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SUGARCANE BYPRODUCTS AS FEED RESOURCES AND PERFORMANCE OF SHEEP FED ON SUGARCANE TOPS BASED DIETS

PhD Dissertation

By

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Addis Ababa University, College of Veterinary Medicine and Agriculture

Department of Animal Production Studies

PhD Program in Animal Production

April, 2019

Bishoftu, Ethiopia

SUGARCANE BYPRODUCTS AS FEED RESOURCES AND PERFORMANCE OF SHEEP FED ON SUGARCANE TOPS BASED DIETS

A Dissertation Submitted to College of Veterinary Medicine and Agriculture of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Animal Production

By

Getahun Kebede Yadete

April, 2019

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As members of the Examining Board of the final PhD open defense, we certify that we have read and evaluated the dissertation prepared by Getahun Kebede, entitled: "**Sugarcane Byproducts as Feed Resources and Performance of Sheep Fed on Sugarcane Tops Based Diets"**, and recommend that it be accepted as fulfilling the dissertation requirement for the degree of Philosophy in Animal Production.

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STATEMENT OF AUTHOR

First, I declare that this dissertation is my *bonafide* work and that all sources of material used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for a PhD degree at Addis Ababa University, College of Veterinary Medicine and Agriculture and is deposited at the University/College library to be made available to borrowers under rules of the Library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

The author was born in 1972 in Tiyo District of Arsi Zone of Oromia Region. He attended elementary and junior secondary education in the then Fite and Chebi Schools from 1980-1986, and high school education in Asella Comprehensive Secondary School from 1987 to 1990. He was enrolled to the then Awassa College of Agriculture and received Diploma in Animal Production and Rangeland Management in July 1992. After graduation, he was employed in the then Ministry of Coffee and Tea Development and worked in Yirga Chefe district of Southern Nation, Nationality and Peoples Regional State of Ethiopia from April 1994 to February 1998. He joined the same college in 1998 and received a BSc degree in Animal Production and Rangeland Management in July 2000. Again, he enrolled to Haramaya University and received MSc in Animal Production in June 2006.

He served in different positions and responsibilities during his career years, which include positions of livestock development expert and a team leader at the district level for four years, forage technology dissemination and training smallholder farmers on improved cattle fattening, poultry production, beekeeping and fish production in the pond. Since March 2001, he has been an employee of the Ethiopian Institute of Agricultural Research as a staff of the Livestock Research Division. His research works are mainly on ruminant nutrition during which he published 17 research publications (nine journal articles, five papers in conference proceedings and three research reports). He served as a leader of the Small Ruminant Research Unit at Debre Zeit Agricultural Research Center. Also, he won a research and development grant from United Nations University in 2012 and implemented it successfully.

He participated in short-term trainings and researches abroad, which include International Diploma in Animal Feed, Netherlands, March 29, 2004 - 25 June, 2004; Cattle Management for meat and milk production using regional Resource, Japan, Sept. 29, 2014 - Nov. 21, 2014; and Research Study on Grazing Management, United Kingdom, May 15, 2008 - November 15, 2008. The author is married and a father of two sons and a daughter.

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I am highly indebted to Ethiopian Institute of Agricultural Research, Debre Zeit Research Center, for giving me the study opportunity and research funds. My appreciation and gratitude are also to the staff of Livestock Research Department of Debre Zeit Research Center, colleagues/friends and laboratory technicians for their all-rounded supports and encouragement while implementing the study. My special thanks goes to Dr. Diriba Geleti, Dr Abebe Atilaw, Dr Getnet Aseffa, Dr. Fekede Feyissa, Dr. Solomon Chaniyalew and Dr Tamirat Degefa for their unreserved contribution in facilitating the working environment (financial support, research inputs, transport, etc) and/or encouragement. I would like to thank Holleta Agricultural Research Center for providing me natural pasture hay used for animal feeding trial.

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Finally, my grateful thanks is to my spouse Sr. Alemitu Tilahun, my sisters and brother- Demissie Kebede and *Ato* Gobe Ismo for their valuable contribution towards my success and in handling our father *Ato* Kebede Yadete.

DEDICATION

This dissertation manuscript is dedicated to my late mother *Woizero* Mulunesh Besha and brother Tesfaye Kebede who are never forgotten, my father *Ato* Kebede Yadete and to my sons- Milkias Getahun and Biniam Getahun, and daughter Saron Getahun.

LIST OF ABBREVIATIONS

AACCSA	Addis Ababa Chamber of Commerce and Sectoral Associations
AOAC	Association of Official Analytical Chemists
AFIA	Australian Fodder Industry Association
ADF	Acid detergent fiber
ADG	Average daily gain
ADL	Acid detergent lignin
BAPH	Bureau of Animal Production and Health
CSA	Central Statistical Agency
CP	Crude protein
CCW	Cold carcass weight
DM	Dry matter
DOMD	Digestible organic matter in dry matter
EE	Ether extract
EBW	Empty body weight
GDP	Gross domestic product
HH(s)	Household(s)
HCW	Hot carcass weight
IVDMD	*In vitro* dry matter digestibility
IVOMD	*In vitro* organic matter digestibility
ILCA	International Livestock Centre for Africa
LAB	Lactic acid bacteria
ME	Metabolizable energy
MJ	Mega joule
MRR	Marginal rate of return
NDF	Neutral detergent fiber
NFC	Non-fiber carbohydrate
NH_3-N	Ammonia nitrogen
NI	Net income
NRC	National research council

SAS	Statistical Analysis System
SBW	Slaughter body weight
SCT	Sugarcane tops
SPSS	Statistical Package for Social Sciences
TDN	Total digestible nutrient
TLU	Tropical livestock unit
TR	Total return
TVC	Total variable cost
WSC	Water soluble carbohydrates

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ABSTRACT

Enhanced feed use of sugarcane byproducts is imperative to improve livestock productivity and reduce production cost in Ethiopia. Four successive studies were conducted. The production and utilization of sugarcane byproducts in Wonji-Shoa and Metehara Sugar Estates were assessed by interviewing farm households (n, 308) and collecting secondary data. Green and burnt sugarcane tops (SCT) (variety N-14) were conserved as silage and hay and evaluated for quality. The green and burnt SCT were ensiled with or without 4% molasses, 1% urea and 1% urea + 4% molasses in mini-silos for 45 days. In the hay experiment, the green and burnt SCT were dried (15% moisture) by applying three drying methods (shed and sun-drying of intact SCT and sun-drying of chopped SCT). An experiment was also conducted to evaluate performances of Arsi-Bale lambs consumed diets based on burnt SCT silage or hay, replacing natural pasture hay at 0, 33 and 67% (on dry matter (DM) basis) and concentrate supplementation (317 g DM/day). Farm households using SCT as feed were high (Wonji-Shoa-100%; Metehara- 100%), moderate for molasses (53; 0.9%) and negligible for bagasse (0; 1.8%). The total production volume (on wet bases) of sugarcane byproducts was in the order of bagasse>SCT>molasses and generally higher in Metehara than in Wonji-Shoa. Availability and feed use share of the burnt SCT surpassed green SCT, which coincided with the critical feed shortage period. The prices of the burnt and green SCT in Metehara (297.86 and 195.5 Birr/cart) were three-fold more than in Wonji-Shoa ($P<0.001$). Farmers preferred the burnt to green and thin- to thick-stem SCT varieties. Sugarcane tops were mainly preserved by sun-drying (Metehara-98.2%; Wonji-Shoa- 80.8%) and stored in open-air (91.8%; 85.9%). Limitations in the feed use of sugarcane byproducts included: low quality of SCT (91.2%), health risks such as mouth injury or toxicity associated with feeding SCT (16.2%) or molasses (74.7%) lack of labour/capital (11.7%), lack of transport

(26%), lack of molasses suppliers (85.1%) and lack of technical supports (89%). The best SCT silage physical properties were attained by ensiling alone or with 4% molasses. The pH of silages ranged 3.7-5.0, except in the green SCT ensiled with urea based additives (pH>5). Total DM loss (2.31%) and temperature (26˚C) were low (P<0.0319) in the green SCT ensiled with molasses alone. Urea addition increased (P<0.0001) silage crude protein (CP). The fiber fractions of burnt SCT silage were not affected (P>0.05) by the additives, while neutral detergent fiber (NDF) increased by 17.5% with urea inclusion and acid detergent fiber (ADF) decreased by 15.6% with molasses addition in green SCT silage. In vitro organic matter digestibility and metabolizable energy (ME) were peaked (P<0.0001) in the burnt SCT ensiled with 1% urea + 4% molasses. The lowest (P<0.0001) non-fiber carbohydrate (NFC) was observed in the green SCT ensiled with urea based additives. The chopped sun-dried SCT had the highest dehydration rate (20.3%/day) and dried in three days, while shed-dried intact SCT had the lowest drying rate (0.96%/day) taking more time to dry (green, 68; burnt, 60 days). The DM and CP contents were not affected (P>0.05) by the drying methods. The sun-dried chopped green and burnt SCT did not differ (P>0.05) in DM digestibility and ME content and had the highest (P<0.0001) ether extract (EE) and hemicelluloses. The DM intake of lambs was lower (P<0.05) at higher (67%) silage offer, but not affected by the SCT hay. The lowest (P<0.0001) intake of CP was at higher SCT hay offer, while for the fiber fractions at higher silage offer (P<0.05). Treatments did not vary (P>0.05) in DM digestibility, lambs' growth performances, feed conversion efficiency, carcass characteristics, and meat chemical composition and cooking loss. The overall average final body weight, total gain, daily gain (ADG) and feed conversion efficiency (FCE) were 27.21 kg, 7.85 kg, 87.22 g and 0.110, respectively. In conclusion, the provision of technical support to farmers on processing, conservation, feeding management and marketing and distribution of sugarcane byproducts is important. Conservation of SCT is more effective by chopping and sun-drying, and by ensiling alone or with 4% molasses in green SCT, and with 1% urea and 4% molasses solution in burnt SCT. Moreover, SCT silage or hay can replace up to 67% of natural pasture hay for yearling Arsi-Bale lambs at an economic benefit.

***Key words**: Sugarcane byproducts; sugarcane tops conservation; silage/hay; sheep; carcass; cost-benefit*

1. INTRODUCTION

Livestock farming is the part and parcel of the Ethiopian economy accounting for 17-25.3% of the national gross domestic product (GDP) and 39-49% of agricultural GDP (including the non-monetary values) and over 50% of household income (Shapiro *et al*., 2017). Livestock provides draught power and manure for crop production and are sources of food (milk, meat and egg) and industrial raw materials (hides, skin and wool). They contribute significantly to economic growth and poverty reduction. The livestock population of the country (based on sedentary areas) is estimated to be 59.5 million cattle, 30.70 million sheep, 30.20 million goats, 2.16 million horses, 0.41 million mules, 8.44 million donkeys, 1.21 million camels and 56.53 million poultry (CSA, 2017b). However, the livestock production system is largely traditional and characterized by low input-output, suffering from various challenges among which insufficient feeds and feeding systems are prominent.

According to CSA (2017b), the country is endowed with various feed resources having different feed use share, which encompassed natural pasture grazing (54.59%), crop residues (31.60%), hay (6.85%), agro-industrial byproducts (1.53%), improved feed (0.31%) and others like animal byproducts, vegetable and fruit wastes (5.11%). However, most of the feed resources are low in quality and quantity, adversely affecting livestock performances (Adugna, 2008, Shapiro *et al.*, 2017). The use of grain based concentrates for ruminant feeding is little practical due to competition with human food and monogastric animals and high cost of production. Besides, the introduction and adoption of improved forage crops into the farming system have been constrained by the lack of land and forage seeds (Adugna *et al*., 2012).

On-farm livestock feed insufficiency is aggravated by changes in land use patterns, frequent drought occurrence, increased feed cost and livestock population and limited use of feed technologies. The expansion of crop production has significantly reduced formerly known natural pasture lands in the highlands. Feed accounts for 75-80% of the total costs of livestock production in the country (Demisse, 2017) and it is critically deficient in the dry season. This, in turn, increases the market price and reduces the supply of quality products, which impairs competitiveness on markets.

In Ethiopia, feed production, its availability and requirement vary with the production system and agro-ecology. According to Shapiro *et al.* (2017), the annual national feed availability was estimated to be 145.2 and 81.3 million tonnes of DM in good and bad years (based on rainfall intensity), respectively. Positive feed balances (20.6 and 3.6 million tonne DM per year) were reported for agro-pastoral areas only in good and average years. Conversely, negative feed balances (21.5 and 48.7 million tonnes DM in average and bad years) were reported for the mixed crop-livestock systems, implying that most animals are fed below their DM requirement (2.5-3% body weight) (Shapiro *et al.,* 2017).

Feed deficit in quality and quantity has adverse effects on animal performances, levels of production and economic benefits. Undernourished farm animals respond little to production interventions (*e.g.,* artificial insemination and estrus synchronization) and are susceptible to diseases and parasites. Feed deficit also restricts feedlot animals' expression of genetic potential for growth, allowing them to take a longer time to finish. Feed remains the major challenge for most smallholder and commercial feedlots and dairy farms in the country, leading to withdrawal from the business and reduced stock size. It also limits the number of new farms coming into the business and increases the market price of products for consumers.

As a coping strategy to feed deficit, looking for alternate agricultural byproducts and improving their utilization through proper processing and conservation is imperative. In this regard, sugar industry byproducts (*e.g.,* sugarcane tops (SCT), molasses and bagasse) are potentially produced, but less exploited as livestock feed in the country. They are produced and available in the sugarcane harvesting season (October to June, each year), which coincides with the period of feed shortage. However, after sugarcane harvesting, most SCT are burnt in the field to ease farming practices and/or collected by local communities mainly for livestock feeding. According to the report of EMAPRM (2016), the production of SCT, bagasse and molasses in the country rise between 2016 and 2020, availing a total of 5703130, 39298730 and 5550925 tonnes, respectively. Moreover, Adugna *et al*. (2012) reported about 356,332 tonne DM SCT is produced annually in the country. Sugarcane tops represent 15-25% of the aerial plant biomass (Suttie, 2000), containing immature stems, leaves and sheaths, and are

potential forages for ruminants (Naseeven, 1988). Molasses and bagasse are generated in bulk during the sugar extraction process. In 2015 alone, about 150,278 tonnes of molasses was produced from Wonji-Shoa, Metehara and Fincha sugar factories (Ethiopian Sugar Corporation). Due to the emerging new Sugar Estates and the expansion of old ones, the present sugarcane production will increase manyfold, which in turn rises the availability of byproducts that when properly exploited (collected, processed and conserved) can bridge the gap in feed supply and reduce production cost.

On the other hand, a diverse indigenous sugarcane germplasms are produced on about 31,237 hectares of land owned by smallholder farmers in different parts of the country (CSA, 2017a), of which 52% of them are in southern Ethiopia (Esayas *et al*., 2016). They are produced primarily for income generation by selling the stalk on local markets for chewing purposes. In these areas, green SCT and leaves are available year-round and used as livestock feed, or sold to generate income (Adugna, 2008).

The nutritional quality of sugarcane tops has been documented, which varied with sugarcane cultivars and stage of harvesting (Sharma *et al.*, 2012). Sugarcane tops are deficient in protein, minerals and energy (Galina *et al.*, 2007), but are high in fiber. The energy value of SCT is about 7.0 MJ ME/kg DM (McKenzie, 2007). Moreover, they are palatable to ruminants and can be fed with protein supplements. Experimental sheep fed on diets containing green SCT (Galina *et al*., 2007), or its silages (Salinas-Chavira *et al*., 2013; Suliman *et al*., 2016) had maintained or increased their body weight.

Conserving the surplus sugarcane tops as silage and hay optimize their feed use particularly in lean periods. Sugarcane tops are rich in water-soluble carbohydrates (WSC) (155g/kg DM, Khanal *et al*., 1995; 82.5 g/kg DM, Chaudhry and Naseer, 2008), which is one of the desirable characteristics for successful ensiling. Studies have shown that the ensiling green SCT with or without additives improves its fermentation and nutritive value (Alemzadeh and Noroozy, 2006). Similarly, burnt sugarcane tops that are available in sugar industries after stalk harvesting can also be conserved as silage (Siqueira *et al*., 2009). The basic requirements to ensile sugar-rich

forages are a source of fermentable nitrogen for the growth of microorganisms and a buffering additive. Yeasts are undesirable organisms since they convert sugars to alcohol, which ends in wastage of dietary energy and DM loss of silage. Additives, which are the source of fermentable nitrogen (e.g., urea and ammonia) and carbohydrate (e.g. molasses) stimulate good fermentation, while others (e.g., lime and limestone) have a buffering effect and inhibit bad fermentation (MacDonald *et al*., 2010).

Despite the abundant availability of sugarcane byproducts (molasses, bagasse and SCT) in Sugar Estates of Ethiopia, they are less exploited as livestock feed, and farms in such areas are suffering from feed shortage as elsewhere in the country. Moreover, limited researches have been done on the production, availability, utilization and management (processing and conservation) of sugarcane byproducts in the country. In line with the development of sugar industries, the production volume of the byproducts is expected to rise many folds, calling for proper manipulation for their efficient feed use. Moreover, livestock feeding packages based on sugarcane byproducts need to be developed. Therefore, this study was initiated with the following objectives:

- To assess the production, feeding, processing and conservation practices of sugarcane byproducts in and around Metehara and Wonji-Shoa Sugar Estates;
- To evaluate the effect of ensiling SCT with or without additives (urea, molasses) on silage fermentative quality and nutritive value;
- To evaluate the effect of different drying methods on the rate of drying, nutrient composition and *in vitro* digestibility of SCT hay; and
- To evaluate the performances of yearling Arsi-Bale sheep fed diets based on burnt SCT hay and silage as a substitute for natural pasture hay.

2. LITERATURE REVIEW

2.1. Red Meat Production and Challenges in Ethiopia

Ethiopia is endowed with 51 indigenous ruminant livestock breeds (23 cattle, 14 sheep, 14 goats) (PSRC, 2017) and camel, which generates red meat representing about 96.3% of the total meat production (cattle- 79.98%, sheep- 9.78%, goat- 5.58, camel- 0.91%) (Shapiro *et al*., 2017). These animals are raised by pastoralists, high land smallholder farmers and commercial feedlots. Despite the presence of large livestock population and genetic resources, the country contributes about 0.2 % to the global meat production being ranked 55th in the world (AACCSA, 2015). The high contribution of ruminant livestock to domestic meat production is due to an increase in the number of animals slaughtered rather than by improved productivity *per se*.

The demand for meat is rising in the developing countries driven by an increase in the human population, urbanization and income of the people (Delgado *et al*., 1999). Per capita meat consumption in Ethiopia is about 9 kg, of which the red meat accounts for 94%. Unless intervention is made in Ethiopia, the current increase in the human population (2.9% per annum), urbanization (3.57% per annum) and income will lead to a deficit of 1.3 million tonnes meat in 2028 (Shapiro *et al*., 2017). Also, the volume of red meat exported from the country is very low considering the available potential and opportunities (high animal resource base, proximity to the markets and high demand for meat).

The primary challenge for red meat production in Ethiopia is the lack of affordable quality feed resulting from reduced grazing lands, unimproved forage production, underdeveloped feed marketing/distribution and inadequate extension support on improved grazing management and feed preservation. The type of feed resource available varies with agro-ecology and production systems (Solomon *et al*., 2017). Most red meat animals are slaughtered at no access to better quality feeds, which impairs their potential productivity. As a result, poorly fed animals take a long time to reach optimum slaughter weight and the meat produced by such animals could not satisfy the desired quality attributes (*e.g*, tenderness/juiciness) of importers, reducing

competitiveness on international markets. However, the Ethiopian government has a development goal of enhancing red meat production from indigenous ruminant livestock through improved husbandry practices. Meeting these goals requires the production of quality feeds and improved utilization of local feed resources as a key intervention area.

2.2. Feed Resources

In Ethiopian, livestock production relies on a variety of locally available feed resources that are classified as natural pasture, crop residues, stubble grazing, improved forages, agro-industrial byproducts such as flour mill byproducts, oilseed cakes, molasses, brewery and distillery byproducts and fruit and vegetable wastes (Adugna, 2008;Tegene *et al*., 2009). Of these feed resources, natural pasture grazing and crop residues are dominantly used for ruminant livestock production. Unlike many other countries, the use of compound feeds or grain based concentrate and mineral for ruminants is very limited because of their low supply and high production cost. Hence, the production and productivity of livestock are hampered by low availability and poor quality of existing feed resources.

