also plays a pivotal role in counteracting the problems of bush encroachment (Tjelele et al., 2014).

Browse has also been ensiled, usually in combination with grains (Mbatha & Bakare, 2018). Most of the time, the need for mixing leguminous browse with cereal crops in silage is to increase the protein content of resulting silage and reduce the concentration of anti-nutritional and toxic metabolites from the browses. For instance, ensiling ground pods of paperbark thorn [*Vachellia sieberiana* (DC.) Kyal. & Boatwr.] for 45 d reduced cyanide content to non-toxic levels and produced an aerobically stable silage (Ngwa et al., 2004). Mixed browse-cereal silages (maize with Leucaena and maize with *Vachellia*) have been compared with maize silage and resulted in improved silage quality, CP, dry matter intake (DMI), milk yield, and milk quality in cows (Mugweni et al., 2000). Phiri et al. (2007) also demonstrated that browse from tree legumes {jumbay [*Leucaena leucocephala* (Lam.) de Wit] and Bolivia wattle [*Vachellia boliviana* Rusby]) ensiled with maize can be used to replace dairy concentrate diets while sustaining intake and body weight gain.

8 | TECHNOLOGIES FOR IMPROVING PRESERVATION AND QUALITY OF FORAGES AND CROP RESIDUES

This section summarizes the literature on technologies that can be used to improve forage preservation. The technologies include silage additives, effective methods of compaction, improved forage varieties, and storage techniques. All of these have been effective even when tested on smallholder farms (Supplemental Table S3), implying that more investment and awareness of the importance of such technologies is needed. This information can help scientists and policymakers understand what has and has not been attempted in SSA to improve forage conservation, and hence determine what to focus on for future research and investments. Further, it can help industry to understand what kind of products are needed to improve forage conservation in SSA, particularly as most of such resources are not readily available on the continent, except perhaps in South Africa.

8.1 | Additives for improving silage preservation

The use of chemical or microbial additives in the conservation of forages is not common in West or East Africa. However, various commercial silage additives are available in South Africa. These are mostly used in commercial farming enterprises, where many use heterofermentative lactic acids bacterial inoculants to improve the aerobic stability of maize silage (Nkosi et al., 2009). However, hardly any of the bacterial inoculants are produced on the continent. Instead, most additives are imported from the United States and Europe. The high cost makes the use of such additives restricted to the commercial farming sector. Therefore, research on low-cost alternatives that are locally produced is a worthy cause. Such additives need to be potent enough to overcome the high environmental temperature effect, which gives aerobic yeasts (Bernardes et al., 2018) and spoilage bacilli (Oude Elferink et al., 1999) competitive advantage over lactic acids bacterial in the silo. The paucity of data on the efficacy of inoculants in SSA also needs to be addressed. In one of the few studies on the subject, researchers at the University of Ibadan, Nigeria, reported that inoculation of guinea grass with *Lactobacillus plantarum* improved fermentation characteristics but accelerated the deterioration of the silage upon aerobic exposure resulting in lower preference by sheep (Adesoji et al., 2010).

The most commonly used additives in SSA are sources of fermentable carbohydrates that improve the fermentation such as molasses or whey and maize bran (Ntakyo et al., 2020). For instance, in southern Africa, maize ears are sometimes treated with these additives to improve the fermentation. Additives like molasses and root crop peels are also used to improve fermentation of protein-rich by-products like cassava leaves and fishery and abattoir wastes (Chedly & Lee, 2000). Other additives from locally available resources like malted sorghum/chibuku (traditional sorghum beer) culture and dried watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai] powder have also improved fermentation of silage made from millet and maize in southern Africa (Matshaba et al., 2014). Also, cereal stover silages are made with urea-molasses mixture (APRRU, 1990) to improve the nitrogen content and supply fermentable energy.