2.2.1. Natural pasture and crop residues

Natural pasture with its wide range of species composition (grasses, legumes and herbs) provides more than 90% of the livestock feed in lowlands (Alemayehu, 2006). Some of the grasses comprising natural pasture are the genera *Andropogon, Digitaria, Panicum, Pennisetum* and *Trifolium* in northwestern Ethiopia (Yihalem *et al.*, 2006). In crop based farming, areas formerly covered by natural pasture have been sharply decreased due to the expansion of croplands derived by the increase in human population and urbanization. Recently, land used exclusively for grazing is ever diminishing sharing about 11.5% of agricultural landmass (CSA, 2017a). Even in most of the vast grazing lowlands, where crop production is less implemented, natural pasture productivity is sub-optimal due to land degradation, emanating mainly from poor grazing management and frequent drought occurrence. The productivity of natural pasture in Ethiopia ranges from 1 to 2 tonnes DM/ha on freely drained and relatively infertile soils and from 4 to 6.4 tonnes DM/ha on seasonally waterlogged

fertile lands (Adugna, 2007; Fekede *et al*., 2013). Generally, the contribution of natural pasture as feed for ruminants in the mixed crop-livestock systems has been decreasing being replaced by crop residues and aftermath grazing.

In the highlands of Ethiopia, natural pasture is often conserved as hay for use during dearth period. However, its nutritional quality is little above most cereal crop residues associated with poor management (lack of fertilizer application, improper stage of harvest, skill gap in hay making and poor storage condition). It is often harvested when the soluble nutrients greatly deplete (e.g., CP content falls below 5%), becoming inadequate even for maintenance requirements (Solomon *et al*., 2008). Fekede *et al.* (2014) reported a delay in natural pasture harvesting time from mid-October to late-November reduced hay CP, IVOMD and ME contents by 30.2, 17.8 and 17.8%, respectively, while the respective increase in NDF, ADF and ADL content was 13.8, 21.6 and 36%, indicating the nutritive value of natural pasture hay decreases with maturity (higher in growing (wet) season than dry season). Moreover, a 23.3% and 36.7% loss in CP content of natural pasture hay was observed after storing under the shed and in an open-air for eight months, respectively (Fekede, 2013).

Factors influencing the nutritive quality of natural pasture hay include its grass-legume proportion, leaf to stem ratio and stage of growth at harvest (Ensminger *et al.*, 1990). Besides, soil and climatic factors, poor conservation and storage condition do affect its quality. The low soluble nutrients contents of natural pasture have negative consequences on rumen fermentation, feed intake and digestibility and animal performances. Sheep fed natural pasture hay alone had poor performances (Fentie and Solomon, 2008).

The nutritive quality of natural pasture can be improved by applying improved management practices. According to Adane and Berhan (2007), the application of nitrogen (22.5 kg/ha) and phosphorus (25.9 kg/ha) fertilizers to natural pasture at growing stage improved CP from 6.8 to 11.8%, total ash from 12.3 to 22.5% and *in vitro* dry matter digestibility (IVDMD) from 67.8 to 79.7% at harvesting stage, while fiber fractions were not changed as compared to unfertilized natural pasture. The

same study also showed a significant reduction in IVDMD, CP, mineral, but an increase in fiber fractions with delay in harvesting times (30 to 120 days).

An enormous variety of food and cash crops have grown in the country, generating residues (straws, stovers and stubble grazing) that are important feed resources. Crop residues are available relatively at low cost compared to other feed resources, and reliance on it as animal feed is ever-increasing in line with the expansion of cropping. The types of available crop residues vary with agro-ecology and farming systems. Maize, sorghum, and millet crop residues are dominant in the mid and lowland agro-ecologies, while teff straw, wheat straw, barley straw and oat straw are dominant in mid to highland areas. Pulse crops are grown in different agro-ecologies and the principal residues are that generated from faba bean, field pea, lentil and chickpea. Some crop residues (e.g., teff straw, wheat/barley straw) are sold on local markets and generate income for farmers and traders (Mesfin *et al*., 2014).

Crop residues are bulky and low in nutritive quality, and if fed alone to an animal cannot support even the maintenance requirement. They are low in CP and dry matter digestibility, but are high in fiber components (cellulose, hemicelluloses and lignin). Strategies used to improve crop residues' nutritive value includes supplementing with protein and energy-rich feeds and physical and chemical treatments (*e.g.*, chopping, ensiling with Urea). However, the degree of their adoption by the farmer is low due to socio-economic factors. A survey conducted in the Tigray region showed that lack of capital, knowledge and skill, molasses and urea had influenced the adoption of straw urea-molasses treatment (Tesfay *et al*., 2016).

2.2.2. Concentrate feeds

2.2.2.1. Bran and wheat middling

Wheat bran is the major byproduct of wheat processing industries and is commonly used as supplemental feed to livestock in Ethiopia. It is relatively rich in protein (14-19% DM), total ash (4-7% DM), phosphorus (0.9-1.3% DM) and oil (3-5% DM), but low in calcium (0.07-0.2% DM) (Heuzé *et al*., 2015b). More of the protein, mineral, oil and fiber contents are contained in the bran than the grain alone or, whole grain. Its

metabolizable energy content was about 12 MJ/kg DM (Adugna, 2008). Wheat bran is fed to livestock often mixed with protein-rich feeds (oilseed cakes), salts and others, making the largest share of concentrate feed mix in the country. The other important byproducts derived from grain flour industries and mill houses are wheat middling (finer which may contain bran, endosperm and germ), wheat short, maize bran, rice bran and screenings). Wheat middling is similar to bran except that they have lower fiber and higher flour contents, so they are higher in digestible energy than bran. It has about 92% energy value of maize, but higher in protein content (Adugna, 2008).

2.2.2.2. Oilseed cakes

The byproducts from oilseeds in Ethiopia include *noug* seed (*Guizotia abyssinica*) cake, cottonseed (*Gossypium spp*.) cake, linseed (*Linum usitatissimum*) cake and rapeseed (*Brassica carinta*) cake or Ethiopian mustardseed cake, groundnut cake, sesame cake, peanut cake and safflower cake. These feed resources are produced mainly by large and small scale edible oil factories, which usually operate below their potential (<50%) due to inadequate supply of oilseeds that in turn influenced by its low production, high demand on the export market and partly by the importation of edible oils from abroad.

Oilseed cakes are rich sources of rumen degradable and by-pass protein and are well palatable to animals. For example, *noug* seed cake varies in the composition of protein (28 - 38%), fat (2.1 to 12.6%) and energy (2.37 Mcal ME/kg DM) depending on the oil extraction method employed (mechanical and solvent) (Adugna, 2008). Cottonseed cake is another potential protein supplement, containing 36-40% protein. However, it contains a toxic chemical- gossypol, which is harmful to young animals with immature rumen. Linseed cake is also a protein supplement containing nearly 30% CP, but has a laxative effect. It results in a shiny coat appearance of feedlot animals, which attracts buyers. However, the majority of oilseed cakes are low in essential amino acids (cystine, methionine and lysine) (Adugna, 2008).

2.2.3. Byproducts of the sugar industry

2.2.3.1. Molasses

Molasses is a byproduct of sugarcane (*Saccharum officcinarum*) available at sugar factories of Ethiopia. As a feed, it provides readily available sugar and phosphorus to the animal body. Molasses contains 20.6% water, 60.8% total sugar, 3.2% CP, 2.2% soluble gums, 8.2% ash and 5.0% free acids (Sindhu *et al*., 2002*)*. It is rich in energy, representing 67-70% energy value of maize, palatable to animals and lowers cost of livestock production. As a source of fermentable carbohydrate, molasses stimulates microbial growth in the rumen and favours fiber digestion. It is a basic ingredient in urea-molasses or feed block production that used as supplemental feed to growing calves and lactating cows. According to Verma (1997; as cited in Sindhu *et al.,* 2002) addition of 10 to 15% molasses increases the palatability of the concentrate mixture. Molasses is better used by diluting in the water at a ratio of 1:2 to 1:4-6 (molasses: water) and given together with dry forages or concentrates and properly supplemented with protein (Senthilkumar *et al*., 2016). In a study where molasses replaced 32.6% of 184.2g maize grain supplemented daily to Horro sheep, improved in body weight gain, carcass yield and economic benefits were noted (Jemal *et al*., 2004), indicating the potential of molasses to replace maize grain as an energy source in a ration for feedlot sheep.

2.2.3.2. Sugarcane tops

Sugarcane tops are forages available in the field after sugarcane stalk harvest in sugar industries and at smallholder sugarcane farms. The yield estimate is about 15-25% of plant biomass (Suttie, 2000), varying with variety, age at harvest, growing conditions and management practices (Nguyen *et al.,* 1996). Sugarcane tops comprise three parts: green leaves (blades), leaf sheath bundle and a variable amount of immature stem. They are palatable to animals and can be fed with concentrate or leguminous feeds. However, SCT is low in protein, digestibility and mineral. It can be converted into good quality silage or hay for feeding animals during the scarcity of fodder. Sugarcane tops with or without leaves have good feeding value and are readily accepted by ruminants either fresh or ensiled (Ortiz-Rubio *et al.,* 2007).

Sugarcane tops are poor in nutritive value. They have energy value of 6.9 MJ ME/kg DM, low in mineral content (total Ash: 9.6; Ca: 0.43; P: 0.15; Na: 0.05; K: 2.31) (Kevelenge *et al.*, 1983), and dry matter (54%) and crude protein (39%) digestibility. Rumen fermentation status of animals fed SCT was improved by supplementing with nitrogen and non-structural carbohydrate (Ortiz-Rubio *et al*., 2007; Gendley *et al*., 2009). Different blood groups of Friesian and Kanana calves fed total mixed ration containing SCT had higher ADG at higher (30%) than lower (20%) inclusion rate (Mahala *et al*. 2013b). Similarly, Salinas-Chavira *et al*. (2013) reported a decrease in feed DM intake with increased level (5 to 10%) of SCT silage in the diet of lambs, but body weight change and feed efficiency were not affected. A study conducted in Ethiopia also confirmed the importance of SCT (360 g DM/day) in the diet of Washera sheep, which resulted in improved performance and economic benefit (Anteneh, 2014).

2.2.3.3. Bagasse

Bagasse is a secondary byproduct of sugarcane extraction factory, representing 30-40% of the sugar production waste (Mashego, 2016), or 30% of sugarcane crushed (Mtunzi *et al.*, 2012). It is produced in surplus and used as a fuel source for boiler in the factory and to manufacture paper pulp and chip wood. Bagasse has little or no use as livestock feed in Ethiopia, while the surplus is often accumulated and removed by burning. On the other hand, the production and availability of bagasse in Ethiopia are expected to rise more than the present in line with the new investments in the sugar industry. Hence, if the nutritional value of bagasse is improved, it will contribute to the available feedstuff in the country.

Bagasse is inherently low in protein and high in fiber that challenges its feed use. It is poorly consumed by animals due to low digestibility (<50%) and low energy density resulting in unsatisfactory animal performance (Pereira *et al*., 2008). The feed value of bagasse can be improved through physical, chemical or biological treatments (Fouda, 2008). Moreover, high-pressure treatment improves the palatability and digestibility of bagasse.

Various experiments have been done to evaluate nutritional values of bagasse. Torres *et al*. (2003) reported low CP content of bagasse and approximately 90% of the nitrogen may be unavailable to animals as it is bound to the fiber components. The ADF content of bagasse ranges between 58 and 62%, lowering the DM digestibility (25 to 30%). Leme *et al*. (2003) evaluated different inclusion levels (15, 21 and 27%) of sugarcane bagasse in diets of beef cattle at high concentrate feeding and reported no difference in performance among the inclusion levels, resulting in a daily body weight gain of 1.51, 1.49 and 1.38 kg, respectively. Bagasse can be fed to ruminants by mixing with molasses or wheat bran for good performance.

2.3. Feed Conservation Practices in Ethiopia

Green forages can be preserved as hay or silage depending on the weather conditions and forage type. The purpose of feed conservation is to preserve it at optimum nutritional quality, to minimize losses during preserving and storing, to increase feed supply in a period of feed scarcity and to ease feed transporting from place to place. In Ethiopia, natural pasture hay and crop residues are stored on-farm for use during feed shortage (Solomon *et al*., 2017). Traditionally, natural pasture is conserved as hay after cutting and drying in the sun, or as standing hay. Hay making is common in areas where pasturelands are privately owned. For instance, about 0.25 to 0.9 ha of land owned by farm household is allotted for hay making in the central and northern parts of Ethiopia (Solomon *et al*., 2017). The optimum hay making stage for natural pasture is at flowering, which falls between September and October. However, it is often harvested at maturity stage when the fiber fractions increase on the expense of soluble nutrients. A study conducted in the central highlands of Ethiopia revealed that delay in harvesting period beyond late October and storing hay in open-air for extended periods reduced greatly its nutritive value (Fekede *et al*., 2014). Losses as much as 20% total digestible nutrients and 40% protein can occur with 10 days delay from the most desirable stage of harvesting forage (Adugna, 2008).

In mixed crop-livestock farming, much of cereal and pulse crop residues are stored for later use. However, the adopted poor conserving and handling practices of crop residues permit spoilage (nutrient loss) and wastage. Crop residues are poorly handled

on-farm as they are stalked in the open-air and exposed to sunlight and spoilage by animal wastes for an extended period (Solomon *et al*., 2017). Different management practices are adopted for improving feed values of crop-residues: chopping, concentrate supplementation, mixing cereal residues with legume residues, soaking with water, brewery residues and salt solution. However, straw-urea treatment and silage making are less practical at the moment. The challenges hampering feed use of crop residues include delay in collection time from fields, lack of labour and transport, lack of storage facility, lack of feeding trough and processing knowledge and skill (Abule *et al*., 2017; Solomon *et al*., 2017).

2.4. Silage Making

2.4.1. Principles of silage making

The primary goal of silage making is to preserve green or high moisture feeds for use during feed scarce period. During silage making, the anaerobic condition has to be met to inhibit the spoilage of feeds. The first factor favoring anaerobic conditions is the packing density of silo. A higher packing density will lead to better preservation, as air is expelled out of the silo at most. According to Meeske (2011) (as cited in Beukes, 2013), the optimum packing density for maize and Lucerne (fresh basis) is 750 and 600 kg/m^3, respectively. Moreover, different packing densities were used to ensile sugarcane (on fresh weight) (724 kg/m^3, Pedroso *et al.*, 2011; 600 kg/m^3, Pedroso *et al.*, 2014) in mini-silos. The low moisture content of forage increases the porosity of the silo, thereby allowing more air to enter. Also, chop length of forage affects packing density, with a shorter chop-length allowing better compaction by expelling air. According to Meeske (2011) (as cited in Beukes, 2013), the optimum chop length varies with crop type and ranges from 0.8 to 1.2 cm.

Proper sealing of silo is equally important to avoid re-entering of the air; otherwise, it will result in excessive growth of unwanted aerobic bacteria. The aerobic bacteria use up the more readily available carbohydrates and produce heat, carbon dioxide and water ending with DM loss and poor quality silage (McDonald *et al.*, 2010).

The second principle of ensiling, after the anaerobic conditions, is to lower pH to inhibit the growth of unwanted micro-organisms (clostridia and enterobacteria). Clostridia are anaerobic bacteria naturally present in the crop and produce butyric acid and degrade amino acids, which reduce silage quality and its consumption by the animal. Enterobacteria ferment sugars to produce secondary products responsible for protein degradation and also produce acetic acid responsible for inhibiting the growth of yeast and mold (McDonald *et al.*, 2010). Hence, lowering the pH to a level they cannot survive is the most effective way of controlling their deleterious effect, which can be done by optimizing conditions for lactic acid bacteria (LAB) to produce lactic acid (Castenada and Birrch, 2011). Lactic acid bacteria ferment soluble carbohydrates to organic acids, of which lactic acid is dominant. A pH of 4 is generally accepted as sufficient for inhibiting the growth of unwanted micro-organisms such as clostridia and enterobacteria (McDonald *et al*., 2010). The same author also stated a crop preferred for silage is that with a high dry matter yield per hectare and has an optimum level of WSC to sustain the growth of LAB. The minimum WSC required for adequate fermentation varies with the plant type and DM content at ensiling, which ranged 21-10% for alfalfa, 14-5% for grass and 10-4% for corn as the DM content increases from 25 to 40% (Pitt, 1990). As a rule of thumb, forage should have WSC content of 13-16% DM before ensilage, which includes SCT (15.5% DM; Khanal *et al*., 1995). Moreover, low buffering capacity of forage ensures a low pH by reducing protein degradation to ammonia and/or inhibiting the growth of undesirable microbes. In this regard, legume forages have high buffering capacity (resistant to pH reduction) and require further wilting (35-45% DM) for adequate fermentation.

Two fermentation phases (aerobic and anaerobic) occur after the silo sealing. During aerobic phase oxygen trapped in the silo is removed by short-term plant respiration, generating CO_2 and heat, i.e., $C_6H_{12}O_6 + 6O_2 => 6CO_2 + H_2O$ + Energy. Microbial amylase hydrolyzes starch, while microbial hemicellulase degrades hemicelluloses at the early stage of ensiling (Ning *et al.*, 2017). However, plant protease is still active, resulting in the breakdown of proteins to amino acids, peptides, amides and NH3. Molds, yeasts and enterobacteria will compete for the WSC needed by the LAB for the reduction of pH. This raises pH and favors anaerobic bacteria (*e.g.*, clostridia) to grow and multiply. For optimum fermentation to take place, the crop must be cut at

the right time and optimum DM or wilted until the optimum DM is reached. The DM of forages optimum for ensiling varies with plant type, commonly ranging from 250-450 g/kg DM and even more (750 g/kg DM) when additives having a conservation role are applied (McDonald *et al.*, 2010).

The anaerobic fermentation will start as soon as the oxygen is depleted. Lactic acid bacteria together with unwanted micro-organisms like clostridia and enterobacteria multiply under these anaerobic conditions due to high pH and the availability of WSC. Proteolytic enzymes are active during the onset of this phase, resulting in the breakdown of plant proteins to soluble non-protein nitrogen. The production of lactic acid lowers the pH of the ensiled material and inhibits the growth of unwanted bacteria and deactivates the proteolytic enzymes (McDonald *et al.*, 2010). The WSC released due to the breakdown of plant cells is fermented mainly to lactic acid and some acetic acid, carbon dioxide and ethanol.

2.4.2. Silage additives

Additives have a positive effect on the growth of beneficial microorganisms (*e.g.*, LAB) and inhibit undesirable ones, such as yeast and clostridia (Ferreira *et al*., 2007). Hence, applying additives controls excessive fermentation, and thereby reduces DM losses and preserves nutrients during the fermentation and feed-out phase (Kung *et al*., 2003). Silage additives are categorized as fermentation inhibitors and stimulants, aerobic deterioration inhibitors, nutrients and absorbents (McDonald *et al*., 2010).

Fermentation stimulants are carbohydrate sources and bacterial cultures. Carbohydrate sources (e.g. molasses, cereals, beet and citrus pulps) serve as an energy source for the LAB. Bacterial cultures such as LAB are widely used to improve the quality of the silage and added to crops during filling the silo. Homofermentative LAB (e.g. *Lactobacillus plantarum, Enterococcus faecium and Pediococcus spp*.) will have the best DM and energy recoveries if aerobic stability is maintained (Muck, 2004). Homofermentative LAB (*L. buchneri*) ferments six-carbon sugars to produce lactic acid, which quickly lowers the pH. Heterofermentative bacteria produce lactic acid together with acetic acid, ethanol and carbon dioxide and results in DM losses, but enhance the aerobic stability due to the acetic acid production (Muck, 2010, as

cited in Beukes (2013). Aerobic deterioration inhibitors are used to reduce DM losses during the feed-out phase. They include heterofermentative inoculants and propionic acid, which inhibit the growth of yeasts and molds as soon as the silage is exposed to air (McDonald *et al*., 2010).

Urea and minerals can be added to forage during ensiling to increase the nutritive value of the silage, also with positive effects on fermentation characteristics. Urea, for example, can be added to a crop with low nitrogen content, and also increases buffering capacity which results in a higher pH. The addition of alkaline additives (e.g., lime and urea) to sugar-rich forages (e.g. sugarcane) before ensiling raises pH at initial stage of fermentation and inhibits the proliferation of yeasts (to reduces alcohol production), hydrolyzes the fiber fractions and increases digestibility (Alcántara *et al*., 1989; Siqueira *et al*., 2007). Fermentation stimulants such as molasses should, therefore, be ensiled together with minerals and urea to counteract the rise in buffering capacity (McDonald *et al*., 2010). Hence, it is advisable to add nitrogen source and minerals to minimize the risk of spoilage and low-quality silage.

2.4.3. Silage quality evaluation

Silage quality is affected by the type of fermentation that occurs during ensiling (Huhtanen *et al*., 2002). It is important to determine the quality of silage before offer to ensure its acceptance by the animals. Physical attributes such as smell, colour, moldiness, texture and taste are the most practical silage quality testing parameters on-farm (Table 1). Furthermore, silage quality can be measured by analyzing for DM, CP and TDN contents. In modern analyses of silage, measurements such as pH, NH_3-N, CP, NDF, ADF, WSC, starch, organic acid contents, and protein solubility are determined (Charmley, 2001).

Table 1. Physical characteristics used for on-farm in silages quality assessment

Criteria	Possible indications
Colour:	
Yellow	Low protein/secondary fermentation if at base
Dark yellow (Temperature>30 °C)	of silo and wet
Dark green	High protein if also leafy
Brown (Temperature: 45-60°C, or >)	Overheated/protein damage– Maillard reaction
Grey/white	Bad aerobic stability – moldy
Texture:	
Wet	Low DM with risk of secondary fermentation
Slimy	Secondary fermentation
Dry	High DM
Leafy	High energy and protein
Stemmy	Low energy and protein
Rough/Abrasive	Low intake if also stemmy
Soft	High intake if also leafy
Sticky	Residual WSC
Smell/taste:	
Sweet	Lactic acid – good fermentation
Vinegar	Acetic acid – mixed fermentation
Fruity	Yeast activity – mixed fermentation
Vomit	Butyric acid – secondary fermentation
Sharp	Excess acidity – pH too low
pH	pH between 3.7-4.5 – good fermentation

Source: BAPH (1996) and Beukes (2013)

2.5. Hay Making

Hay is forage conserved by drying to feed livestock during periods of shortage caused by limited pasture growth or inadequate availability of alternative feeds. Unlike silage making, hay is forage conserved in aerobic and limited moisture content, the target is 15-20% moisture for stacking or baling (MacDonald *et al*., 2010). This inhibits the action of plant and microbial enzymes. In hay making, moisture is removed as quickly as possible to achieve the target DM content through the process called curing, which is normally accomplished by sun energy and/or by aeration.

There is no absolute preservation of fresh forage. Dry matter and quality losses are common in preserved forages compared to fresh forages due to plant metabolism,

microbial metabolism (which lasts longer than plant metabolism) and physical losses (shattering). As a result, most nutritious parts (e.g. leaves) and digestible nutrients (sugar, protein, and fat) are susceptible to losses. Therefore, the goal in forage conservation must be on minimizing losses. Hay storage losses are low and can be related solely to moisture content. In contrast, silage storage losses are much larger often 20% or more, and the subject is complex (McGechan, 1990).

2.5.1. Factors affecting hay making

According to Collins and Owens (2003), moisture loss during hay making can be influenced by plant factors, weather condition and management type. Physical characteristics of plants affect the drying process. The drying process slows with an increase in stem thickness because of increased radial distance from the stem core to the epidermis, which impairs water removal. Hence, thick-stemmed plants such as maize, sorghum and whole sugarcane or its tops usually dry at a slow rate compared to the thinner stemmed plants. Also, a waxy impermeable cuticle, covering the epidermis of leaves inhibits moisture loss. As to plant species, grasses tend to dry faster than legumes and forages with the higher leaf to stem ratios dry faster as leaves dry faster than stems. The differences in drying rates among forage species are mostly a consequence of a high surface area to dry weight ratio (Romero *et al*., 2015).

Favourable conditions for hay production include high temperature, high solar radiation, and moderate wind speed with low air relative humidity. The drying rate is faster at the beginning of the drying process; however, it slows down and reaches zero when moisture equilibrium with the environment is reached. If the humidity in the environment is greater than 70%, moisture loss will cease even if temperatures are high (Romero *et al*., 2015).

Good management practices help speed up the drying process, preserve nutrients and maintain forage quality (Rotz and Shinners, 2007). Harvesting forages at the right maturity stage is important to achieve the proper balance between adequate yield and nutritive value. The nutritive value of the forage diminishes with advance in maturity, as there is a high accumulation of fiber fractions (cellulose and hemicelluloses lignin,) compared to cell contents (i.e., protein and soluble carbohydrates) and mobilization of

nutrients from the vegetative tissue (leaf and stems) to the reproductive tissue, or seed head. As a general rule, the best time of harvesting legumes is at the early blooming stage and that for grasses is just as they begin emerging seed heads. The curing process includes conditioning forage to help accelerate the drying rate. For instance, chopping of forage creates openings that promote moisture loss, especially from stems. This reduces hay-curing time and is most effective on forages with a low leaf to stem ratio. A research report has indicated that chopping berseem (*Trifolium alexandrinum)* increased the drying rate, reducing the drying time by 24 to 36% (Misra *et al*., 1997). The same authors also stated that chopping provides homogeneous feed material rich in CP content by preventing the loss of dried leaves, which in turn increases the digestibility of CP over unchopped material (Misra *et al*., 1997). On the other hand, tedding (dispersing forage across the field) and raking (turning the tedded forage one or more times) allow quick and uniform drying, particularly for forages with high moisture (>40%).

2.5.2. Effect of high moisture on hay quality at the storage

The high moisture content of hay affects its quality at storage. Dry matter loss during the storage period is about 5.6% when baling or stacking moisture is about 15% and hay is stored in good condition (MacDonald *et al*., 2010). However, with high moisture forage, spoilage starts soon and the plant respiration and microbial activity consume sugars and proteins ending with dry matter loss, increased fiber content and heat generation. The production of excess heat rises temperature that triggers the Maillard reaction resulting in less digestible compounds. According to Romero *et al*. (2015), DM loss of hay averages about 1% for each moisture percentage above 10% at the time of storage. Moreover, hay stored at above 20% moisture can cause heat damages due to mold development, which generates mycotoxins posing a potential health hazard for animals and human being (Romero *et al*., 2014).

2.6. Performances of Sheep in Feedlot

2.6.1. Feed dry matter intake and growth

Feed DM intake has the most profound effect on the growth performances of the animal. Factors that influence DM intake of the animal include feed palatability,

digestibility, rumen outflow rate, fiber and moisture content of the feed (McDonald *et al.*, 2010). It is important to predict the DM intake of the animals to ensure optimum growth, minimize wastage and increase economic benefit from production. Dry matter intake of sheep varies with breed, age, physiological stages and body weight (3.8–4.2%) (NRC, 1985). The dry matter consumed must meet the energy and protein requirements of animals to ensure optimum growth and development. The energy requirement of animals depends on the stage of maturity, growth rate, sex and level of feed intake (McDonald *et al.*, 2010). The protein requirement of the growing animal is reliant on the energy density of the diet.

Growth is defined as the increase in weight of animal until it reaches a mature body size (Lawrie and Ledward, 2006). It follows a basic sigmoid curve, having three phases with time: a slow growth rate, followed by an exponential growth phase till it reaches mature size and a declining growth rate. Younger animals in the exponential growth phase have a better feed conversion ratio than older animals and therefore better perform in feedlot. Also, early maturing breeds will grow faster than the late maturing breeds and start depositing fat at a younger age, attaining a lower weight and finish at short time. Thus, early maturing breeds will be ready for slaughter at a younger age, but the late maturing breeds can be slaughtered at higher body weight, but take longer time to finish. In this regard, lowland sheep (e.g., Afar sheep) mature late and finish at higher body weight compared with the highland sheep (ESGPIP, 2011). Male animals will also perform better than female animals in a feedlot. On average, the growth rate of indigenous sheep is low and drops considerably from about 100 g/day at an early age to 50 g/day after weaning (EARO, 2000). However, indigenous sheep (yearling lambs) supplemented in-door with protein and energy-rich agro-industrial byproducts increase feed intake and growth performance (Abebe *et al*., 2010; Hirut *et al*., 2011; Tsegay *et al*., 2013; Getahun, 2015).

2.6.2. Carcass characteristics and meat quality

Feeding regime (nutrition) is among factors (breed, age, sex, castration) influencing sheep carcass yield, composition and quality. Most indigenous sheep are slaughtered at yearling age with body weight less than 20 kg and carcass weight 8-10 kg (dressing 42% on average). However, yearling local lambs fed on concentrate based diets had

better slaughter body weight, carcass weight and dressing percentage than the groups not fed concentrate (Abebe *et al*., 2010; Hirut *et al*., 2011; Tsegay *et al*., 2013; Chala *et al*., 2014). These authors also reported increment in the yield of non-carcass components with supplementation. Feeding intensity can also alter the composition of fat in lamb's carcass, and the association between muscle (protein) and fat determines the marbling and tenderness of meat (Borys *et al*., 2011). Moreover, the amount of protein deposited in sheep is influenced by energy supply and protein providing an adequate amount of essential amino acids (Knapik *et al*., 2016).

Cooking loss and water holding capacity are among the meat quality measurements that explain juiciness and tenderness. Cooking loss is a combination of liquid and soluble matters lost from the meat, water being the main component (Heymann *et al*., 1990). The meat with low cooking loss is desirable as it has a great impact on eating qualities (tenderness and juiciness). During meat cooking, water is probably lost due to heat-induced protein denaturation, which causes less water to be entrapped within the protein structures held by capillary forces. The quality of raw meat has a great impact on the cooking loss, with more loss to occur in meat characterized with low pH and high drip loss (Aaslyng *et al*., 2003), which in turn is affected by meat water holding capacity (ability to retain water) and fat content. The water holding capacity of meat can be improved by animal feeding management (e.g., supplementing with vitamin E, feeding low digestible carbohydrates). Meat from lambs raised on grass pasture with dams had a lower water holding capacity than the group raised on pasture with concentrate supplementation or in feedlot on concentrate and wheat straw (Santos-Silva *et al*., 2003).

3. MATERIALS AND METHODS

This chapter describes details of methodologies used to conduct the studies, which included the description of survey work, SCT conservation experiments (silage and hay making) and sheep feeding experiment. Moreover, the mathematical models, the statistic used to analyze data and economic evaluation of experimental diets were discussed.

3.1. Survey on Production and Utilization of Sugarcane Byproducts

3.1.1. Description of the survey areas

The study was conducted in and around Wonji-Shoa and Metehara Sugar Estates, which are located in Rift Valley of East Shoa Zone of Oromia Region, Ethiopia (Figure 1). Wonji-Shoa sugar factory is located between 8˚31′ N and 39˚12′E at an altitude of 1550 meter above sea level (midland), while Metehara sugar factory is located between 8˚51′ N and 39˚ 52′ E at 950 meters above sea level (lowland). The factories are 110 and 200km far away from Addis Ababa. The average annual rainfall is about 800 mm for Wonji-Shoa and 554 mm for Metehara Sugar Estates (Esayas *et al*., 2018). The two Sugar Estates are the oldest in the history of Ethiopian sugar production. Wonji-Shoa sugar factory commenced production in 1954, while Metehara sugar factory in 1970. Currently, the potential crushing capacity of Wonji-Shoa and Metehara sugar factory is 6250 and 5300 tonnes sugarcane a day, holding sugarcane plantation area of 12800 and 10235 hectares, respectively. The Sugar Estates were purposely selected for this study because of their long years of production experience, high capacity of byproduct production and proximity.

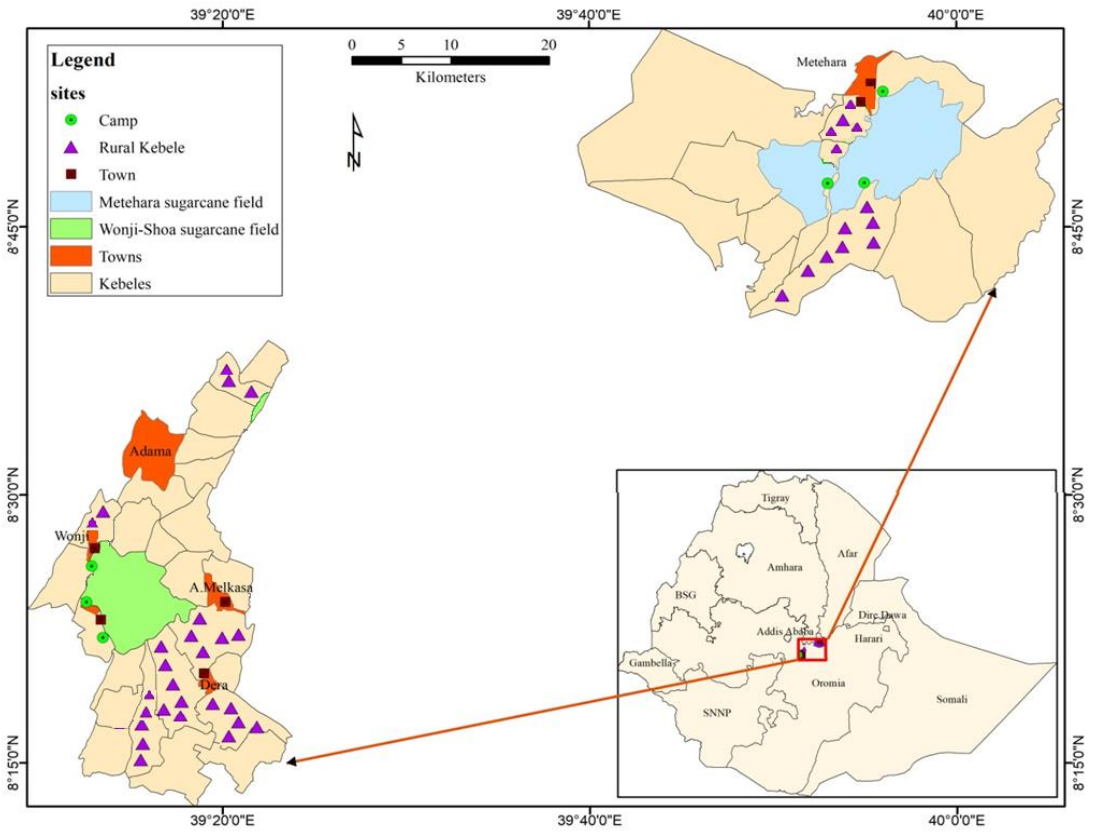


Figure 1. Map of the study areas

3.1.2. Survey procedure and data collection

Smallholder livestock farms close to the Sugar Estates, having access to sugarcane byproducts were the target population of the study. At each Sugar Estate, farm HHs in rural *kebeles*, towns and camps were assessed. The "urban" farms encompassed livestock producers in towns (Metehara, Addis Ketema, Melkassa, Dera, Wonji and Alem Tena) and in camps within the sugarcane plantation, since towns and camps are governed by the same municipality and the livestock production system and feeding managements are alike. While "rural" farms indicate rural *kebeles* nearby sugar plantation (pastoral or mixed crop-livestock system), both of which are potentially accessible to sugarcane byproducts. For this, list of households (HHs) owning livestock in rural *kebeles* was obtained from Agricultural Office of Adama Zuria, Fantale and Dodota districts, while farms in urban (towns and camps) were obtained by conducting inventory. A preliminary visit to some of the farms was also done by the researcher and data enumerators of the respective location to make observations

on feed resources available and feeding practices. Residents (workers) in camps within the Sugar Estates raise livestock (mainly cattle) confining in open barns (zero-grazing) found mainly at the boundaries of sugarcane plantation. A total of 9 rural *kebeles* (Metehara, 3, Wonji-Shoa, 6), 6 towns (2, 4) and 6 camps (3, 3) were purposively selected based on livestock population and accessibility. The survey was conducted between November and December 2016.

The sample size of respondents was determined as described by Fluid Surveys (2014):

Sample Size Calculation:

Sample Size = (Distribution of 50%) / ((Margin of Error% / Confidence Level Score)^2)

Finite Population Correction:

True Sample = (Sample Size X Population) / (Sample Size + Population – 1)

Considering a 50% distribution accounted for respondents' variation on a response, a margin of error of 5% and 95% confidence level score of 1.96, a population of 1546 smallholder livestock farms in the study areas (Metehara, 552; Wonji-Shoa, 994) who have access to the byproducts, the total number of respondents (N) was calculated to be 308. Of the HHs owning livestock in the selected rural and urban kebeles of Metehara and Wonji-Shoa, only the respective (53, 57) and (103, 95) HHs were selected randomly proportionate to their size and interviewed.

A semi-structured questionnaire, containing multiple choice and open-ended questions, was developed and pre-tested. At each Sugar Estate, data enumerators were trained in interviewing procedures (approaches, proper questioning, etc) prior to conducting the study. A single-visit-multiple-subjects survey method (ILCA, 1990) was employed to gather quantitative and qualitative data from a HH head (respondent) on various aspects: family size, education, occupation, herd size and structure, land holdings, feed resources, availability and utilization of sugarcane byproducts (uses, feeding practices, market price, processing and conserving, storage condition and constraints).

At the factory level, secondary data on annual production volume and utilization of the major sugarcane byproducts (molasses, bagasse and sugarcane tops), area of

sugarcane harvested and sugarcane crushed during the past nine years (2008-2016) were taken and/or estimated. In the case of Wonji-Shoa, data of area harvested, sugarcane yield and the byproducts were the aggregate of the factory's own data and that of the out-growers' farm. The volume of SCT produced in each year was estimated by dividing the amount of sugarcane crushed by 10 (Deshmukh, 1983). Similarly, the amount of SCT generated from seedcane produced and harvested in the respective year was estimated and added to give the total SCT production.

Besides, adequate amounts (500 g) of molasses, SCT and grass hay samples were taken in bags from 1/3rd of the HHs interviewed at each Sugar Estate, while bagasse was sampled from sugar factories as it was not available on farms during the study period. The samples were bulked per site (urban/rural) followed by Sugar Estate and then sub-sampled. It was dried and ground to pass a 1 mm sieve in a Willey mill and put in deep freezer until taken for laboratory analyses. The samples were analyzed for DM, CP, ash, NDF, ADF and ADL contents in the nutrition lab of Debre Zeit Agricultural Research Center.

3.1.3 Data analysis

Survey data were entered into a computer and analyzed using the Statistical Package for Social Science (SPSS, 2011; version 20). Descriptive statistics (percentage, frequency and mean) was employed to describe data. The significant difference between discrete variables was computed using the Pearson Chi-square test (X^2), while "The Mean statement" was used for continuous variables. The associations between variables and Sugar Estates were tested by pooling data of rural and urban farms for each Estate.

3.2. Silage Experiment

3.2.1. Experimental site

Sugarcane tops silage and hay making (section:3.3) experiments and sheep feeding experiment (section:3.4) were conducted at Debre Zeit Agricultural Research Centre (DZARC), located at 45 km southeast of Addis Ababa (08°44'N latitude, 38°58'E longitude; altitude of 1900 meters above sea level). The area is known for bimodal

rainfall distribution (June-September and March-May), with an average annual rainfall of 814 mm and minimum and maximum temperature of 10.9 and 28.3°C, respectively (DZARC, 2017).

3.2.2. Treatments and design

The treatments were set in a 2 x 4 factorial arrangement: two SCT types (green and burnt) and four silage treatment types (no additive, 4% molasses, 1% urea and 1% urea + 4% molasses) in a completely randomized design. Fertilizer grade urea (46% nitrogen) was used for this purpose. A polyethylene container ("*mini-silo")* with a volume of 1.09 liter was used in 5 replicates per treatment, making a total of 40 experimental silos. The additives were incorporated on the basis of forage dry matter and the levels of the application were adopted from former research reports (Khanal *et al*., 1995; Suárez *et al*., 2011).

3.2.3. Sampling and ensiling procedure

Sugarcane tops of mature sugarcane (variety N-14, also called "Natal") were collected from Wonji-Shoa sugar factory plantation before and after burning the sugarcane field for harvesting. The sugarcane field was often burnt to ease the harvesting practices and add ash to the soil. The sugarcane was grown on heavy black soil (*Vertisols*), aged 23 months and harvested at the first stage of cutting after planting. Sampling was done randomly at six marked sites (at an interval of 17 m) along a gradient line (diagonally and horizontally) in one hectare sugarcane field. The green SCT were sampled overnight before burning, while the burnt samples were taken after burning from the same site. The cutting point for SCT sampling was as used by staff (cutters) of the sugar factory for sugarcane harvesting (at the highest fully formed node). Immediately after cutting, the respective samples were put into polyethylene bags and transported to the Research Center. After arrival, the burnt and green samples were mixed thoroughly and independently, chopped using electrically operating machine (Ethio-chopper) into 2-3 cm length. The amount of chopped SCT (green/burnt) used for ensiling was weighed and wilted under a shed to attain about 35% DM (Table 21). Urea was diluted with water at a ratio of 1:1.5 when used as a sole additive. When

molasses alone, or urea and molasses were applied the amount of water used for dilution equals the amount of molasses used by weight (Suárez *et al.*, 2011).