8.2 | Improved silo sealing

Relatively little research has been done to demonstrate the reductions in silage losses and spoilage due to using improved sealing technologies in SSA. One of the few studies on the subject reported that oxygen barrier films have gained recognition to reduce silage top layer losses in commercial silos in South Africa (Ndleleni et al., 2020). However, such films are unaffordable for most other farming systems in SSA. Consequently, most farmers use single or multiple sheets of standard gauge polythene sheets to line pit and other silos to reduce spoilage and losses. To protect silage from rainwater seepage, heavier gauge polythene sheets are used. Nevertheless, DM and quality losses are relatively high due to improper sealing. In Zimbabwe, bagged maize silages had significantly lower pH and higher lactic acid content compared to bunker maize silage (Mugweni et al., 2000). In general, more attention needs to be paid to improving silo sealing and silage storage across SSA.

8.3 | Improving crop residue quality

The nutritional value of crop residues can be maintained or enhanced using various interventions including (a) physical treatment of crop residues such as chopping, pelleting, and densification; (b) chemical treatment with acids and alkalis; and (c) biological treatment with select micro-organisms or their products. Effects of various forage and crop residue preservation methods on forage quality and animal performance measures are also summarized in (Supplemental Table S3).

Reducing particle size of crop residues and forages usually improves feed intake (Osafo et al., 1997), which often leads to improved livestock performance as compared to livestock fed with coarser crop residues (Fernandez et al., 2004). Physical forage processing involves manual labor in many parts of SSA but locally made forage choppers are increasingly becoming available and some have been more widely adopted when adapted for women (Fischer et al., 2017, 2018). Crop residue quality can also be preserved by densification, which improves handling, management, and storage of crop residues and facilitates mixing with other additives (Walli et al., 2012). Densified crop residues are molded into blocks and pellets augmented with important nutrients like minerals, protein, and readily available carbohydrates. However, densification relies on electric or gas-powered equipment, which has been inaccessible to many smallholder farmers but cheaper, locally made prototypes (Gonzalez-Valadez et al., 2008) are increasingly used by feed cooperative unions in SSA.

Urea treatment is probably the most widely promoted forage preservation and crop residue nutritive value enhancement method due to its efficacy at increasing the nitrogen concentration and DM digestibility, as well as the relatively low hazard levels and costs relative to more caustic alkalis or acids (Sarnklong et al., 2010; Schiere et al., 1993). Due to improvements in crop residue nutritive value, urea treatment increases intake, digestibility, and body weight gain of ruminants (Gashu et al., 2014; Mattoni et al., 2007; Wanapat et al., 2009). Yet, it is still not widely used in SSA. For example, feeding rice husks treated with 1.5 or 2.5% urea to Yankasa sheep in Nigeria increased feed intake, average daily gain and feed conversion efficiency relative to those fed diets treated with 0 or 1% of urea (Alabi et al., 2013). However, the adoption of chemical treatment of crop residues by smallholder farmers is constrained by resource, knowledge, and skill limitations (Balehegn et al., 2020) as well as unavailability and hazards involved for more potent chemicals like acids and alkalis.

Some studies in Ethiopia reported that treating straw using undisclosed "effective microbes" and ammonia (Alemu et al, 2020), or effective microbes alone (Mulugeta, 2015) increased the nutritive value, suggesting their relevance for use by smallholders. Applying *Pleurotus* spp. mushrooms also increased CP concentration of maize stover and decreased lignin concentration of millet stover (Ntokome, 2019). More research is needed on effective and affordable biological treatments for improving silage preservation and enhancing crop residue quality.

9 | REASONS FOR POOR ADOPTION OF FORAGE CONSERVATION PRACTICES

Unlike silage making, which is almost exclusively practiced by commercial urban and peri-urban dairy farmers (Maleko, Msalya, et al., 2018), hay making is traditionally practiced across most of SSA. The main challenge with hay making is low quality and shelf life of hay due to limited understanding of best practices for hay making (Feyissa et al., 2013). Common reasons for the low level of adoption of forage conservation among smallholder producers in SSA include limited awareness of the value of proper forage conservation and limited knowledge and skills to conserve the forages properly, particularly as silage (e.g., Njarui et al., 2011; Tesfay et al., 2016). Additional reasons include limited access to inputs such as machinery for precision chopping and baling, appropriate silos, land for forage production, and lack of conducive climatic conditions (Muinga et al., 2015). Further reasons for poor adoption of forage conservation technologies are limited labor availability, financial constraints, and poor access to markets for the conserved forages (Kabirizi et al., 2004). Other problems include the general lack of conservable forage that is a result of lack of breeding programs that focus on optimal forages for livestock (rather they focus on dual-purpose forages), and lack of participation of farmers when improved forage research is conducted, coupled with lack of proper extension support.