The chopped forages were weighed and thoroughly mixed with the respective additive (except for control treatment) on polyethylene sheet laid on a concrete floor. The forages were filled into the mini-silos lined inside with polyethylene sheets. All silos were filled at a similar packing density of 767g per 1.09 liter plastic bottle (250 kg DM/m^3) by hand filling and pressing with a wooden stick. The packing density was close to that reported by Siqueira *et al*. (2007) for sugarcane ensilage. The tightly packed silos were immediately closed, tightly sealed and placed under a shed and left to ferment for 45 days at ambient temperature. Adequate samples of the respective treated and untreated forages were taken right before ensiling and put in polyethylene bags, sealed and stored in a deep freezer (-20°C), pending laboratory analyses.

3.2.4. Silage temperature and pH

Experimental silos were weighed on the beginning day of the experiment and on day 45^{th} of ensiling to determine fermentation loss by difference. The silage temperature was measured immediately after opening silos using a laboratory thermometer inserted into the silo's center. The ambient temperature at times of silo opening was recorded (average, 28°C). After observation for mold, the silages were removed, homogenized and sampled in two parts where one part was immediately frozen, while the remaining was used for physical characteristics assessment. For pH determination, about 20 g of frozen silage sample per treatment was taken in a beaker to which 100 ml of distilled water was added (AFIA, 2011). The samples were blended using a glass stirrer and left for one hour before filtering using filter paper. Silage pH was measured from the extract using a conventional digital pH meter (Hanna's Benchtop pH meter), calibrated with buffer solutions (pH 4 and 7).

3.2.5. Visual appraisal of silage quality

The silages were evaluated for physical attributes by a panel test involving six trained personnel on the scales adopted for silage quality characterization. The panelists were from the Department of Livestock Research with different professional backgrounds

but had experiences in silage making. They were trained on how to apply the criteria set (subjective score 1-4; Table 2) and exercised independently before commencing the actual evaluation. Observation for mold formation was done starting from the opening of the silos, while color, smell and texture were evaluated after content extraction. The visual observation for color assessment was also aided by standard color charts. The scores of each individual for all attributes were used in the statistical analysis.

Table 2. Description of the scale used as indices of silage quality assessment

Rating scores	Smell	Color	Texture	Moldiness	PH
1 (Bad)	Rancid and musty smell /pungent/	Dark/deep brown	Putrefactive and agglutinative	Highly moldy	>5.0
2 (Moderate)	Irritative /offensive; alcohol/acidic	Brown (Medium)	Slightly viscous /slimy	Medium	4.4-5.0
3 (Good)	Light acidic (*pleasant*)	Brown-yellow	Medium (*loose and soft, firm*)	Slightly moldy	4.1-4.3
4 (Excellent)	Pleasant and sweet- acidic (*very pleasant*)	Light /greenish-yellow/Olive green	Loose and soft, Firm	Without mold	≤4.0

Source: BAPH (1996) and Ososanya and Olorunnisomo (2015)

3.3. Hay Making Experiment

3.3.1. Experimental design and treatments

The experiment was set as a 2 x 3 factorial arrangement of treatments in a completely randomized design (CRD). The factors were: 2 SCT types (green and burnt) and 3 drying methods (sun-drying of intact SCT, under shed drying of intact SCT and sun-drying of chopped SCT). However, in this study, the chopped materials were not dried under a shed, since the rapid drying of chopped sugar-rich forages (e.g., sugarcane/tops) using sun radiation is recommended in order to avoid fermentation and loss of sugar (Archimède and Garcia, 2010).

3.3.2. Sampling and drying procedure

The type of SCT (variety- N-14, burnt/green) used and the sampling procedures were similar to that of the silage experiment (Section 3.2.3). After cutting, the samples were put into polyethylene bags and immediately transported to the research center. At arrival, the burnt and green SCT samples were mixed thoroughly and independently. About one-third of each forage type was chopped into 2-5 cm length using electrically operating forage chopper (Ethio-Chopper) and was dried under the sun. The remaining intact sample per SCT type was divided into two equal parts for drying under the shed and in the sun. Each treatment (drying method) was replicated 5 times and a replicate was spread uniformly on a sack at initial swath density 4 kg/m^2. The shed used for this trial was high roofed (with corrugated iron), well-ventilated (side walls wire meshed), built of a concrete floor and protected SCT from exposure to direct sunlight. For all drying methods, samples were turned twice daily at 10:00 am and 3:00 pm. Forage samples were taken per replicate at day 0, 1, 2, 3, 8, 18, 24, 34, 45, 51, 60 and 68 for DM determination. At each sampling day, about 120 g of SCT was taken per replicate and care was taken to sample proportionally from the stem and leaf part. According to the drying method, forage drying was terminated when the average DM content of the replicates approached 85%, at which microbial damage becomes minimal and the hay is ideal for storage (Andy *et al*., 1987; McGechan, 1990). The samples were dried in a forced-air oven at 105ºC for overnight (to constant weight) for DM assay. Also, representative samples of the fresh forages (day 0) and those sampled at the end of the drying period were dried and ground (section 3.5) and stored in a freezer (-20°C) until used for laboratory works. The dehydration rate was computed.

$$\text{Drying rate (\%/day)} = \frac{\text{\% initial moisture - \% final moisture}}{\text{Drying duration (days)}} \text{ x100}$$

During the experimental period (December 25, 2016 - March 2, 2017), the daily temperature, relative humidity and wind speed ranged 7.6-27.5˚C, 39-66%, 0.01-3.65 m/s, respectively, while there was no rainfall throughout (Figure 2). However, the variation in microclimate between the two drying sites (under the shed and in the sun) was small, where the average ambient temperature was 26.6°C in the shed and 27.4°C outside the shed.

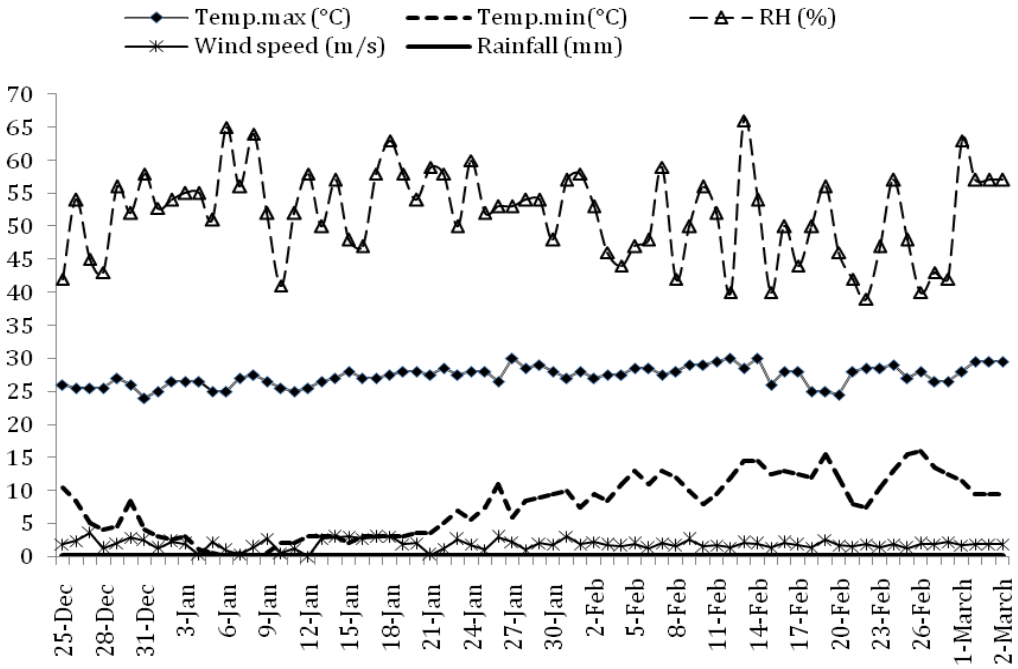


Figure 2. Climate data of the study site for hay making experiment

3.4. Sheep Feeding Experiment

3.4.1. Feed preparation

Adequate amounts of burnt SCT (variety N-14) were collected postharvest from Wonji-Shoa sugarcane fields and transported to Debre Zeit Agricultural Research Center. After arrival, the SCT were immediately chopped for silage and hay making as described in section 3.2.3 and 3.3.2. The best method to conserve burnt SCT as silage (by adding 1% urea + 4% molasses) and hay (chopping and sun drying) were adopted from the results of the previous experiments (section 4.2 and 4.3). In silage making, 5 ground Pits, each with a dimension of 1.20 m length, 1.20 m width and 1.50 m depth and capacity of about 500-600 kg fresh roughage was prepared. The chopped forages were homogenized manually with the selected additive (1% urea + 4% molasses), filled and compacted batch by batch (ensiling 10kg forage per batch) in the pits lined with polyethylene sheet, which finally sealed and left to ferment under the anaerobic condition for 45 days. The pits accommodated the total amount of SCT silage required for the feeding period. On the other hand, an adequate amount of chopped burnt SCT was sun-dried for three days (at 85% DM) and stored pending

feeding trial. A concentrate mix (90.7% DM) was prepared from 14.6% maize, 34.8% wheat bran, 49.6% *noug* cake and 1% common salt (on DM basis) for use as a supplement.

Natural pasture hay used as a control basal diet in this study was grown on wetlands of Ada Berga district, West-Shoa Zone of Oromia Region. It was harvested in late October 2017 (half month past full heading stage) and sun-dried and baled before being transported to the Research Center. The pasture hay was dominated by grass species (*Andropogon abyssinicus, Pennisetum and Cyperus/Sedge)* than by legumes and forbs (Seyoum and Fekede, 2008).

3.4.2. Animals, treatments and design

Thirty yearling intact male Arsi-Bale sheep were purchased from local markets and transported to the experimental site. Upon purchasing them care was taken to have animals at yearling age (similar dentition, i.e., with unbroken paired incisor) and healthy. All animals were ear-tagged and quarantined for three weeks, during which they were vaccinated against viral diseases (sheep pox, pasteurellosis and anthrax) and treated with a broad-spectrum antiparasitic agent (Ivermectin) against internal and external parasites. After the acclimatization period, each animal was weighed (using a movable weighing scale) after overnight fasting on two consecutive days and the average was taken as initial body weight. Animals were then blocked into six blocks of five animals each based on body weight. Animals in each block were randomly allotted to one of the dietary treatments (6 lambs/treatment) in a randomized complete block design. Experimental lambs were assigned randomly to individual pens (0.70 m × 1.70 m) with concrete floor, a feeding trough and a watering bucket. The pens were cleaned and disinfected before moving animals in and also cleaned daily. The animals were adapted to the test feeds for two weeks before commencing the data collection.

Table 3 indicates the physical and chemical compositions of experimental feeds. Sugarcane tops silage or hay replaced natural pasture hay on DM basis at feeding time. Silage was wilted overnight before offered to the lambs the next morning. Besides, each animal was supplemented with a fixed level (350 g/day; 90.71% DM) of concentrate mix to meet the lambs' nutrient requirements for maintenance and

growth. The ration had 9.51, 9.55, 9.60, 9.27, 9.02% CP and ME of 9.1, 8.8, 8.6, 8.8, 8.5 MJ/kg DM in T_1 to T_5, respectively. The chemical composition of roughage refusals is given in Appendix Table 1.

Table 3. Physical and chemical compositions of feedstuffs used in sheep feeding trial

	Natural pasture hay	Burnt SCT silage	Burnt SCT hay	Concentrate (g/day)*
Physical composition (as %DM, except for DM):				
T_1 (control)	100	-	-	350
T_2	67	33	-	350
T_3	33	67	-	350
T_4	67	-	33	350
T_5	33	-	67	350
Nutrient composition, % DM:				
Dry matter (%)	86.97	34.23	87.73	90.71
Crude protein	4.56	4.75	3.50	20.15
Ash	9.44	10.90	14.43	6.58
Neutral detergent fiber	69.02	65.55	71.71	42.38
Acid detergent fiber	46.17	38.36	42.07	17.62
Acid detergent lignin	9.53	8.25	7.30	5.86

* = as fed basis (DM, 90.71%); SCT= sugarcane tops; T = treatment

3.4.3. Intake and growth trial

Feed intake and growth data were collected for a period of 90 days. The roughages were fed *ad libtum*, allowing 15% refusal daily, while concentrate was fed twice daily at 8:00 am and 2:00 pm. Tap water was provided for all animals free of choice. Daily feed offered and the refusal was measured and recorded for each animal to determine nutrient intake by difference (using the chemical composition of feed offered and refusal samples). Samples of the roughage and concentrate offered and refusals were taken daily and sub-sampled biweekly for DM determination. All animals were weighed every 15 days after overnight fasting. The average daily gain (ADG) of each lamb was estimated by regressing the difference between two successive body weights over days elapsed, while feed conversion efficiency (FCE) was calculated as:

$$\text{Feed conversion efficiency} = \frac{\text{Average daily gain (g)}}{\text{Daily feed DM intake (g)}}$$

3.4.4. Digestibility trial

At the end of the intake and growth trial, all lambs of the respective treatment were harnessed to fecal bags. The trial lasted for 10 days (three days as a preliminary period to adapt animals to fecal bags, and seven days for feces collection). The diets and feeding management were similar to that of the intake and growth trial. The daily feed offered and refusal and feces voided were weighed and recorded for each animal. About 10% of the daily excreted feces was sampled and put in a deep freezer (-20°C) till used for chemical analyses. The apparent digestibility (AD) of DM, OM, CP, NDF and ADF were determined as follows:

$$\text{AD} = \frac{\text{Total amount of nutrients in feed} - \text{total amount of nutrients in feces}}{\text{Total amount of nutrients in feed}} \times 100$$

3.4.5. Carcass measurements

After the completion of the digestibility trial, all lambs were transported to ELFORA export abattoir in Debre Zeit town for slaughtering. The lambs were devoid of feeds for 18 hrs and weighed right before slaughtered. After bleeding the animals, skin, heads, blood, liver, kidney, heart, lung and trachea, testis and penis, spleen, tail fat, omental fat, gut total, digesta and empty gut and internal organs were removed, weighed and recorded. Fresh carcasses were weighed including the tail fat and split along the vertebral column into the left and right sides. From all lambs, adequate meat samples were taken from the *longissimus dorsi* muscle of the right half carcass (5^{th}-13^{th} ribs) and immediately vacuum-packed in plastic bags and stored in a deep freezer (-20°C) until used for the subsequent laboratory works. The left sides of the carcass were chilled for 24 hrs at 4°C, deboned into lean, fat and bone components and weighed. Each component was multiplied by two (except tail fat) and expressed as a proportion of whole carcass weight or empty body weight (EBW). The digestive tract was weighed when full and empty in order to compute gut content (digesta) by

difference. Empty body weight was computed by deducing the weight of the gut content from the slaughter weight. Chilling loss was calculated as the percentage of the difference between hot carcass weight (HCW) and cold carcass weight (CCW) divided by HCW. Dressing percentage was calculated as the proportion of hot and cold carcass weight to slaughter weight or empty body weight: HCW (CCW)/SBW*100 and HCW (CCW)/ EBW*100.

3.4.6. Meat quality measurements

Meat quality attributes were assayed in the laboratory of Ethiopian Institute of Agricultural Research, Addis Ababa. Cooking loss was determined using 1.5 g of thawed frozen samples of *L.dorsi* muscle placed in a boiling tube in replicates and immersed in a water bath having a temperature of 85°C. It was cooked for 30 minutes and cooled to room temperature and weighed after removing water and blotting with a dry towel. Cooking loss was calculated as the differences between initial and final weights and expressed as a percentage loss of initial sample weight (AOAC, 2000).

The moisture content of meat was determined using the methods developed for meat product analyses (AOAC, 2000). Two g meat sample was taken per replicate on the pre-weighed aluminum cup and cut into the same size slices and dried in an oven for 24 hr at 105°C, cooled in desiccators for 30 minutes and weighed. The weight difference represented water retained in meat and was expressed as a percentage of the initial sample weight.

The frozen *longissimus dorsi* muscle was freed from any external fat traces, minced, partially dried in an oven (at 60 °C for 72 hr) cooled in a desiccator and used for analyses of protein, fat and ash contents. Meat protein was determined using Kjeltec^{TM} 8400, a fully automated Kjeldahl analyzer, while ash content was determined by burning three g of meat sample at 550°C for six hours in a muffle furnace (AOAC, 2000).

The determination of intramuscular fat (ether extract) was done as described by Method 99/.36 (AOAC, 2000). The ether extract in *L. dorsi* muscle was assayed by taking two grams of dried meat and mixing it with 10 g sand (SiO_2) on the aluminum

cup and placing in Soxhlet apparatus. It was then refluxed using petroleum ether (boiling point 40–60°C) for 1.05 hr until all the fat from the meat was transferred to the ether. The defatted sample was then cooled in desiccators and reweighed. The fat content was expressed as the percentage of the extracted fat in the initial meat sample.

3.4.7. Cost-benefit analysis

The partial budget analysis was used to evaluate the relative economic importance of dietary treatments using the procedures of Upton (1979). It measures profit or losses, where net income (NI) is the difference between total variable costs (TVC) and total returns (TR): NI = TR-TVC. The change in net income (ΔNI) was the difference between the change in total return (ΔTR) and the change in total variable cost (ΔTVC), i.e., ΔNR = ΔTR - ΔTVC. While, the marginal rate of return (MRR) measures the increase in net income (ΔNI) associated with each extra unit of cost (ΔTVC), i.e., MRR = (Δ NI/ ΔTVC).

The economic benefit of production was estimated considering the costs of major inputs (feeds and labour) and the prevailing (end of the main fasting season of Ethiopian Orthodox Christian) market price of finished lambs as estimated by three experienced local sheep traders. However, the benefit that can be generated from manure production was not included in this experiment. The partial budget analysis was performed under two scenarios: when the cost of purchasing SCT was considered (*Case I)* and not considered (*Case 2*). This was because quite a large number of livestock farms obtain SCT by purchasing from collectors and/or freely from sugarcane fields.

3.5. Chemical Analyses of Feeds and Feces

The fecal samples were thawed, thoroughly mixed and sub-sampled per sheep. Both feed and fecal samples were dried in forced-air oven at 60°C for 72 hours to a constant weight and ground to a 1.0 mm size using a Wiley mill and stored in plastic bags. Dry matter, CP (N *6.25), ash, EE, calcium (Ca) and phosphorus (P) contents were determined according to AOAC (1990), while neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) contents were analyzed

according to Van Soest and Robertson (1985). The IVOMD was determined according to Tilley and Terry (1963) by applying a two-stage digestion process, where 0.5 g samples were first fermented in rumen fluid obtained from donor animals (three rumen-fistulated steers), followed by acid (pepsin) digestion for 48 hours.

For silage samples, percentage of total dry matter loss (TDML) was computed as ((DM of fresh forage - DM of silage)/DM fresh forage*100) (Pedroso *et al.*, 2011). The non-fiber carbohydrate (% NFC) = 100–% (CP+Ash+ EE+NDF) (Hall, 2000). Metabolizable energy (ME, MJ/kg DM) = IVOMD (g/kg DM) *0.016 (McDonald *et al*., 2010) and Hemicelluloses = NDF-ADF.

3.6. Statistical Model and Data Analysis

Experimental data were subjected to analysis of variance using the General Linear Model procedure of the SAS program (SAS, 2004). When the interaction between factors was non-significant, only the main effect means were presented and discussed, otherwise simple effect means were presented. Mean separation was done using Tukey test at 5% probability. The following statistical models were used.

- Silage experiment: $Yijk = \mu + \alpha i + Tj + (\alpha T)ij + \varepsilon ijk$; where; Yijk was the response variable; μ = Overall mean, αi = the effect of SCT type (i = burnt and fresh); Tj = Effect of silage treatment type (j = ± additive), $(\alpha T)ij$ = Interaction effect of SCT type "i" with silage treatment type "j", εijk = the experimental error.

- Hay making experiment: $Yijk = \mu + \alpha i + \beta j + (\alpha\beta)\ ij + \varepsilon ijk$. Where; Yijk is the response variable; μ = Overall mean; αi = the effect of SCT type; βj = Effect of drying methods; $(\alpha\beta)$ ij = Interaction effect of SCT type and drying methods; εijk = random error.

- Sheep feeding experiment: $Yij = \mu + Ti + Bj + \varepsilon ij$. Where: Yij = Experimental observation; μ = Grand mean of treatments; Ti = Effect of treatment; Bj = Effect of block; εij= Experimental error

4. RESULTS

In this section, details of survey results on production, utilization and management of sugarcane byproducts are presented (section 4.1), followed by results of SCT silage (section 4.2) and hay experiments (section 4.3). Section 4.4 presented performances of sheep diets based on SCT silage or hay replacing natural pasture hay.