Generally, low adoption of forage conservation practices is caused by a variety of interrelated causes, some of which are shown in Supplemental Table S3. It is difficult to rank the main causes because the studies in Supplemental Table S3 identified various causes of low adoption of forage conservation. The main limiting factors, according to reviewed studies are limited knowledge and skills (mentioned in five studies), followed by lack of proper machinery and tools for forage conservation (mentioned by three studies), and lack of resources for constructing silos (storage structures) (mentioned by three studies) (Supplemental Table S3).

9.1 | Limited knowledge and skills

Though widely produced, the quality of hay in most of SSA is moderate to poor due to limited knowledge and skills about optimizing hay production, storage, and quality. The way hay is prepared, stored, and utilized causes loss in the form of spoilage, waste, and leaching of nutrients. Quality of hay is also usually below optimum with natural pasture hay having average CP values of 6.6% and neutral detergent fiber 73.8% (Suttie, 2000). As a result, technical knowledge, and skills to identify the right stage of harvest and optimal storage conditions are recommended (Suttie, 2000).

Silage making is a very knowledge intensive practice and limited knowledge and skills for making silage is one of the frequently mentioned reasons for low or no adoption of silage among many surveyed smallholder farmers (Supplemental Table S3). In the coastal lowlands of Kenya, the main reasons listed by surveyed farmers were lack of skills and knowledge (63%), lack of materials (13.7%), and high cost (10.1%) (Muinga et al., 2015). Limited knowledge has also been identified as a reason for low adoption levels of silage making in Zimbabwe (Mugabe et al., 2016) and among agro-pastoralists in Kiruhura district of Uganda (Robert et al., 2020). In a survey of 60 farmers in Uganda, lack of technical knowhow accounted for (53.3%) of the causes of nonadoption of silage making by smallholder farmers in Kkingo, Kabonera, Mukungwe, and Bukulula subcounties (Teklehaimanot, 2014). Of 227 farmers surveyed in three districts in coastal Kenya, out of those who did not adopt silage making, 11% mentioned lack of skills and knowledge as their main reason (Mwamuye et al., 2013).

9.2 | Lack of proper, long-term, sustained extension services

Limitations in knowledge and understanding of hay and silage making are mainly due to lack of proper long-term sustained extension support. Livestock extension systems in many SSA countries are constrained by lack of relevant technology; failure by research and extension to involve clientele in problem definition and solving; lack of incentives and resources for extension agents; and weak linkages between extension, research, and farmers (Davis, 2008). The latter is exacerbated by location of extension and research in agriculture and livestock and education ministries, respectively, which creates silos with different priorities, constrained funding, and limited opportunities for crosstalk between extension and research scientists. Although many researchers have realized the importance of conducting on-farm agronomic and animal trials, they are typically short term in nature and are terminated once funding ends. Consequently, no sustained extension support is provided, and adoption is very limited or absent. The problem is compounded by the fact that support of extension or research is very low or nonexistent. These factors reveal the need for strengthening long-term extension support for farmers and fostering dialogue among private sector, researchers, extensionists, and farmers.

9.3 | Lack of or limited involvement of farmers in research and development

Given that forage conservation, especially silage making, is an alien practice to many smallholder farmers in SSA, development of proper technology for chopping, compaction, silos, and additives requires an understanding of local situations, which in turn necessitates the participation of farmers in all phases of research and development. Unfortunately, most agricultural research in Africa is donor driven with limited or superficial involvement of farmers. For instance, a forage chopper developed in Tanzania without consultation with local farmers and through understanding of the local labor situation was rejected (Fischer et al., 2017, 2018).

9.4 | Negative attitudes towards forage conservation technologies

No studies were found from SSA on attitudes about forage conservation and how they limit adoption, indicating that this is an important area for future research. Studies elsewhere have demonstrated that farmers' socio-psychological attitude towards' forage preservation technologies such as silage making, are important in determining the level of adoption (García et al., 2021).