4.1. Production and Utilization of Major Sugarcane Byproducts

4.1.1. Household characteristics

Table 4 presents the characteristics of surveyed HHs in the study areas. A larger percentage of male-headed than female-headed HHs were engaged in livestock farming at no notable (P=0.251) difference between the two Sugar Estates. However, there were more female-headed HHs in urban than rural Wonji-Shoa, while the reverse was true for Metehara. The average age of HH-head was higher (P=0.032) in Wonji-Shoa than Metehara. The majority (85%) of respondents were educated, among which 5% received a Diploma and more. The illiteracy percentage was higher (P=0.042) in Metehara compared to Wonji-Shoa. The average family size (persons/HH) of the farm HHs in Metehara and Wonji-Shoa did not differ (P>0.05). The percentages of HHs relying on different economic activities, except trading, varied significantly (P<0.05) between Metehara and Wonji-Shoa. The major ones were dairying (87.3 *vs* 83.8%), fattening (57.3 *vs* 76%), crop production (32.7 *vs* 63.6%) and employment (40 *vs* 31.8%). The rural and urban HHs producing crops in Wonji-Shoa exceeded that of Metehara Sugar Estate.

Table 4. Characteristics of the farm households in the study areas

	Metehara			Wonji-Shoa			*P*-value
Parameters	Rural (*n*,53)	Urban (*n*,57)	Total (*n*,110)	Rural (*n*,103)	Urban (*n*,95)	Total (*n*,198)	Sugar Estates
Sex of HH head (%):							0.251
Male	86.8	93.0	90.0	92.2	82.1	87.4	
Female	13.2	7.0	10.0	7.8	17.9	12.6	
Age of HH head	41.2	38.7	39.9	41.7	44.0	42.8	0.032
Education of HH head (%):							0.042
Illiterate	39.6	3.5	20.9	8.7	14.7	11.6	
Read and write	24.5	45.6	35.5	37.9	33.7	35.9	
Grade1-8	13.2	26.3	20.0	23.3	10.5	17.2	
Grade 9-12	17.0	21.0	19.1	25.2	34.8	29.8	
≥Diploma	5.7	3.5	4.5	4.9	6.4	5.5	
Family size	6.2	5.5	5.8	6.2	5.6	5.9	0.720
The career of HH (%):							
Dairying	92.5	82.5	87.3	87.4	80.0	83.8	0.444
Animal fattening	58.5	56.1	57.3	83.5	68.4	76.3	0.033
Crop production	60.4	7.0	32.7	94.2	30.5	63.6	<0.001
Employee	34.0	45.6	40.0	15.5	49.5	31.8	<0.001
Trading	9.4	3.5	6.4	4.9	2.1	3.5	0.111
Retired employee	0	1.8	0.9	0	2.1	1.0	0.078

P-value compares within a row total for the two Sugar Estates*; n* = number of respondents; HH= household

4.1.2. Land and livestock holdings

Except for the private grazing land holding that did not differ (*P*=0.127), lands owned for other purposes were higher (*P*<0.001) in Wonji-Shoa than Metehara Sugar Estate (Table 5). The cultivated land holding in Wonji-Shoa (1.64 ha/HH) was about five fold more than in Metehara Sugar Estate. The private grazing land holding was negligible in the study areas, particularly in rural Metehara and urban Wonji-Shoa.

The average total land holding in Wonji-Shoa and Metehara was 1.82 and 0.40 ha/HH, respectively. Total land holding in rural areas of Metehara was 75% lower than in Wonji-Shoa (2.84 ha/HH). In both Sugar Estates, land holding was relatively low in urban than rural farms.

Table 5. Land and livestock holdings of the farm households in the survey areas

	Metehara			Wonji-Shoa			*P-value*
Variables	Rural (*n*,53)	Urban (*n*,57)	Total (*n*,110)	Rural (*n*,103)	Urban (*n*,95)	Total (*n*,198)	Sugar Estates
Land holdings (ha/HH):							
Cultivated land	0.67	0.04	0.35	2.54	0.67	1.64	<0.001
Grazing land	0.00	0.03	0.02	0.10	0.00	0.06	0.127
Residence area	0.04	0.02	0.03	0.19	0.05	0.12	<0.001
Total	0.71	0.10	0.40	2.84	0.72	1.82	<0.001
Livestock holdings (TLU/HH):							
Local cattle	4.50	3.63	4.05	3.95	2.36	3.19	0.004
Crossbred cattle	0.00	0.01	0.01	1.11	2.26	1.66	<0.001
Sheep	0.99	0.08	0.52	0.48	0.11	0.30	0.030
Goat	0.44	0.03	0.23	0.32	0.03	0.18	0.586
Horse	0.35	0.13	0.23	0.26	0.14	0.20	0.528
Donkey	0.18	0.0	0.09	0.49	0.09	0.30	<0.001
Camel	0.42	0.0	0.20	0.0	0.0	0.0	na
Chicken	0.03	0.0	0.02	0.07	0.04	0.05	<0.001
Total	6.90	3.88	5.33	6.67	5.03	5.88	0.235

P-value compares within a row total for the two Sugar Estates; n = number of respondents; HH= household; na = not applicable; TLU = Tropical livestock Unit; Cattle $_{TLU}$ = [Cow (local=1, cross=1.8) + Oxen (local=1.1, cross=1.9) + Bull (local = 0.6, crossbred = 0.8) + Heifer (local = 0.5, crossbred = 0.7) + Calf (local = 0.2, cross = 0.4)], sheep/goat = 0.1, Horse = 0.8, Donkey = 0.5, Mule = 0.7, Camel = 1, Poultry = 0.01; na = not applicable. *Source*: Gryseels (1988) and Bekele Shiferaw (1991).

Total livestock holdings in Metehara and Wonji-Shoa were not different (P=0.235), although it appeared higher for rural than urban farms. However, except lack of difference (P>0.05) for goat and horse holdings, the other livestock holdings varied (P<0.05) between the two Sugar Estates. Cattle holding represented the lion share, with local cattle holding higher (P=0.004) in Metehara than Wonji-Shoa Sugar Estate, while crossbred cattle holding in Wonji-Shoa (1.66) surpassed (P<0.001) that in Metehara (0.01 TLU/HH). Higher sheep and camel, but lower (P<0.05) donkey and chicken were owned in Metehara than Wonji-Shoa. However, none of the Metehara urban HHs owned donkey, camel and chicken.

4.1.3. Feed resources, availability and feeding systems

Feed resources available in the study areas include natural pasture, crop residues, stubble grazing, collected fodder such as SCT and green grass and concentrate feeds (Table 6). Natural pasture grazing and green grass collected from sugarcane plantation fields or its hay were dominantly used (P<0.05) as livestock feed in Metehara than in Wonji-Shoa, while stubble grazing was largely used by Wonji-Shoa HHs (P <0.001). Most rural HHs used natural pasture and stubble grazing than urban HHs. In Wonji-Shoa, grazing resources were limited to small private lands around homesteads, in areas with low crop farming potential (*e.g.*, swampy areas, road and riverside and cropland boundaries).With the exception of maize stover, which was common in Metehara (P<0.05), the other crop-residues were used dominantly as livestock feed in Wonji-Shoa (teff straw, wheat straw and barley straw). However, legume residues, sorghum stover, planted forage crops and bagasse had limited feed use. Remarkably, SCT was used as livestock feed by all of the surveyed HHs. The available concentrate feeds were wheat bran, wheat middling, *noug* seed cake, linseed cake and brewery residues. However, the use of concentrate feeds was more practiced (P<0.05) in Wonji-Shoa than Metehara Sugar Estate. Larger proportion of urban than rural HHs used concentrate for their livestock.

Table 6. Percentage of farm households using different feed resources

	Metehara			Wonji-Shoa			*P*-value
Feed type	Rural (*n*,53)	Urban (*n*,57)	Total (*n*,110)	Rural (*n*,103)	Urban (*n*,95)	Total (*n*,198)	Sugar Estates
Pasture grazing	94.3	12.3	51.8	61.2	5.3	34.3	0.003
Stubble grazing	81.1	8.8	43.6	94.2	26.3	61.6	<0.001
Grass hay	66	47.4	56.4	11.7	24.2	17.7	<0.001
Wheat straw	7.5	7.0	7.3	71.8	40.0	56.6	<0.001
Barely straw	0	0	0	43.7	21.1	32.8	na
Teff straw	35.8	24.6	30.0	99	73.7	86.9	<0.001
Legume residues	1.9	0	0.9	18.4	3.2	11.1	0.001
Maize stover	92.5	47.4	69.1	59.2	49.5	54.5	0.013
Sorghum stover	1.9	0	0.9	5.8	2.1	4.0	0.118
Browse trees/ shrubs	1.9	0	0.9	0	1.1	0.5	0.672
*Planted forage	0	0	0	5.8	3.2	4.5	na
Sugarcane tops	100	100	100	100	100	100	1.000
Green grass	62.3	94.7	79.1	37.9	29.5	33.8	<0.001
Bagasse	3.8	0	1.8	0	0	0	na
Wheat bran	0	47.2	22.7	46.3	72.8	60.1	<0.001
Wheat middling	1.9	24.6	13.6	25.3	55.3	40.9	<0.001
Noug seed cake	9.4	45.6	28.2	12.6	25.2	19.2	0.070
Linseed cake	0	59.6	30.9	8.7	14.7	11.6	<0.001
Cotton seed cake	1.9	7.0	4.5	10.7	22.1	16.2	0.003
Commercial concentrate	0	0	0	4.9	10.5	7.6	na
Molasses	0	1.8	0.9	62.1	43.2	53	0.013
Brewery residue (*atela*)	9.4	38.6	24.5	41.7	52.6	47	<0.001

P-value compares within a row total for the two Sugar Estates; *n* = number of respondents; na = not applicable;* Oat, Vetch, Cowpea, Elephant grass, Rhodes grass, *Sesbania*, *Leucaena*

Feed shortage was noted in the study areas, as evidenced by different proportions of farm households between locations, farming systems and seasons of the year (Figure

3 and 4; pooled for urban/rural). In both Sugar Estates, the proportion of farm households indicating feed supply shortage (range: 9.6-6.1%) was low between June to September, particularly for Wonji-Shoa. Conversely, feed shortage was high in the dry season, which slightly began in October and increased progressively to the end of May, coinciding with the lower rainfall intensity. It peaked in April (94.4%) for Wonji-Shoa and in February (79.1%) for Metehara Sugar Estates. As shown in Figure 4, a relatively larger percentage of rural than urban HHs faced feed supply shortage between June and December. However, the period of high feed supply shortage (October to May) coincides with the sugarcane harvesting season, when the sugarcane byproducts such as SCT are potentially produced and available as livestock feed. According to the respondents, the major causes of feed shortage were (in descending order): lack of grazing land, drought occurrence, lack of forage seeds and land and lack of capital and high cost of feeds.

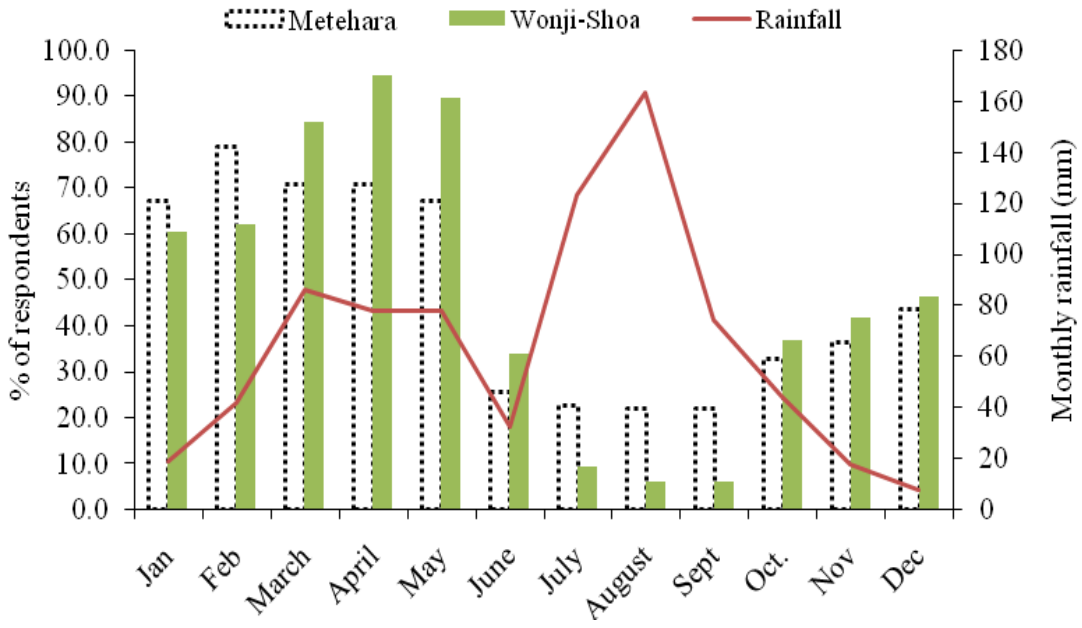


Figure 3. Percent of households who reported feed shortage in Metehara and Wonji-Shoa Sugar Estates

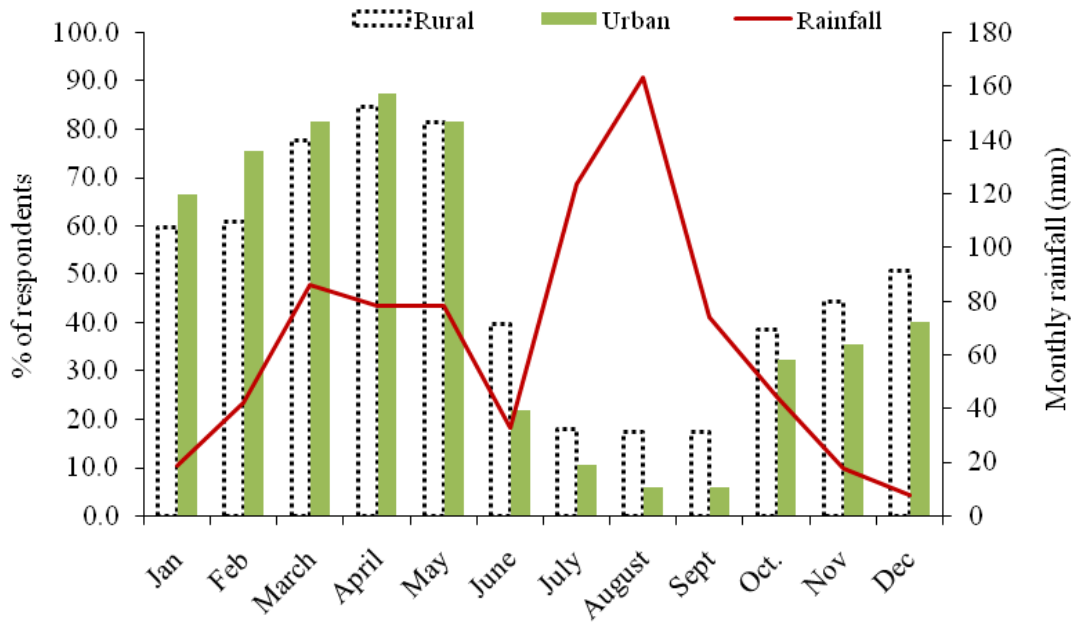


Figure 4. Percent of urban and rural households who reported feed shortage in Metehara and Wonji-Shoa Sugar Estates

The Sugar Estates were different (P<0.001) in livestock feeding systems and sources of water used for livestock (Table 7). Free grazing alone and stall feeding alone were the dominant livestock feeding systems, the former being practiced exclusively by rural HHs and the later by urban HHs (except for 1% HHs in Wonji-Shoa). On average, about 51% of Wonji-Shoa and 42.7% of Metehara HHs used free grazing alone, while sole stall feeding was practiced by 25.3 and 39.1% HHs, respectively. About 24.6% of Metehara and 42.1% of Wonji-Shoa urban HHs practiced both free grazing and stall feeding of their livestock.

Sources of water for livestock in the study areas included Awash river, tap water, pond and irrigation water. Irrigation scheme, targeting sugarcane cultivation was used (P<0.001) mainly by Metehara (26.4%) than Wonji-Shoa(7.6%) HHs. Tap water was more important for urban farms of Metehara (80.7%) than Wonji-Shoa (36.5%). Tap water was also used by 19.4% of the Wonji-Shoa rural HHs. The pond water was used by 43.7% rural HHs in Wonji-Shoa mainly in the dry season, while none of the HHs of Metehara used pond and well-waters for their livestock.

Table 7. Feeding systems and sources of water for livestock in the study areas (% respondents)

Parameters	Metehara			Wonji-Shoa			*P*-value
	Rural (*n*,53)	Urban (*n*,57)	Total (*n*,110)	Rural (*n*,103)	Urban (*n*,95)	Total (*n*,198)	Sugar Estates
Feeding systems :							
Free grazing alone	88.7	0.0	42.7	98.1	0.0	51.0	<0.001
Stall feeding alone	0.0	75.4	39.1	1.0	51.6	25.3	<0.001
Stall feeding and free grazing	0.0	24.6	12.7	1.0	42.1	20.7	<0.001
Tethered grazing	11.3	0.0	5.5	0.0	6.3	3.0	0.9630
Source of water:							
River	64.2	1.8	31.8	29.1	0.0	15.2	<0.001
Tap water	0.0	80.7	41.8	19.4	36.8	27.8	<0.001
Irrigation water	35.8	17.5	26.4	0.0	15.9	7.6	<0.001
Pond water	0.0	0.0	0.0	43.7	0.0	22.7	na
Well water	0.0	0.0	0.0	0.0	10.5	5.1	na
River and tap water	0.0	0.0	0.0	7.8	36.8	21.6	na

P-value compares within a row total for the two Sugar Estates; na=not applicable

n = number of respondents

4.1.4. Feed expenses and consequences of supply shortage

As shown in Table 8, the monthly feed expense per household was 1036.21Birr in Metehara, while 842.67 Birr in Wonji-Shoa Sugar Estate. However, some rural HHs located far away from towns had no access to concentrate feeds, hence relayed largely on private and communal grazing lands, crop residues and to some extent on homemade concentrates. Numerically higher monthly feed cost was noted for urban than rural HHs, which likely affected the promotion of improved urban livestock farming and benefits from them.

Table 8. Monthly feed purchasing expenses (Birr) per household in the study areas

Sugar Estate	Study area	Mean±SE	Minimum	Maximum	*P*-value
Metehara	Rural	557.52±56.8	0.0	1449.17	0.098
	Urban	1472.91±162.9	108.3	4629.17	
	Total	1036.21±99.3	0.0	4629.17	
Wonji-Shoa	Rural	597.00±57.3	0.0	3323.33	
	Urban	1117.72±121.2	50.0	7677.50	
	Total	842.67±67.2	0.0	7677.50	

P-values compare total of the two Sugar Estates; SE= standard error

The supply shortage of quality feeds had negative consequences on the performances of livestock farms (Table 9). A larger proportion of Wonji-Shoa than Metehara households (P=0.004) reported low animal performance (milk yield and/or growth), loss of animal through death (P=0.089), low profit (P=0.005), destocking (P=0.001) and withdrawal from farm operation (P<0.05). In general, most risks associated with feed shortage were relatively low for urban than rural HHs of the Sugar Estates.

Table 9. Impact of feed deficit on the performances of farms (% respondent)

Parameter	Metehara			Wonji-Shoa			*P-value*
	Rural (*n*,53)	Urban (*n*,57)	Total (*n*,110)	Rural (*n*,103)	Urban (*n*,95)	Total (*n*,198)	Sugar Estates
Low performances	90.6	73.7	81.8	89.3	80	84.8	0.004
Animal death	50.9	45.6	48.2	59.2	47.4	53.5	0.089
Destocking	69.8	36.8	52.7	68.9	37.9	54.0	<0.001
Low profit	47.2	19.3	32.7	87.4	82.1	84.8	0.005
Withdrawal from the farm operation	7.5	1.8	4.5	5.8	30.5	17.7	0.001

P-value compares within a row total for the two Sugar Estates; *n* = number of respondents

4.1.5. Production and availability of sugarcane byproducts

The two Sugar Estates were different with respect to the production volume of sugarcane byproducts (SCT, molasses and bagasse) (Table 10). Based on data available, the area of sugarcane field harvested in 2016 was increased by 58% over the base year 2008 in Wonji-Shoa, while the area harvested in Metehara Sugar Estate was variable and not increasing consistently. However, in 2016, the total area under sugarcane plantation was about 12800 hectare (ha) in Wonji-Shoa and 10235 ha in Metehara. During the survey period, Wonji-Shoa sugar factory was operating at 72% of its potential capacity, crushing 4500 tonnes of sugarcane a day, while Metehara sugar factory was operating at 91% of its capacity and crushed 4800 tonnes a day. In Wonji-Shoa, the annual production of sugarcane byproducts between 2008 and 2012 was nearly constant (tonne, fresh weight): SCT, 59151.2; Bagasse, 171433.5; Molasses, 17993.0). However, the amount of sugarcane stalk crushed and the byproducts generated in 2013 were the lowest, since the old factory was not operating until replaced by the new plant at Dodota site. As the new sugar factory commenced production in 2014, the annual production of SCT, bagasse and molasses was increased over the previous years' production.

In Metehara Sugar Estate, the respective average annual production of SCT, bagasse and molasses during 2008-2016 was 105708, 292280 and 35370 tonnes (wet basis), which was over 150% higher than the corresponding production in Wonji-Shoa Sugar Estate. The level of production per unit of sugarcane yield was highest for bagasse, followed by SCT and molasses production. Considering yield estimates for green SCT and area of sugarcane field harvested between 2008 and 2016, the average yield was 12.7 tonne/ha (= 2.9 tonnes of DM) for Wonji-Shoa and 16.1 tonne/ha (= 3.7 tonnes of DM) for Metehara Sugar Estate. However, the actual biomass could be lower than the estimate since certain DM loss is expected due to a pre-harvest burning of sugarcane field. The surplus byproducts that remained after industrial use and domestic sale could have been potentially exploited as livestock feed.

Table 10. Production volume (tonne, fresh weight) of the major sugarcane byproducts in Wonji-Shoa and Metehara Sugar Estates (2008-2016)

Wonji-Shoa Sugar Estate									
Year	2008	2009	2010	2011	2012	2013	2014	2015	2016
Area harvested (ha)	4193	4786	4594	4924	5500	2770	5017	6980	6620
Sugarcane yield*	491298	593727	528756	640791	621037	361733	681671	906240	810465
SCT [1]	50769	61012	54514	65718	63743	37812	69806	92263	82685
Bagasse	148042	180075	159020	187919	182111	109924	209492	278560	275737
Molasses	14872	17522	16080	20089	21403	12883	28138	37146	32811
- Domestic deal[#]	30752	24808	31842	74357	12105	na	192844	81061	59169
Metehara Sugar Estate									
Area (ha)	7130	7633	7393	5789	5043	4985	6960	8198	6745
Sugarcane yield*	1141549	1216376	1186450	1004193	972917	907557	1169710	1110987	803977
SCT yield[1]	114155	121638	118645	100419	97292	90756	116971	111099	80398
Bagasse	316526	336283	329421	276651	266843	252541	323554	308325	220379
Molasses	42482	41679	35830	30967	28898	33685	38001	35417	31367
- Used for ethanol	na	na	28975	31130	27811	36038	35209	18695	11559
- Domestic deal[#]	17773	15376	na	na	13309	na	na	na	18198
Sold abroad[#]	43822	20668	na	na	na	na	na	na	na

* = Sugarcane crushed + seedcane; [1]=Estimated based on sugarcane crushed and seedcane yield (Deshmukh, 1983); [1]Seedcane SCT represented 1.8 -4.3%(*av*., 2.7%) in Wonji-Shoa and 1.0 - 2.1% (*av*., 1.3%) in Metehara Sugar Estates; # Sold from storage tanks; Price of molasses at factory = 68,82 Birr/qt; SCT= sugarcane tops; na = not available; Area of seedcane harvested: Wonji-Shoa -174 ha/year, Metehara - 80.6 ha/year *Source*: Wonji-Shoa and Metehara sugar factories

At Wonji-Shoa sugar factory, molasses was sold for domestic consumption. The major buyers were alcohol producers, commercial feedlots, retailers and smallholder livestock producers. According to the factory's personnel explanation, the volume of molasses generated per unit time exceeded the amount sold to customers from a deposit tank, implying that there existed surplus molasses, which can be potentially exploited as livestock feed. The surplus molasses often reported to cause storage problems at the factory, and therefore dumped or used for road maintenance. However, in Metehara sugar factory, molasses has been used mainly for ethanol production since its inception in 2010, consuming annually 48449.6 tonnes molasses to produce 12,500 cubic meter ethanol. Sometimes the amount of molasses used for ethanol generation or sold for domestic consumption exceeded the production for that year due to additional use from storage tanks. In recent years, the government has permitted the domestic sale of excess molasses found at the sugar factories.

Similarly, the generation of baggase was proportional to the amount of sugarcane crushed at the factory. Part of the bagasse generated has been used as a fuel source in the factory's boiler to generate electricity. The amount of bagasse consumed by a boiler operating at full capacity was about 55 tonne/hr (1320 tonne/day) for Metehara sugar factory, while 70 tonne/hr (1680 tonne/day) for Wonji-Shoa sugar factory. However, due to various operational problems (*e.g.*, low machine efficiency), a boiler usually consumes below capacity, leaving an excess of 45 to 60% bagasse generated. Although the surplus bagasse is sold for domestic users (e.g., *ye betoch lemat* uses it for chip wood production), its huge amount is still dumped and removed by burning.

4.1.6. Farm-level uses and mechanism of attaining sugarcane byproducts

Feed and alternative uses of sugarcane byproducts at the livestock farms are indicated in Table 11. Percentage of HHs using SCT as livestock feed, fuel and income source did not differ (P>0.05) between the Sugar Estates. However, about 37% of Wonji-Shoa HHs and 24% of Metehara HHs utilized SCT for construction purposes (house/fence). The entire surveyed HHs utilized SCT as livestock feed, while over 50% of HHs in Wonji-Shoa and Metehara Sugar Estates utilized SCT as firewood (fuel). A relatively lower proportion of farm HHs used it for construction (roof,

fencing), stall bedding (for calves) and income source (by collecting and selling). Molasses has feed use (P=0.013) both in Wonji-Shoa and Metehara Sugar Estates, while bagasse was barely used only in Metehara.

Table 11. Different uses of sugarcane byproducts for the farm households in the study areas (% respondents)

Parameter	Metehara			Wonji-Shoa			*P*-value
	Rural (*n*,53)	Urban (*n*,57)	Total (*n*,110)	Rural (*n*,103)	Urban (*n*,95)	Total (*n*,198)	Sugar Estates
Sugarcane tops:							
Livestock feed	100	100	100	100	100	100	1.000
Fuel source	62.3	49.1	55.5	44.7	61.1	52.5	0.296
Construction	37.7	36.8	37.3	11.7	37.9	24.2	0.001
Stall bedding	13.2	7	10	0	30.5	14.6	<0.001
Income source	9.4	15.8	12.7	2.9	2.1	2.5	0.442
Molasses:							
Livestock feed	0	1.8	0.9	62.1	43.2	53	0.013
Bagasse:							
Livestock feed	3.8	0	1.8	0	0	0	na

P-value compares within a row total for the two Sugar Estates; *n* = number of respondents; na=not applicable

Sources of sugarcane byproducts and means of attaining them by farmers are shown in Table 12. Sugarcane plantation field of the respective sugar industry was the main source of SCT, except about 7% of Wonji-Shoa HHs, who also produced it on-farm. About 98.2% of Metehara and 91.9% of Wonji-Shoa HHs obtained (P<0.001) SCT by collecting freely from the sugarcane fields, while most HHs also purchased from collectors. Distance from the sugarcane field varied (P=0.002) between the Sugar Estates, which had an effect on the HHs access to SCT. The majority of surveyed HHs were found within a 15 km radius from the source areas, of which 61.8% of Metehara and 52.5% of Wonji-Shoa HHs were found within a 5 km radius distance.

Table 12. Sources of sugarcane byproducts (% respondent), and distance (km) from the homestead

Parameter	Metehara			Wonji-Shoa			*P*-value
	Rural (*n*,53)	Urban (*n*,57)	Total (*n*,110)	Rural (*n*,103)	Urban (*n*,95)	Total (*n*,198)	Sugar Estates
Sugarcane tops:							
Collecting from field	100	96.5	98.2	99.0	84.2	91.9	<0.001
Purchase from collectors	81.1	73.7	77.3	29.1	86.3	56.6	<0.001
Purchase from market	7.5	0	3.6	0	0	0	na
Own farm	0	0	0	6.8	7.4	7.1	na
Distance from field:							
<5km	39.6	82.5	61.8	54.4	50.5	52.5	
5-15km	45.3	17.5	30.9	43.7	49.5	46.5	0.002
15-30km	15.1	0	7.3	1.9	0	1	
Molasses*:*							
Buying from factory	0	0	0	37.9	35.8	36.9	na
Buying from retailers	0	1.8	0.9	4.9	4.2	4.5	0.967
Buying in group from the factory	0	0	0	29.1	14.7	22.2	na
Buying from District Agri. Office	0	0	0	17.5	5.3	11.6	na
Distance from the factory:							
<5km	0	100	100	73.8	94.7	83.8	
5-10km	0	0	0	14.6	5.3	10.1	<0.001
10-20km	0	0	0	11.7	0	6.1	

P-value compares within a row totals for the two Sugar Estates; na = not applicable
SCT = sugarcane tops; *n* = number of respondents

Despite most of the surveyed Metehara HHs were found in close proximity to the factory, feed use share of molasses was negligible (0.9%). Here, the only source of molasses was retailer-shops. However, over half of the farm HHs of Wonji-Shoa used molasses for livestock feeding by purchasing it independently or in group with farmers from the sugar factories, retailer shops and District Agricultural Offices. In Wonji-Shoa, the majority (83.8%) of HHs using molasses as livestock feed were located within 5 km radius from the factory.

4.1.7. Types of sugarcane tops available

Depending on sugarcane production purpose and harvesting method employed, SCT were available in burnt or green form (Figure 5 and 6; pooled for sugar Estates). The prevailing pre-harvest burning practice of sugarcane field has favoured the availability of abundant burnt SCT than the green SCT in the study areas. The farm HHs disclosed that burnt SCT were most available between November and June, coinciding with the green feed scarce period. According to respondent households, SCT availability peaked in March (83.4%) and decreases thereafter, and the lowest between July and October, during which factories cease sugar production and hence no sugarcane harvesting. During this period, some farmers utilized either conserved SCT or that produced on-farm.

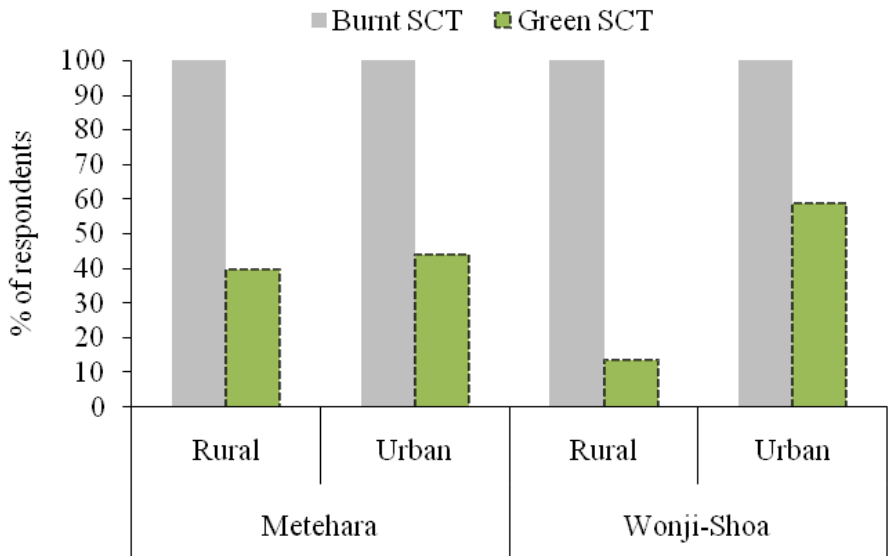


Figure 5.Percentage of households using green/burnt sugarcane tops (SCT) as livestock feed.

Green sugarcane tops are available during seedcane harvesting period, each year between December and March. In Wonji-Shoa Sugar Estate, about 7.1% of livestock farm HHs obtained green SCT and leaves from their own farm often when sugarcane stalk is harvested and sold on the market for income generation. A larger percentage of urban HHs (Metehara, 43.9; Wonji-Shoa, 58.9) than rural HHs (39.6, 13.6) used SCT as livestock feed.

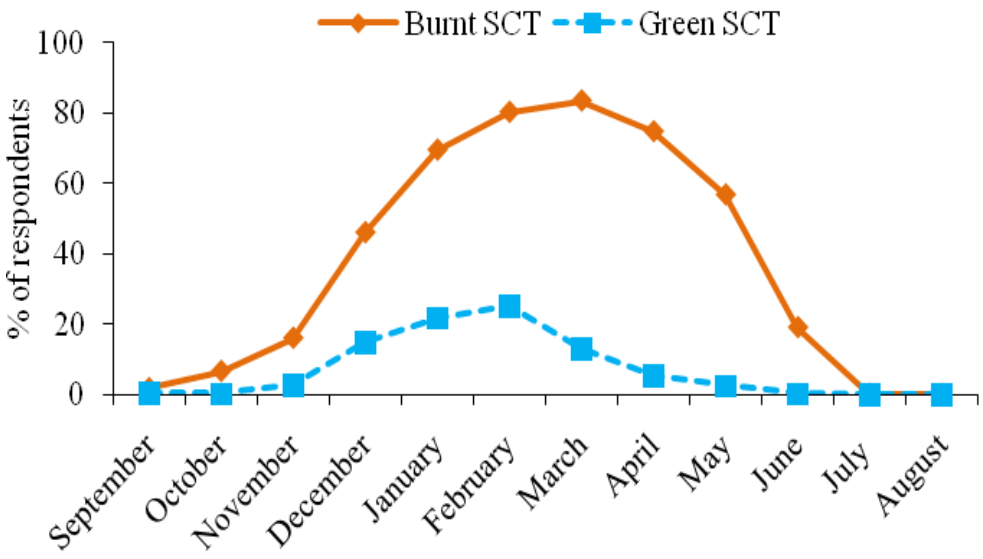


Figure 6. Seasonal availability of burnt and green sugarcane tops (SCT)

4.1.8. Market price of sugarcane byproducts and farmers' preference

The market prices of molasses and SCT in Metehara and Wonji-Shoa Sugar Estates are shown in Table 13. During the survey period, the fixed selling price of molasses was 82 Birr/qt at Wonji-Shoa and 68 Birr/qt at Metehara sugar factory. The price of molasses at retailer shops of Metehara (120 Birr/qt) and Wonji-Shoa (141 Birr/qt) Sugar Estates did not differ significantly ($P>0.05$).

Sugarcane tops were bargained widely in the study areas. A horse cart was the major unit of exchange for SCT bargaining, where local traders were the main suppliers. A horse cart carries a range of 150-250 kg SCT (wet basis), varying with the type and amount of SCT (green/burnt) collected from the field. The average bargaining prices of burnt and green SCT (297.86, 195.5 Birr/cart) in Metehara were three-fold ($P<0.001$) more than in Wonji-Shoa. Distance to sugarcane field from a homestead and the cart size (amount of SCT collected) were the major price determining factors. The other SCT price determinants were: SCT type/variety and quality, transport availability/cost, season, demand level, lack of labour (Appendix Table 2).

Table 13. Market prices of sugarcane byproducts in the study areas

	Metehara			Wonji-Shoa			
	Min	Max	Mean+SE	Min	Max	Mean+SE	*P*-value
Molasses(Birr/qt):							
Factory gate	-	-	82	-	-	68	-
Retailer shop	-	-	120	108	200	141±4.7	0.448
SCT (Birr/horse cart*):							
Burnt SCT	200	375	297.9±5.0	30	180	82.36±3.4	<0.001
Green SCT	150	250	195.5±9.0	25	150	52.39±6.0	<0.001

P-value compares within a row mean of the two Sugar Estates; SCT = sugarcane tops

* caries 150-250 kg SCT

Farmers in the study areas depicted variable preferences for SCT types (Table 14). A large percentage (98) of HHs preferred burnt SCT to green SCT (22.4%), explaining that the later is high in moisture (low in consumable dry matter) and has spines, which causes mouth injury to animals during feeding. Sugarcane tops from thin-stem varieties had got good acceptance by farmers as they are soft, juicy and edible/palatable to an animal with minimum risk of mouth injury. Also, less leafy SCT (36%) were preferred to more leafy ones (1.6%). Farmers witnessed that SCT leaf is slightly burnt with fire (flame) at burning sugarcane fields for harvesting, then after dries fast and become rough and inedible to animals. Certainly, burning has depleted SCT nutrients, which could be largely from the leaf part (Table 18). Of the sugarcane varieties on production during this survey period, farmers perceived that variety- B52298 (Wonj-1), NCo334 and SPY-421 had desirable feed quality, whereas N-14 (Natal), *Burbarius morris* (Barbados) and 341-Mexico were less important as livestock feed. The good varieties had been given different local names: "*Bishoftu, Qachine, Kidhane, Nechi ageda, Shinkurte and Engida",* while the less preferred varieties were named *"Machide, Kerchame, Atana, Wetete and Key ageda*". The nutrient compositions of sugarcane byproducts and other feeds sampled from HHs in the study areas are indicated in Appendix Table 3.

Table 14. Farmers' preferences for green and burnt sugarcane tops(% respondents)

	Metehara (*n*,110)	Wonji-Shoa (*n*,198)	Total (*n*,308)	*P*-value
Burnt SCT	99.1	98.0	98.4	0.673
Green SCT	34.5	15.7	22.4	<0.001
Thin stem SCT	33.6	41.4	38.6	0.115
Thick stem SCT	3.6	7.1	5.8	0.059
SCT with less leaf	32.7	30.8	31.5	<0.001
SCT with more leaf	0.9	2.0	1.6	0.186

P-value compares within row values of the two Sugar Estates; *n* = number of respondents; SCT = sugarcane tops

4.1.9. Feeding, processing and preserving practices of sugarcane byproducts

There were differences ($P<0.05$) between the two sugar Estates in the proportion of farm HHs using sugarcane byproducts as livestock feed (Table 15). Sugarcane tops were principally fed to dairy cattle, as represented by larger proportions of Metehara (91%) and Wonji-Shoa (87%) farm households. Moreover, it was fed to fattening bull/oxen, draught oxen, fattening sheep/goat, equines and camel (in descending order). According to respondents, the green SCT were fed mainly to calves. On the other hand, molasses had limited feed use share in Metehara Sugar Estate, while it was used as supplemental feed for large ruminants, calves, sheep and goats in Wonji-Shoa Sugar Estate.

Table 15. Species/class of livestock feeding sugarcane byproducts (% respondents)

Parameter	Metehara			Wonji-Shoa			*P*-value
	Rural (*n*,53)	Urban (*n*,57)	Total (*n*,110)	Rural (*n*,103)	Urban (*n*,95)	Total (*n*,198)	Sugar Estates
Sugarcane tops:							
Dairy cows (all)	98.1	84.2	90.9	88.3	86.3	87.4	0.090
Lactating cows	98.1	71.9	84.5	84.5	65.3	75.3	<0.001
Dry cows	96.2	47.4	70.9	86.4	78.9	82.8	<0.001
Pregnant cows	94.3	36.8	64.5	87.4	61.1	74.7	<0.001
Heifers	83.0	26.3	53.6	63.1	70.5	66.7	0.004
Calves	83.0	61.4	71.8	58.3	60.0	59.1	0.263
Fattening bull/oxen	75.5	49.1	61.8	85.4	81.1	83.3	0.008
Draught oxen	54.7	5.3	29.1	66.0	16.8	42.4	<0.001
Fattening shoat	34.0	3.5	18.2	20.4	11.6	16.2	<0.001
Equines	20.8	1.8	10.9	6.8	3.2	5.1	0.002
Camel	3.8	0	1.8	0	0	0	na
Molasses:							
Dairy cows (all)	0	0	0	46.6	35.8	41.4	na
Lactating cows	0	0	0	46.6	30.5	38.9	na
Dry cows	0	0	0	40.8	22.1	31.8	na
Pregnant cows	0	0	0	24.5	14.7	19.8	na
Fattening cattle	0	1.8	0.9	52.4	25.3	39.4	<0.001
Fattening sheep/ goat	0	1.8	0.9	7.8	0	4.0	0.020
Draught oxen	0	0	0	32.0	3.2	18.2	na
Heifers	0	0	0	26.2	18.9	22.7	na
Calves	0	0	0	11.7	8.4	10.1	na

P-value compares within a row total for the two Sugar Estates; na = not applicable;
n = number of respondents

Farmers' experience in feeding practices of molasses to animals is shown in Table 16. On average, large ruminants were fed a range of 1-3 jugs (=1.6-4.8 kg) of molasses a day, while sheep and goats about 0.5-1 jug (0.8-1.6 kg) molasses a day. In Wonji-

Shoa, molasses was fed by mixing with water, or concentrate feeds and also soaked with dry roughages diluted or undiluted with water (Figure 7). When fed mixed with water, the ratio of water to molasses used varied significantly (P<0.002) between the two Sugar Estates, which depends on the type and amount of feedstuff fed. About 34-35% of Wonji-Shoa HHs used a mixing ratio of 1-6:1(weight/weight), while ratios below 1:1 were less used. However, about 21% of rural HHs in the study areas used water to molasses ratio exceeding 6:1. The drier the feed, the higher mixing ratios were used.