9.5 | Limited understanding of the profitability of forage conservation, especially silage making

Silage making can be profitable in SSA. For instance, a study in Uganda estimated a benefit/cost ratio of 5.5 and 2.7 for silage and hay, respectively (Ntakyo et al., 2020). However, studies such as the latter from SSA on the profitability of silage making are very few, such that most smallholder farmers do not realize that silage making can be profitable. Profit margins from the practice, as compared to feeding fresh green forage seem to increase with the amount of forage ensiled (Wilkinson et al., 2003). Therefore, silage making is usually practiced or adopted by larger commercial farms, as compared to small-scale subsistence farms (Prospero-Bernal et al., 2017).

To address this challenge, silage making by feed unions, cooperatives, entrepreneurs should be encouraged rather than by smallholders. This will overcome the challenges smallholders face with providing sufficient resources like funds, time, and labor for silage making. Adoption of best management practices to ensure the silage is well made, accessible, and affordable and marketed to close areas will also be crucial to success, while providing affordable, accessible silage in manageable sizes. For example, a government, farmer, industry, financial and extension integrated approach for introduction of silage making in the semi-arid and hilly region of Loess Plateau, China, increased household income by 28.6% between 2010 and 2017 and increased meat production by 48.3% between 2013 and 2018 (Gansu Economic Daily, 2018). The use of low-cost inputs can also make silage making profitable. For instance, a modelling study in Kenya on the use of small bag silo demonstrated that farmers can double revenue per cow by making silage using small bags instead of directly feeding napier grass (Methu et al., 2021).

9.6 | Lack of financial and other resources

Though potentially profitable, hay and silage making requires considerable initial investment for labor, harvesting, baling, chopping, and compaction machinery, silos, additives etc. This high initial investment contributes to the limited adoption of silage making among smallholders, who usually find it difficult to access these resources. In central Uganda, approximately 57% of surveyed farmers indicated that the high cost of inputs and labor for construction of silos and, chopping and compaction were the main reasons why they did not conserve forage as silage; in addition, 92% did not have adequate land for forage production (Kabirizi et al., 2004). A survey in Zimbabwe identified that main reasons for limited adoption of silage included unavailability of forage choppers, lack of requisite resources, and inadequate knowledge (Mugabe et al., 2016). Similarly, in the Kiruhura district in Uganda, limitations in labor and silage-making equipment restricted silage adoption by smallholders (Robert et al., 2020). In a survey of 60 randomly selected farmers in Uganda, main factors that impeded the adoption of silage making included lack of technical know-how (53.3%), high input costs (26.7%), lack of storage space (6.7%), lack of interest (6.7%), and lack of adequate land (1.7%). These factors highlight the importance of provision of incentives like credit schemes or subsidies that will increase the affordability of silage making.

In addition to limiting silage adoption, the high cost and unaffordability of silage equipment results in poor-to-moderate quality silage because of challenges with controlling factors that affect silage quality like forage moisture concentration at ensiling, chop length, stubble height, time spent filling the silo, packing density, silo design, and rate of feeding out the silage. Chop length is particularly critical when using crop residues or mature grasses as longer chop lengths impede compaction, thus predisposing the silage to spoilage and reduce feed intake. Manual chopping crop residues to shorter lengths is common and beneficial but tedious, time-consuming, and less effective for proper compaction relative to precision chopping.

9.7 | Limited supply of conservable forage

Limited supply of conservable forage is also a reason for low adoption of hay and silage making in Africa. In the semi-arid regions, 33–46% of surveyed farmers indicated that they did not make hay because they lacked adequate forages, though lack of technical skills (59.1%) and high investment requirement (13.4%) were also mentioned (Njarui et al., 2011). In three districts in coastal Kenya, 77% of farmers who did not practice silage making mentioned limited availability of forage as a reason (Mwamuye et al., 2013).