The advantages of feeding SCT and molasses to animals were described by farmers, which included highly edible, increases the palatability and intake of roughages, increases water uptake by an animal, increases milk yield of lactating cows, animals gain fast and their coat colour appears shiny and reduces production cost by replacing costly concentrates.

Table 16. Amount of molasses fed to animals, and the percentage of households using different water to molasses mixing ratios

Amount fed (jug/day)					
Sugar Estate	Cows	Fattening Ox/Bull	Heifer	Calf	Sheep/Goat
Wonji-Shoa	1.42(1-3)	1.49(1-3)	1.1(0.5-2)	0.65(0.5-1)	0.56(0.5-1)
Metehara	0	2	0	0	0.5
Mixing ratio (water:molasses, wt/wt)					
	Wonji-Shoa		Metehara		
Mixing ratio	Urban	Rural	Urban	Rural	
<1:1	4.2	1.9	na	na	
1-6:1	34.8	33.9	na	na	
>6:1	2.1	21.4	1.8	na	

1jug ≈1.6kg; na = not available

About 98.2% of Metehara and 63.6% of Wonji-Shoa HHs offered intact SCT (neither chopped nor blended with other feeds) to their animals, while the HHs offering

chopped SCT represented 43 and 85%, respectively (Figure 7). In Wonji-Shoa Sugar Estate, chopped SCT was fed to animals by mixing with other roughages, purchased concentrates, molasses, salt or brewery and distillery residues or by soaking with water. Farmers manually chopped SCT during feeding them to animals to increase consumption and reduce wastage and risk of mouth injury. The proportion of farm HHs who chopped and offered SCT alone to their animals was higher for Wonji-Shoa, while feeding sole unchopped SCT was commonly practiced in Metehara. Molasses was fed to animals usually after blending with water and other feedstuffs mainly by farm households of Wonji-Shoa Sugar Estate.

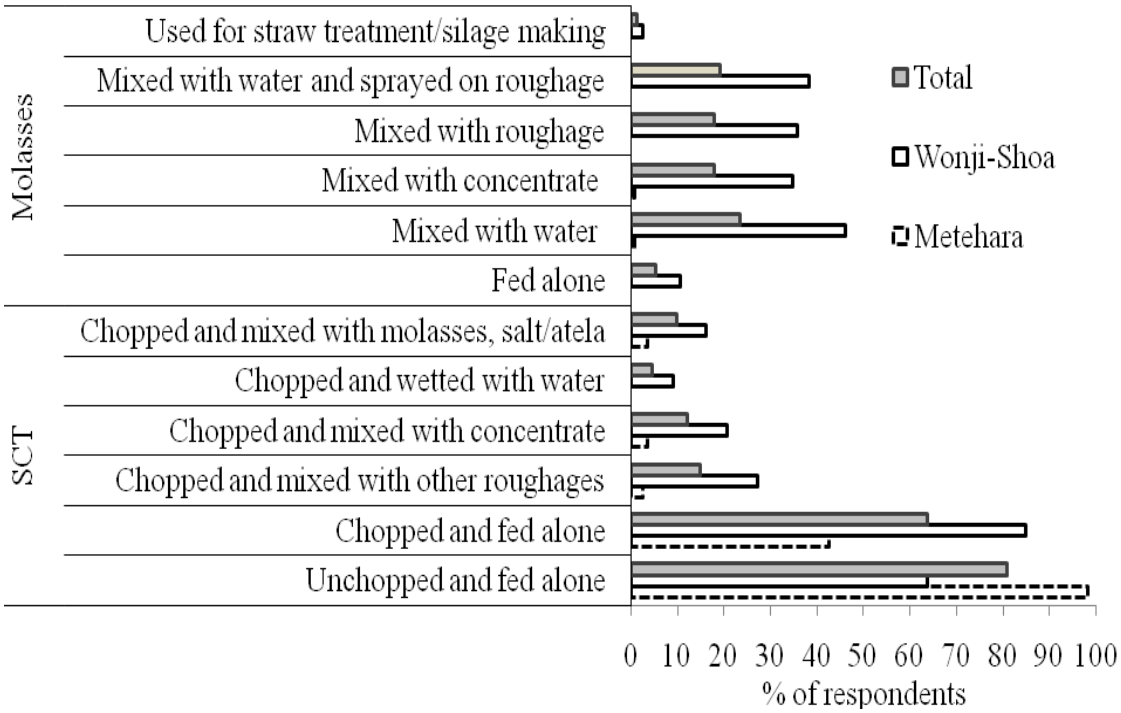


Figure 7. Processing and feeding practices of sugarcane tops and molasses

Large proportions of Metehara and Wonji-Shoa HHs conserved the burnt SCT, while a small proportion of HHs conserved green SCT (Table 17). In the study areas, sun-drying of SCT was more practiced compared to under-shed drying before storing. Farmers stacked SCT mainly in an open-air, or along fences and in sheds.

Table 17. Farmers' preserving practices of sugarcane tops and quality loss at storage (% respondents)

Parameter	Metehara			Wonji-Shoa			P-*value*
	Rural (*n*,53)	Urban (n,57)	Total (*n*,110)	Rural (*n*,103)	Urban (*n*,95)	Total (*n*,198)	Sugar Estates
Type of SCT preserved:							
Green SCT	32.1	38.6	35.5	11.7	45.3	27.8	<0.001
Burnt SCT	98.1	98.2	98.2	99	100	99.5	0.577
Drying method:							
Sun drying	100	96.5	98.2	69.9	92.6	80.8	<0.001
Shed drying	34.0	29.8	31.8	62.1	16.8	40.4	<0.001
Storage condition:							
Stacked in an open air	86.8	96.5	91.8	75.7	96.8	85.9	<0.001
Stacked under shed	35.8	61.4	49.1	46.6	29.5	38.4	0.790
Stacked along fence	58.5	0	28.2	51.5	56.8	54.0	0.001
Storage duration:							
1week-1 month	24.5	47.4	36.4	28.2	24.2	26.3	0.006
1-≤ 4 month	54.7	47.4	50.9	54.4	31.6	43.4	
4 -8 month	18.9	5.3	11.8	14.6	29.5	21.7	
>8 month	1.9	0	0.9	2.9	14.7	8.6	
Quality loss characteristics:							
No quality loss	9.4	1.8	5.5	17.5	3.2	10.6	<0.001
Bad smell	88.7	53.6	70.6	66.0	92.6	78.8	0.365
Color change	69.8	66.1	67.9	74.8	87.4	80.8	0.188
Mold incidence	81.1	73.2	77.1	68.0	58.9	63.6	0.122
Rough in texture	34.0	0	16.5	39.8	42.1	40.9	0.034

P-value compares within a row total for the two Sugar Estates; SCT = sugarcane tops
n = number of respondents

The storage duration of SCT varied (*P*=0.006) between farm HHs of the two sugar Estates, where 87.3% of Metehara and 69.7% of Wonji-Shoa HHs stored SCT for a week to four months period for use as livestock feed. Other farms stored SCT for a period longer than eight months. Most of the surveyed HHs in Metehara and Wonji-

Shoa observed the quality loss of SCT upon storing for a longer period. This works for the green and burnt SCT that stored without adequate drying after taken from the field. Farmers perceived SCT spoilage by a bad smell, colour change to dark brown, mold appearance and leaves become hard in texture and inedible to animals.

4.1.10. Farmers' perceived constraints on sugarcane byproducts

About 89% of the surveyed HHs did not receive technical supports on processing, conservation and proper feeding of SCT (Figure 8). Low nutritive quality of SCT particularly that stored for a longer period, and lack of transport were principal challenges to livestock farmers. Less important constraints were health risks (mouth injury) associated with feeding unchopped SCT and lack of labour and capital. Farmers in the study areas had the interest to purchase mechanical chopper for processing SCT, but had no information and support from the supply side. Recently, "Wonji Sugarcane Growers Union" purchased a chopper to help farmers chop SCT for complete feed preparation. With regards to molasses, major challenges were lack of suppliers and knowledge on feeding management and risks associated with improper feeding (e.g. diarrhea, rumen acidosis-locally named "stomach burning").

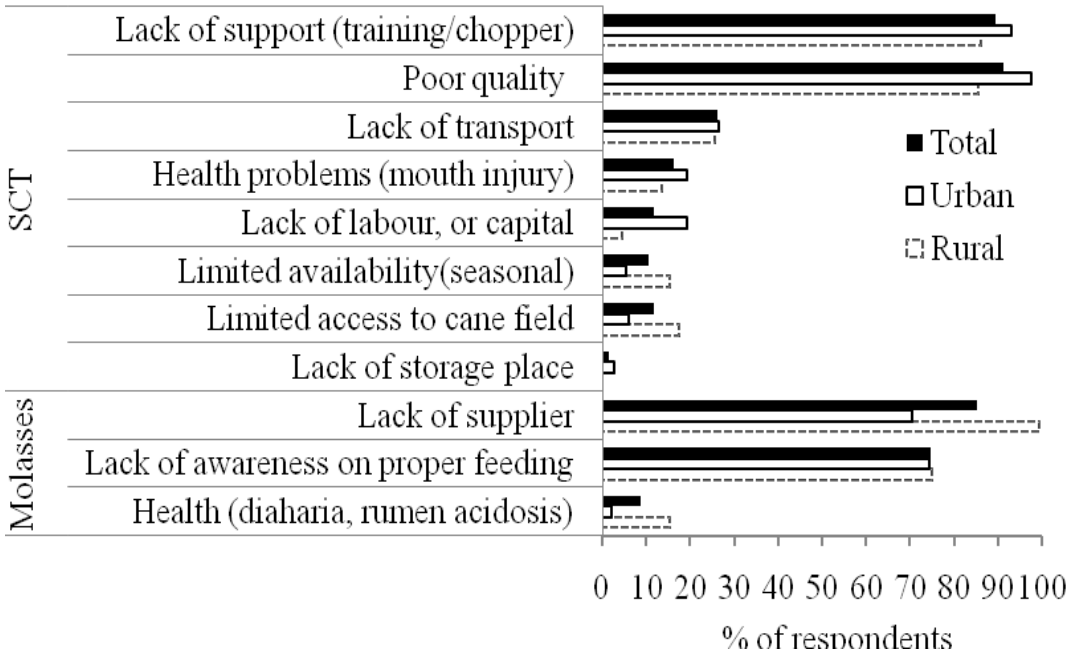


Figure 8. Major constraints facing farmers in using sugarcane byproducts as feed

4.2. Sugarcane tops Silage Experiment

4.2.1. Chemical composition of sugarcane tops and molasses

The chemical composition of SCT and molasses used for conservation trials are indicated in Table 18. The burnt and green SCT did not differ markedly in nutrient contents. However, the burnt SCT had slightly lower contents of CP and non-fiber carbohydrate (NFC), but was higher in other nutrients, except ADF which was the same for the SCT types, than the green SCT. Burning increased DM by 18.6% and total ash by 8.3%, but decreased CP by 11.6% and NFC by 7% over the green SCT.

Table 18. Chemical composition (% DM) of fresh sugarcane tops (N-14) and molasses used in this study

Parameters	Green SCT (*n*,5)	Burnt SCT (*n*,5)	Molasses (*n*,2)
Dry matter (%)	23.05	27.34	75.07
Crude protein	2.77	2.45	3.15
Ash	10.80	11.70	14.04
Ether extract	1.22	1.42	ND
Neutral detergent fiber	68.40	68.80	0.30
Acid detergent fiber	39.20	39.20	0.11
Acid detergent lignin	5.40	6.40	0.12
Hemicelluloses	29.20	29.60	0.19
Calcium	0.38	0.56	1.30
Phosphorus	0.19	0.33	0.90
In vitro organic matter digestibility	47.03	48.22	nd
Metabolizable energy (MJ/kg DM)	7.52	7.71	nd
Non-fiber carbohydrate (NFC)	16.81	15.63	nd

n = number of replicates; nd = not determined; SCT = sugarcane tops

4.2.2. Silage physical properties and total dry matter loss

Silage physical properties as affected by the additives and SCT harvesting type are indicated in Table 19 and 20. The pH of pre-ensiled SCT treated with urea alone was higher (P<0.05) compared to untreated SCT (control), but no variation among the treated forages, partly indicating the buffering effect of urea even at the initial stage. Regardless of the treatments used, the initial pH was higher (P=0.0025) in green than in burnt SCT. The pH of SCT after 45 days of fermentation was significantly (P<0.05) affected by the interaction of treatment and SCT types, where the burnt SCT were not affected by the treatment type, while in green SCT silage pH was higher (P<0.001) with urea based additives compared to control or that treated with 4% molasses. On the other hand, except for SCT treated with 1% urea + 4% molasses where the pH was lower for the burnt SCT silage, the pH of the burnt and green SCT were similar for the other urea based treatments. Sugarcane tops ensiled with molasses exclusively had similar pH with silages without additive (control). However, when green SCT was ensiled with urea exclusively, its pH was significantly (P<0.05) higher than that of control silage. On the other hand, when molasses was used in combination with urea it failed to significantly counteract the effect of urea alone to reduce silage pH both in green and in burnt SCT silages.

There were treatment effect and treatment and SCT type interaction effect (P<0.05) on the silage total dry matter loss (TDML) and temperature. No significant (P>0.05) difference in TDML among treatments based burnt SCT, but was lower (P<0.05) in green SCT ensiled with molasses alone than with urea based additive. Treating green SCT with urea alone resulted in three-fold more TDML compared to that treated with molasses alone (2.31 *vs* 8.19%) or molasses+urea solution (2.31 *vs* 8.5%). On the other hand, silage temperature measured upon opening the silos were ranged from 26 to 29.8˚C. However, the values were similar (P>0.05) among treatments for the burnt SCT, while for green SCT the temperature of molasses alone treated silage was lower than the other treatments.

Table 19. pH, temperature and total DM loss of sugarcane tops (SCT) ensiled with or without urea, molasses and their combination used as additives

Parameter	SCT type	Treatment (T)					SCT type			Effect (*P-value*)		
		Control	Mol. -4%	Urea -1%	Urea1%+ Mol 4%	SEM	Burnt	Green	SEM	SCT type	T	SCT type x T
pH*i*		5.54^{b}	5.64^{ab}	5.72^{a}	5.64^{ab}	0.03	5.58^{b}	5.69^{a}	0.02	0.0025	0.0051	0.7953
pH @45d	Burnt	4.13^{b}	4.19^{b}	4.69^{ab}	4.18^{b}	0.15				0.0007	<.0001	0.0007
	Green	4.04^{b}	4.14^{b}	5.30^{a}	5.28^{a}							
TDML	Burnt	3.13^{bc}	6.06^{abc}	5.95^{abc}	5.00^{abc}	1.17				0.1651	0.0319	0.0149
(%)	Green	5.81^{abc}	2.31^{c}	8.19^{ab}	8.50^{a}							
Temp.	Burnt	29.00^{ab}	29.80^{a}	29.80^{a}	29.40^{ab}	0.31				<0.0001	0.0004	<.0001
(°C)	Green	29.40^{ab}	26.00^{c}	28.9^{ab}	28.10^{b}							

[a-c] Means with different superscript letters in the same row and column for each parameter differ (P<0.05); pH*i* = pH before ensiling; TDML = total DM loss; Mol. = molasses; Temp.= temperature; d= day; SEM = standard error of the mean

Table 20. Average subjective scores (*scale: 1-4) for physical properties of sugarcane tops (SCT) ensiled with or without urea, molasses and their combination used as additives

Parameter	SCT type	Treatment (T)					SCT type			Effect (*P-value*)		
		Control	Mol-4%	Urea-1%	Urea-1% +Mol 4%	SEM	Burnt	Green	SEM	SCT type	T	SCT type x T
Smell		3.23^{b}	3.81^{a}	3.48^{ab}	3.63^{a}	0.09	3.65^{a}	3.42^{b}	0.06	0.0161	0.0010	0.1427
Color		3.53^{ab}	3.63^{a}	3.59^{ab}	3.24^{b}	0.10	3.42	3.57	0.07	0.1304	0.0335	0.5066
Texture	Burnt	3.79^{ab}	3.51^{bc}	3.63^{abc}	3.37^{c}	0.06				<0.0001	0.0047	0.0031
	Green	3.82^{a}	3.91^{a}	3.64^{abc}	3.76^{ab}							
Moldiness		3.09^{b}	3.67^{a}	3.08^{b}	3.16^{ab}	0.13	3.45^{a}	3.05^{b}	0.09	0.0049	0.0110	0.1874
pH	Burnt	3.20^{a}	3.20^{a}	1.80^{b}	3.20^{a}	0.25				0.0092	<.0001	0.0003
	Green	3.60^{a}	3.00^{a}	1.60^{b}	1.20^{b}							
Average		3.41^{ab}	3.58^{a}	3.1^{c}	3.16^{bc}	0.07	3.39^{a}	3.23^{b}	0.05	0.0328	<.0001	0.2594

[a-c] Means with different superscript letters in the same row and column for each parameter differ (*P< 0.05*); *(1- bad; 2-moderate;3-good; 4-excellent) Mol = molasses; SEM = standard error of the mean

Except for texture and pH, there was no significant (P>0.05) interaction between treatment and SCT type on the average score values of silages (Table 20). The average score value for the smell was higher (P<0.001) for molasses based additives compared to control, and was also higher (P<0.0025) in the burnt than the green SCT silage. The score for color was lower (P>0.05) in silages treated with molasses+urea than with molasses alone. The score for texture was higher (P=0.0047) in molasses based treatments of the green SCT than burnt SCT silages. Among the burnt SCT based treatments, the texture score was lower in molasses+urea treated silage than control silage. Moldiness score was greater with molasses based additives and was higher in burnt than green SCT silages. Generally, a slight mold was observed on top of all silos, which could be due to air trapped while sealing the silos. The score of pH was low in burnt SCT ensiled with urea alone and in green SCT ensiled with urea based additives. The best overall average score values were attained in SCT ensiled without additive or with 4% molasses alone and in burnt than green SCT silage.

4.2.3. Change in the chemical composition of silage

There was a significant interaction between treatments and SCT types (P<0.05) on the chemical composition of silages except for ether extract (Table 21). Dry matter content of pre-ensiled burnt SCT was higher for 4% molasses+1% urea treatments than for molasses alone or urea alone treated ones, while among the green SCT it was the highest in molasses+urea added treatments. The addition of molasses increased (P<0.05) the DM content of green SCT silages compared to control silage or that treated with urea alone. On average, DM content was reduced by 3.4% in burnt SCT silage and by 5.9% in green SCT silage compared to the DM content of the respective pre-ensiled materials. The addition of molasses alone did not alter (P>0.05) the CP content of the green and burnt SCT silages compared to control silages. However, SCT ensiled with urea based additives had significantly higher (P<0.05) CP content than the treatments without additive.

The additives had variable effects (P<0.05) on the content of silage fiber components. In green SCT silage, NDF content increased (P = 0.0003) with urea based additives, while ADF decreased (P<0.0001) with molasses based additives. However, in burnt

SCT silage NDF and ADF were lower (P=0.0003; P<0.0001) with 4% molasses+1% urea than with urea alone used as additives. The addition of molasses alone lowered NDF in green than burnt SCT silage, while it was reduced in burnt than green SCT ensiled with urea and molasses solution.

The *in vitro* OM digestibility (IVOMD) and ME contents were lowest (P<0.0001) in green SCT ensiled exclusively with urea, but were highest (P<0.0001) in burnt SCT ensiled with urea + molasses. Except for the molasses treated silages that did not differ significantly (P>0.05) between SCT types, higher OM digestibility values were obtained in the burnt than green SCT silages.

The lowest NFC content (1.65%) was observed in green SCT silage treated with urea + molasses, followed by green SCT ensiled with urea alone. The highest (P<0.0001) NFC contents were obtained in green SCT ensiled without additive and with molasses alone. Also, the burnt SCT ensiled without additive, and with molasses and 1% urea + 4% molasses had the highest (P<0.0001) NFC content. Ether extract contents of the silages were not affected by SCT types and treatment (P>0.05).