The reasons for limited supply of conservable forage are complex, but most have to do with lower productivity potential of native range and pasturelands in SSA and limited adoption of improved forage production technologies such as improved forages, pastureland improvement technologies, and a disproportionate focus on food crops compared with feed crops (Balehegn et al., 2020).

9.8 | Systemic limitations with the production system, land tenure, and market access

The extent to which conserved forages are used is highly dependent on the production system and livestock species (Mapiye et al., 2011; Scholtz et al., 2009). For instance, apart from commercial farming systems, conservation of forages for ruminant feeding was very uncommon in Botswana because many smallholder farmers relied primarily on natural pastures/rangelands even when they supplied insufficient nutrients and biomass to optimize livestock production (Maphane & Mutshewa, 1999). However, the demand for forage to bridge the dry season feed gap, which causes loss of body condition and in some cases death of the animal, is encouraging farmers in the arable zones of Botswana to harvest, chop, and sell cereal crop residues to livestock farmers. Consequently, planted forages and forage conservation are becoming more common in Botswana (Maphane & Mutshewa, 1999). Similar trends are evident in other SSA countries.

Land tenure is also an important determinant of adoption of forage conservation practices. Forage conservation practices differ with the type of land tenure under which livestock production is practiced (Adams et al., 2003; Palmer & Ainslie, 2006). Under communal/subsistence or emerging farming systems (e.g., in eastern and southern Africa), livestock are primarily reared extensively on the natural veld or rangelands, and seldom are forages planted in these communal areas to supplement dry season feed shortages. However, even under these production systems, farmers purchase preserved forages to feed their livestock throughout the periods of feed shortages (Müller et al., 2019; Palmer & Ainslie, 2006; Samuels et al., 2016). In the intensive or commercial livestock production systems, reliance on planted forages as well as conserved forages are greater, particularly in the dairy and beef industries, for which the conserved forages contribute substantially to the diets of these livestock (Muller, 2017).

The absence of forage quality regulations in SSA (Dione et al., 2015), and the absence of quality-price relationships (e.g., Ayantunde, 2020; Blümmel, 2019; Jarial et al., 2017), make commercialization of feeds and adoption of improved forage preservation technologies challenging, as there is currently no financial incentive for preserving feed quality.

9.9 | Gender-related constraints

Another reason for poor forage conservation adoption is the unaffordability or inaccessibility of the technology to women, who are key to improved agricultural production in many parts of SSA. Unfortunately, women's roles are often mainly confined to the collection and feeding of forages, activities that do not require much technical knowhow (Balehey, et al, 2018). For instance, except under the supervision of gender-promoting activities by Non-Governmental Organizations, women are not directly involved in ensiling in northern Ghana, rather they are involved in the collection, drying, and sale of forages (Konlan et al., 2018).

10 | RECOMMENDATIONS FOR IMPROVING ADOPTION OF FORAGE CONSERVATION IN AFRICA

To address the problem of lack of knowledge and skills of smallholder farmers on forage quality and preservation, improving awareness of the importance of increasing forage quality and benefits, particularly financial, of forage conservation is necessary. Most smallholder farmers in SSA do not have a proper understanding about forage quality and how it can be improved, nor do they know about how silage can bridge the dry season feed gap or improve animal performance. Though farmers assess forage quality visually, it is mostly subjective and hence inadequate for proper quality assessments. Our current research in Ethiopia and Burkina Faso has shown that there is no relationship between forage prices and qualities. So visual assessment, occurs in some but not other smallholder settings in SSA, and even where it does, it is inadequate to truly assess quality of forage. Addressing this problem requires sustained and effective agricultural extension support to raise awareness about the benefits and need to conserve forages, especially silage making. Visual assessment occurs in some but not other smallholder settings in SSA, and even where it does, it is inadequate to truly assess quality of forage. Research and extension are needed to demonstrate the animal performance and profitability gains that can accrue from feeding high quality conserved forages. Such studies should be planned and implemented on farms with market-oriented farmers, including women and youth. This should target farmers who are willing to set aside fertile land, even cropland for producing the improved forages. It is important to develop affordable mechanization such as small-sized silage bags, hay balers, simple but appropriate and effective machinery for harvesting, adoption of best management practices including proper chopping, additive use when needed, silo design, proper packing, sealing, and feed out. Emphasis should also be on limiting the distance of transport of the silage due to the high-water content. In places where guidelines for optimal silage or crop residue preservation are unavailable, research should focus on developing such guidelines and then sustained extension support is needed for dissemination and adoption of the guidelines. Hay making is already widespread among farmers in SSA, so the focus needs to be on increasing quality by building capacity to foster adoption of improved harvesting and storage methods that reduce nutrient losses by leaching and handling, timely harvesting to optimize quality, and incorporation of legumes to increase quality and soil fertility (Feyissa et al., 2013). Efforts should also target raising awareness about the importance of forage quality for optimizing livestock productivity and profitability. These should include developing forage quality indices, making them the basis of forage pricing, increasing analytical capacity to assess forage quality, for instance with mobile near-infrared spectroscopy (NIRS) systems, incentivizing adoption of best management practices such as by initiating silage and hay competitions among farmers, and subsidizing forage quality analysis.

To address the lack of long-term, sustained, and proper extension support, extension services should aim to educate producers on the importance, benefits, and profitability of increasing forage conservation. Hands-on trainings to farmers, on demonstration farms where forage conservation can improve the confidence of farmers and encourage participation. Extension officials should target cooperatives as implementers of forage conservation to ensure sufficient resources are available. Farmer-to-farmer training and extension approaches are specifically important in encouraging learning and ultimately adoption of technologies (Nakano et al., 2018).

To ensure that farmers' priorities, potential challenges, and limitations are taken into consideration in research for developing adoptable forage conservation technologies or strategies, proper participation of farmers in all phases of research and development must be achieved. The FEAST (the Feed Analysis Tool) (https://www.ilri.org/download-g-feast) developed by the International Livestock Research Institute is an important feed-focused tool that helps identify local farmer's priorities, challenges, and potentials. Other forms of participatory research in the livestock sector (Conroy, 2005) provide potential approaches that can be used to include farmers' opinions in research and development.

To address the limited understanding of the profitability of forage conservation, or the interventions required to assess the profitably of forage conservation, on-farm studies should be undertaken that examine if and how much additional productivity and income is generated when quality conserved forages are fed instead of the current normal practices. If such studies validate the profitability of silage and hay making as in previous studies (Methu et al., 2021), it is vital to target market-oriented farmers or farmer cooperatives who specialize in forage conservation at larger scales and sell it to

FIGURE 3 Some small silo options for smallholder farmers in Ethiopia (Photo: Dr. Akililu Mekasha, Ethiopia)

smallholder farmers who would not be able to profitably produce it at the farm level. It is important to ensure that such farmers and cooperatives have access to the best markets for their forages and livestock or forage and livestock products. In central Uganda, greater adoption of silage making in Kingo subcounty (43%) compared with Bukulula subcounty (3%) was associated with greater access to a secured market for milk from silage-fed cows (Teklehaimanot, 2014). Such studies are critically needed due to the paucity of studies assessing the profitability of forage conservation to smallholder and emerging and commercial farmers in SSA, particularly because of the high initial investments required (Ntakyo et al., 2020).

To tackle the challenge of high cost and unaffordability of forage conservation equipment, locally made and sourced appropriate machinery for mowing, baling, compressing and packing forage into hay and silage, should be developed as affordable alternatives to the conventional and expensive imported machines often promoted for processing or preserving forages. Building capacity of farmers about locally available additives and storage options (Figure 3) have increased the affordability and viability of forage conservation. For instance, small plastic bag silos have proven effective in various instances (Reiber et al., 2009). An important approach to foster forage conservation adoption is to rely on cooperatives and the private sector, particularly women and youth entrepreneurs, to produce and supply affordable, high-quality hay or silage to smallholders. This addresses the unaffordability and inaccessibility problems, while creating jobs and providing quality forage. However, financial and policy incentives are needed to provide the enabling environment that will encourage such forage businesses.

To increase supply of conservable forage, increasing technical knowledge is critically needed on which improved forages to produce and how to optimize their production and conservation. These efforts should include on-farm agronomy and livestock feeding experiments designed and conducted in a participatory manner with farmer cooperatives and individual farmers. This will allow improvements in livestock productivity achievable from growing and feeding improved high-quality forages to be demonstrated to market-oriented farmers and featured prominently at forage field days.

To address systemic limitations, there is a need for solving organizational bottlenecks to improve forage conservation adoption. This is because even when pertinent feed improvement and conservation technologies are accessible, adoption is limited by organizational issues. The forage value chain is generally underdeveloped (Ayantunde et al., 2014). Therefore, improvement of the forage value chain by bringing together actors, building their capacity, addressing their problems, and promoting dialogue among them are needed as well as strengthening markets and institutions, and developing forage associations (Lugusa et al., 2016). The need to strengthen fodder markets and access to them by forage producers is particularly important. It will in turn require further forage production specialization, development of forage quality indices to inform forage pricing, and enforcing regulations and quality standards.

Improving resilience of smallholder farmers to droughts and other shocks: Strategies that increase resilience of farmers or farms can facilitate forage conservation adoption. For instance, adoption of hay in the Karamoja region of northern Uganda, where pastoralism is dominant, increased from 1.5 to 16% in a survey of 305 households, when information on drought early-warning systems was provided (Akwango et al., 2016). Provision of other resilience-enhancing interventions is likely to increase adoption, particularly when bundled. For instance, coupling of small-scale irrigation technologies with sustained access to seeds and extension support for growing drought-tolerant, disease-resistant, high yield, and quality locally improved forages, is more likely to increase adoption than the individual measures.

To address gender-related constraints to forage production and conservation, there is a need for women and youth focused interventions. Women and youth groups should be encouraged to engage in providing and selling conserved forages and providing paid forage conservation services to smallholder farmers. Such groups should be the target of extension efforts and should participate in research trials demonstrating the importance of forage conservation. Their capacity should be built in forage production and conservation as well as pertinent aspects of ruminant production to ensure they understand and can promote their products properly to farmers. Such groups should be linked with farmer cooperatives and dairy farmers, who would be the main purchasers of the conserved forages (Kilelu et al., 2021).

To address the lack of knowledge about optimizing feed quality, development of location appropriate feeding standards or forage quality indices is needed, and these should inform forage pricing. This needs to achieve through concerted collaboration among private sector representatives, researchers, and agricultural extension providers. If properly done, the financial incentive from higher quality forage will lead to reductions in spoilage and losses, and increases in animal performance, and profitability.

To address the low availability of forage-testing facilities, focus should be on validated mobile NIRS systems, which have been proven to be far cheaper but just as precise for estimating forage quality (Prasad et al., 2019). This is necessary to overcome the dysfunctional state of many laboratories in SSA due to reliance on inaccessible reagents and equipment. To ensure continuity of the service, providers of NIRS services should be part of networks or communities of practice that include one or more advanced NIRS labs to ensure regular training updates as well as timely updates for calibration and validation equations. This could lead to feeding balanced rations, greater animal productivity, less waste, less greenhouse gas emissions, and proper labelling of feeds and forages, which will drive greater adoption of conserved forages.

11 | CONCLUSION

Forage conservation either as silage or hay is perhaps the greatest opportunity to bridge the feed gap due to the seasonal variability in feed quality and availability in SSA. It is also fundamental to address the hotspots of herder–farmer conflict in many parts of the continent, as well as desertification, bush encroachment, and reduction in grazing lands. While forage conservation is increasingly a critical component of commercial livestock production systems, the adoption of silage making by smallholder farmers who produce most of the livestock on the continent remains very low. This is due to resource, knowledge, labor, and skill limitations as well as gender constraints, systemic issues, and lack of sufficient land or conservable forage. Hay making is practiced all over SSA, but the quality is often low, as is the case for silage and crop residues. In addition to suboptimal management practices, the low quality is partly due to widespread feeding of native forages, particularly stovers and straws. To address these problems, major investments to increase the awareness about the need, benefits, and best strategies of growing and conserving improved forages are needed across the continent. A paradigm shift in the objective of livestock production from one that sustains large heads of poor productivity herds to a smaller number of well-fed and high productivity animals is needed. This requires a move away from feeding unimproved crop residues, which are typically poor in quality. Rather the focus should be on feeding balanced rations containing upgraded crop residues with improved harvested or conserved forages and other ingredients that can sustainably optimize livestock productivity and profitability. This requires on-farm studies with market-oriented farmers, and cooperatives that specialize in forage conservation, to demonstrate the profitability of forage conservation and proper feeding with well conserved forages instead of crop residues or native forages. This must be complemented by sustained extension support that provides technical knowledge to optimize forage production, conservation, and quality. Forage-breeding programs that currently focus on dual-purpose legumes and cereals for food and feed consumption should also focus on developing high yield and quality forages for which the whole plant will be fed to optimize livestock productivity by progressive farmers. Whole crop cereal silage could increase the overall family income beyond what they get from selling the grain alone. Research is needed to validate this assertion, which has been proven elsewhere (Gansu Economic Daily, 2018). While most farmers will need to continue focusing on dual-purpose cereal varieties in the near future, there is a critical need to develop forage lines to improve livestock productivity on farms that have the resources to do so. Such farms are already focused on making a profit not food security. In Ethiopia, for example, farmers who already recognized the benefits of forage are converting farmlands of cash crops such as coffee to grow forage (Getnet et al., 2016; Gonfa, 2015). In addition, appropriate, accessible, and affordable equipment is a fundamental need. Emerging appropriate and affordable technologies are beginning to address this problem, including locally developed equipment such as choppers, balers, and compressors for making densified feed blocks, various silo options, silage additives, etc. However, scaling of such technologies across countries is still critically needed. In addition, establishment of feeding standards and forage testing capacity, such as through NIR lab consortia, is key to increasing demand for quality forages, as well as ensuring quality-based pricing, labelling, and feed formulation. A second paradigm shift is required to include smallholders as buyers rather than makers of conserved forages because many lack time and other resources to making high quality conserved forage. Rather, the focus should be to incentivize establishment of forage-conservation and allied businesses and cooperatives that produce quality hays and silages for smallholders, particularly among women and youth.

It is important to note that the adoption of feed technologies requires a different approach from the classic agricultural transfer approaches. Most adoption of feed technologies are driven by financial incentives; therefore, feed conservation practices are probably going to be more successful in areas where there is an enabling environment, particularly a good market for the feeds, animals, and livestock products (Balehegn et al., 2020). Due to the threat of climate change, and the predicted effects it will have on forage production in the future, the formation of a SSA Feed Network is recommended to ensure continued research and extension on best practices to improve livestock production using high quality and high-yielding conserved forages that are adapted to the agro-ecological conditions of the specific regions.

AUTHOR CONTRIBUTIONS

Mulubrhan Balehegn: Conceptualization; Data curation; Investigation; Methodology; Project administration; Resources; Writing-original draft; Writing-review & editing. Augustine Ayantunde: Conceptualization; Data curation; Formal analysis; Writing-original draft; Writing-review & editing. Tunde Amole: Conceptualization; Data curation; Methodology; Writing-original draft. Donald Njarui: Data curation; Methodology; Writing-original draft; Writing-review & editing. Bhutikini D. Nkosi: Conceptualization; Data curation; Writing-original draft; Writing-review & editing. Francuois L. Müller: Data curation; Methodology; Writing-original draft; Writing-review & editing. Robin Meeske: Conceptualization; Data curation; Writing-original draft; Writing-review & editing. Tlou J. Tjelele: Data curation; Writing-original draft; Writing-review & editing. Ingrid M. Malebana: Writing-original draft; Writing-review & editing. Othusitse R. Madibela: Data curation; Writing-original draft; Writing-review & editing. Wame S. Boitumelo: Data curation; Writing-original draft; Writing-review & editing. Ben Lukuyu: Conceptualization; Data curation; Writing-original draft; Writing-review & editing. Addah Weseh: Data curation; Formal analysis; Writing-original draft; Writing-review & editing. Elias Minani: Data curation; Writing-original draft; Writing-review & editing. Adegbola T. Adesogan: Conceptualization; Data curation; Writing-original draft; Writing-review & editing.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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