Table 21. Nutrient contents (%DM) and digestibility of SCT ensiled with or without urea, molasses and their combination as additives

Variable	Bunt SCT silage				Green SCT silage					Effect (*P*-value)		
	Control	Mol-4%	Urea-1%	Urea1%+ Mol 4%	Control	Mol-4%	Urea-1%	Urea1% +Mol4%	SEM	SCT type	T	SCT*T
DM*i*	34.97^{e}	35.57^{ced}	35.48^{ed}	36.24^{bc}	35.12^{e}	36.55^{b}	36.16^{bcd}	37.42^{a}	0.15	<.0001	<.0001	0.0164
DM	34.45^{ab}	34.09^{b}	33.94^{b}	34.9^{ab}	33.50^{b}	36.26^{a}	34.03^{b}	35.22^{ab}	0.41	0.1673	0.0051	0.0059
Ash	11.90^{dc}	11.50^{de}	11.92^{dc}	10.97^{e}	13.76^{b}	12.30^{c}	14.17^{ab}	14.76^{a}	0.17	<.0001	<.0001	<.0001
CP	2.75^{c}	2.82^{c}	3.91^{ab}	4.00^{ab}	3.15^{c}	2.80^{c}	3.67^{b}	4.09^{a}	0.09	0.3892	<.0001	0.0096
EE	1.443	1.464	1.437	1.467	1.592	1.466	1.427	1.702	0.084	0.1241	0.3065	0.4080
NDF	68.20^{cd}	70.20^{bc}	70.80^{bc}	67.40^{d}	66.20^{d}	67.00^{d}	72.40^{b}	77.80^{a}	0.59	0.0003	<.0001	<.0001
ADF	40.80^{bc}	39.40^{bc}	41.40^{b}	35.60^{c}	46.00^{a}	38.80^{c}	44.80^{a}	41.60^{b}	0.52	<.0001	<.0001	<.0001
ADL	7.55^{ab}	6.69^{bcd}	7.05^{abc}	7.87^{a}	6.12^{de}	5.59^{e}	6.77^{bcd}	6.55^{dc}	0.20	<.0001	<.0001	0.0306
Hemi	27.40^{d}	30.80^{bc}	29.40^{bcd}	31.80^{b}	20.20^{e}	28.20^{dc}	27.60^{dc}	36.20^{a}	0.73	0.0015	<.0001	<.0001
IVOMD	45.95^{b}	45.05^{b}	44.61b^{c}	48.34^{a}	42.84^{c}	44.25^{bc}	40.20^{d}	44.21^{bc}	0.42	<.0001	<.0001	0.0009
ME	7.35^{b}	7.21^{b}	7.14^{bc}	7.74^{a}	6.85^{c}	7.08^{bc}	6.43^{d}	7.07^{bc}	0.07	<.0001	<.0001	0.0009
NFC	15.70^{a}	14.01^{ab}	11.93^{b}	16.17^{a}	15.29^{a}	16.43^{a}	8.34^{c}	1.65^{d}	0.60	<.0001	<.0001	<.0001
Ca	0.40^{d}	1.44^{a}	0.91^{bc}	1.32^{a}	0.43^{d}	0.65^{d}	0.59^{cd}	1.16^{ab}	0.08	<.0001	<.0001	0.0002
P	0.30^{cd}	0.51^{ab}	0.64^{a}	0.13^{e}	0.27^{d}	0.59^{a}	0.43^{bc}	0.38^{bcd}	0.03	0.3178	<.0001	<.0001

[a-e] Means within treatment and SCT type with different superscript letters in the same row differ (P<0.05); SCT = sugarcane tops; DM*i* = Dry matter of pre-ensiled forage; DM= dry matter of silage; CP= crude protein; NDF/ADF = neutral/acid detergent fiber; ADL= acid detergent lignin; Hemi.= hemicelluloses; ME = Metabolizable energy; IVOMD = *In-vitro* organic matter digestibility; NFC= non-fibrous carbohydrate; Mol=molasses; T= treatment; SEM= standard error of mean.

4.3. Sugarcane Tops Hay Experiment

4.3.1. Drying rate and dry matter content of SCT

Drying methods had an effect ($P<0.0001$) on the moisture loss of SCT samples as evidenced by the different dehydration rates (Figure 9 and Table 22). The overall lowest ($P<0.0001$) moisture loss rate was attained by the shed-dried intact SCT (0.96% per day), followed by the sun-dried intact SCT (1.35% per day), which took 68 and 60 days for green and burnt samples, respectively, to attain the safest moisture (average, 14.4%) for storage. However, the average dehydration rate was not affected ($P>0.05$) by -SCT type. The sun-dried chopped burnt and green SCT attained 86.4% and 85.3% DM at day 3, losing moisture at a rate of 19.8 and 20.7% per day, respectively, which significantly ($P<0.0001$) surpassed the other drying methods. Except for the chopped SCT dried in the sun, the rate of moisture loss during the first 8 days was nearly the same in the other two drying methods, where the sun-and shed-dried intact green SCT lost moisture at 2% and 1.9% per day, respectively. Similarly, the respective moisture loss rate during the first 18 days for the sun- and shed-dried intact burned SCT was 1.4 and 1.2% per day. The drying rate of the intact SCT was peaked between 18^{th} and 24^{th} days, except for the sun-dried intact green SCT that peaked between 24^{th} and 34^{th} days, when the relative humidity (RH) dropped below 60% and the mean ambient temperature was moderate (range:13.5-15°C) (Figure 2). However, the mean DM contents of SCT over the drying period did not differ ($P>0.05$) among the drying methods and between the SCT types.

Table 22. Average drying rate (% per day) and DM content in the green and burnt SCT subjected to different drying methods

Parameter	Drying methods (T)				SCT type			*P*-value		
	Intact, Sun-dried	Chopped, Sun-dried	Intact, Shed-dried	SEM	Burnt	Green	SEM	SCT type	T	SCT type x T
Drying rate	1.35[b]	20.27[a]	0.96[c]	0.167	7.37	7.69	0.140	0.1094	<0.0001	0.2006
Mean %DM (over drying time)	47.3	63.2	52.5	6.27	56.0	52.6	5.24	0.6491	0.2912	0.9877

[a-c] Means within treatment and SCT type with different superscript letters in the same row differ ($P<0.05$) ($P < 0.05$); SCT = sugarcane tops ; SEM = standard error of the mean; DM = dry matter

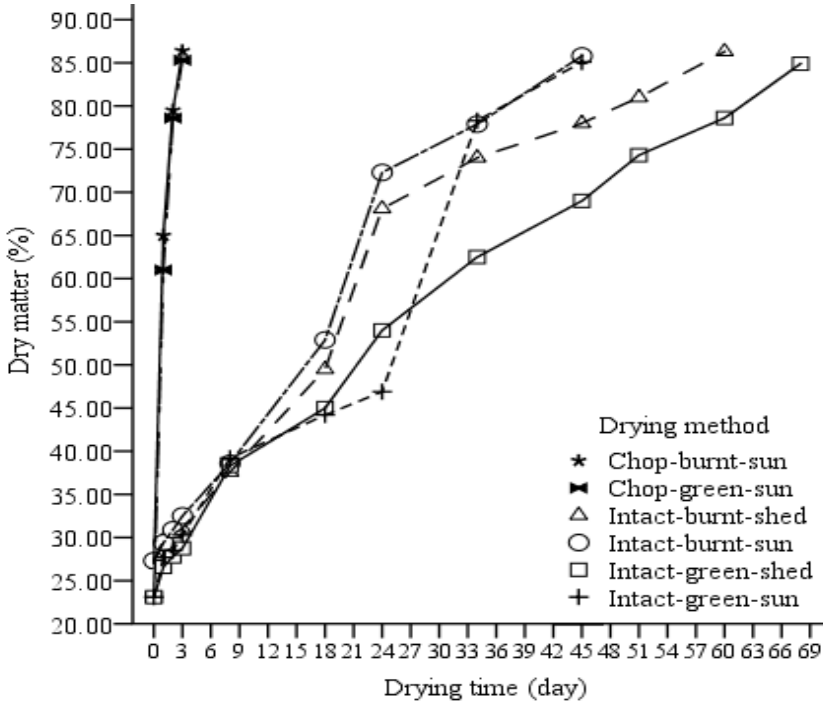


Figure 9. Dehydration curve of intact and chopped green and burnt sugarcane tops dried in the sun and shed

4.3.2. Effect of drying methods on SCT quality

The drying methods had variable effects on the nutrient contents of SCT hay (Table 23). The DM and CP contents of SCT were unaffected ($P>0.05$) both by drying method and SCT type. Ether extract content was highest for sun-dried chopped SCT and lowest for shed-dried intact SCT ($P<0.05$), while values for the burnt and green SCT were similar ($P>0.05$). There were significant ($P<0.05$) interaction effect of drying methods and SCT types on ash, NDF, ADL, IVOMD, ME, NFC and P contents, which implies that the burnt and green SCT were differently affected by drying. Except for the sun-dried intact SCT that did not vary ($P>0.05$), the NDF content was lower ($P<0.001$) in the green than burnt SCT for the other two drying methods. For burnt SCT, NDF content was lower ($P<0.05$) in sun-dried intact samples as compared to the other drying methods, but values for the green SCT were similar ($P>0.05$) among the drying methods. However, ADF contents of the sun- and shed-dried intact SCT were not significantly ($P>0.05$) different, while the values for sun-dried chopped samples were lower ($P<0.0002$) than the other two drying methods.

The hemicellulose contents were higher ($P<0.05$) for sun-dried chopped SCT, and did not vary ($P>0.05$) for shed- and sun-dried intact SCT. However, the green SCT hay had lower ($P<0.0001$) hemicelluloses content than the burnt SCT hay. The NFC content showed an opposite trend to that of the fiber fractions and was lower ($P<0.05$) in the sun-dried chopped burnt SCT and shed-dried intact burnt SCT than the intact sun-dried forages and intact shed-dried green SCT. However, shed-dried intact green SCT had higher NFC content than sun-dried chopped green SCT ($P<0.05$).

In vitro OM digestibility and ME contents of the burnt SCT were not affected ($P>0.05$) by the drying methods. For the green SCT, *in vitro* OM digestibility and ME contents were higher for chopped sun-dried samples as compared to the other drying methods. This is consistent with the lower ADF content in chopped sun-dried SCT.

Table 23. Nutrient composition (% DM) and *in vitro* OM digestibility of green and burnt SCT subjected to different drying methods

		Drying methods (T)				SCT type			*P*-value		
Parameter	SCT type	Intact, Sun-dried	Chopped, Sun-dried	Intact, Shed-dried	SEM	Burnt	Green	SEM	SCT type	T	SCT type x T
Dry matter (%)		85.45	85.83	85.62	1.00	86.17	85.10	0.81	0.3609	0.9652	0.9780
Ash	Burnt	9.62^{c}	11.10^{ab}	10.30^{bc}	0.18				0.1557	<.0001	<.0001
	Green	10.90^{ab}	11.20^{a}	9.58^{c}							
Crude protein		2.51	2.56	2.47	0.07	2.47	2.56	0.06	0.3282	0.6642	0.1913
Ether extract		0.90^{c}	1.36^{a}	1.14^{b}	0.05	1.14	1.12	0.04	0.7125	<.0001	0.6291
NDF	Burnt	70.40^{b}	72.91^{a}	73.20^{a}	0.47				<.0001	0.0025	0.0362
	Green	69.20^{b}	70.12^{b}	69.40^{b}							
ADF		39.50^{a}	37.70^{b}	41.10^{a}	0.47	38.93	39.93	0.39	0.0793	0.0002	0.5912
ADL	Burnt	6.04^{a}	6.25^{a}	6.47^{a}	0.24				0.0258	0.0007	0.0008
	Green	6.38^{a}	4.56^{b}	6.41^{a}							
Hemicelluloses		30.30^{b}	33.82^{a}	30.20^{b}	0.61	33.24^{a}	29.64^{b}	0.50	<.0001	0.0003	0.1097
IVOMD	Burnt	42.15^{abc}	43.48^{ab}	41.93^{abc}	0.77				0.0545	0.0003	0.0237
	Green	38.85^{c}	44.77^{a}	40.04^{bc}							
ME (MJ/kg DM)	Burnt	6.88^{ab}	6.96^{ab}	6.71^{abc}	0.14				0.0441	0.0028	0.0232
	Green	6.22^{c}	7.16^{a}	6.41^{bc}							
NFC	Burnt	16.74^{ab}	12.07^{d}	12.82^{cd}	0.52				<.0001	<.0001	0.0002
	Green	16.31^{ab}	14.76^{bc}	17.2^{a}							
Calcium	*Burnt*	0.58^{b}	0.59^{b}	0.68^{a}	0.02	0.61	0.63	0.01	0.3723	0.0004	0.1990
Phosphorous	Burnt	0.33^{abc}	0.31^{bc}	0.37^{ab}	0.02				0.0017	<.0001	<.0001
	Green	0.16^{d}	0.28^{c}	0.41^{a}							

[a-d] Means with different superscript letters in the same row and column for each parameter differ ($P < 0.05$); SEM = standard error of the mean; DM = dry matter; NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin; IVOMD = *In-vitro* organic matter digestibility; ME = metabolizable energy; NFC=non-fiber carbohydrate

4.4. Sheep Feeding Experiment

4.4.1. Nutrient intake

The average daily DM intake (g/day) of lambs varied (P<0.05) among the dietary treatments (Table 24). The higher (P<0.05) roughage and total DM intakes were observed in T_1, T_2 and T_4 compared to T_3. However, the roughage and total DM intakes of lambs in T_3 and T_5 did not differ (P>0.05). The substitution of natural pasture hay with either 33% SCT silage or 33% and 67% SCT hay did not alter (P>0.05) the roughage and total DM intakes. In T_3, the roughage and total DM intakes were depressed (P< 0.05) by about 26.4 and 16.5%, respectively, over the effect of the control diet (T_1). However, lambs in T_1, T_2, T_4 and T_5 had similar (P>0.05) DM intakes. Total DM intakes of lambs on silage based diets reached plateau at about two months of the feeding period and reduced thereafter mainly in lambs on T_3 diet (Appendix Figure 1). However, the trend of total DM intake in lambs on diets without silage was increasing until day 75^{th} of feeding. Likewise, the trend of roughage DM intake was similar to that of total DM intake since the amount of concentrate consumed was the same for all lambs.

The partial replacement of natural pasture hay with either SCT silage or hay influenced (P<0.0001) feed CP intake in lambs. The lowest CP intake was at the higher proportion of SCT hay inclusion (T_5), while lambs fed on high silage part had lower (P<0.0001) CP intake than the group consumed control diet. However, there was no significant difference (P>0.05) in CP intake among T_1, T_2 and T_4.

Intake of fiber components varied significantly (P<0.05) among lambs fed the test diets. The lower intake of NDF (P=0.0125) and ADF (P=0.0013) were observed in lambs fed high silage diet (T_3) compared to the group fed on T_1 and T_4 diets. However, this was not affected (P= 0.7820) by replacing natural pasture hay with SCT hay (T_4 and T_5). Intake of ADL was lower (P=0.0020) in T_3 and T_5 compared to the control diet (T_1).

Table 24. Mean nutrient intake (g/day) of Arsi-Bale lambs fed diets based on SCT silage/hay as a partial substitute for natural pasture hay

Variable	Treatment (T)					SEM	*P*-value
	T_1	T_2	T_3	T_4	T_5		
rDM	525.91[a]	505.23[a]	387.05[b]	526.36[a]	456.16[ab]	34.64	0.0404
tDM	843.39[a]	820.73[a]	703.79[b]	842.33[a]	773.65[ab]	34.79	0.0427
rCP	24.47[a]	22.95[ab]	17.89[b]	24.00[ab]	10.18[c]	1.52	<.0001
tCP	88.44[a]	86.52[ab]	81.72[b]	87.67[ab]	74.16[c]	1.56	<.0001
rAsh	49.28	51.34	40.94	49.83	48.04	3.56	0.2977
tAsh	70.17	72.10	61.78	70.62	68.93	3.57	0.3047
rNDF	358.43[a]	332.43[ab]	251.32[b]	375.57[a]	325.55[ab]	23.83	0.0121
tNDF	492.98[a]	466.15[ab]	385.55[b]	509.48[a]	460.10[ab]	23.89	0.0125
rADF	243.09[a]	203.00[ab]	143.22[b]	226.14[a]	184.85[ab]	15.48	0.0012
tADF	299.03[a]	258.59[ab]	199.03[b]	281.82[a]	240.79[ab]	15.50	0.0013
rADL	48.00[a]	42.66[ab]	30.48[b]	43.03[ab]	31.27[b]	3.23	0.0019
tADL	66.61[a]	61.15[ab]	49.04[b]	61.55[ab]	49.88[b]	3.24	0.0020

[a,b,c]Means with different superscript letters in the same row differ significantly ($P<0.05$); T_1(control) = 100% Natural pasture hay *ad libtum*+ 350 g/day concentrate; T_2 = (67% Natural pasture hay + 33% SCT silage) *ad libtum* + 350 g/day concentrate; T_3 = (33% Natural pasture hay + 67% SCT silage) *ad libtum* + 350 g/day concentrate; T_4 = (67% Natural pasture hay + 33% SCT hay) *ad libtum* + 350 g/day concentrate; T_5 = (33% Natural pasture hay + 67% SCT hay) *ad libtum* + 350 g/day concentrate; t = total; r = roughage; DM = dry matter; CP= crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin; SEM = standard error of the mean

4.4.2. Growth performances and feed efficiency

Growth performances and FCE of lambs did not differ ($P>0.05$) among the treatments (Table 25). The overall average final body weight, total gain, ADG and FCE of the treatments were 27.21 kg, 7.85 kg, 87.22 g and 0.11, respectively. Although statistically not significant ($P>0.05$), the average values for final body weight, total gain and ADG were numerically low for lambs fed on the higher silage diet (T_3). The trend of average body weight of lambs in all treatments was increasing linearly with time, but at a slow rate for lambs in T_3, particularly after 60 days of feeding (Appendix figure 2).

Table 25. Growth and feed conversion efficiency of Arsi-Bale lambs fed diets based on SCT silage/hay as a partial substitute for natural pasture hay

Parameter	Treatment (T)					SEM	*P*-value
	T_1	T_2	T_3	T_4	T_5		
Initial BW (kg)	19.40	19.38	19.33	19.42	19.27	0.27	0.9959
Final BW (kg)	27.63	27.42	26.58	27.13	27.29	0.78	0.9029
Total gain (kg)	8.23	8.04	7.25	7.71	8.02	0.64	0.8381
ADG (g)	91.42	89.35	80.55	85.64	89.12	7.16	0.8381
FCE (g gain/g DMI)	0.110	0.110	0.113	0.102	0.115	0.009	0.8890

Means with different superscript letters in the same row differ significantly ($P<0.05$); T_1(control) = 100% Natural pasture hay *ad libtum* + 350 g/day concentrate; T_2 = (67% Natural pasture hay + 33% SCT silage) *ad libtum* + 350 g/day concentrate; T_3 = (33% Natural pasture hay + 67% SCT silage) *ad libtum* + 350 g/day concentrate; T_4 = (67% Natural pasture hay + 33% SCT hay) *ad libtum* + 350 g/day concentrate; T_5 = (33% Natural pasture hay + 67% SCT hay) *ad libtum* + 350 g/day concentrate; BW = Body weight; ADG = average daily gain; FCE = feed conversion efficiency; DMI = Dry matter intake; SEM = standard error of mean; *vs* = versus

4.4.3. Apparent dry matter and nutrient digestibility

There was no significant ($P>0.05$) difference among the dietary treatments on the apparent DM and OM digestibility (Table 26). However, CP digestibility was low ($P=0.0067$) at higher than lower SCT hay inclusion, which was also lower than the control diet (T_1). Except in T_5, other treatments did not vary ($P>0.05$) in CP digestibility. The substitution of natural pasture hay with SCT silage or hay had an effect on fiber digestibility, where lower NDF and ADF values were noted at higher silage (T_3) and hay (T_5) feeding. It appeared that the digestibility of nutrients at the same levels of SCT silage and hay offer did not statistically ($P<0.05$) differ.

Table 26. Apparent nutrient digestibility in Arsi-Bale lambs fed diets based on SCT silage/hay as a partial substitute for natural pasture hay

Parameter	Treatment (T)					SEM	*P*-value
	T_1	T2	T_3	T_4	T_5		
DM	70.2	68.9	65.8	68.4	66.3	1.25	0.0724
CP	73.5^{a}	71.7^{ab}	70.9^{ab}	73.2^{a}	68.3^{b}	1.09	0.0067
OM	71.9	70.2	67.8	70.5	68.2	1.18	0.0737
NDF	69.0^{a}	66.8^{a}	60.5^{c}	66.1^{ab}	63.1^{bc}	1.39	0.0002
ADF	62.5^{a}	60.7^{ab}	54.4^{bc}	59.7^{ab}	51.4^{c}	1.67	<.0001

[a,b,c]Means with different superscript letters in the same row differ significantly (P<0.05); T_1(control) = 100% Natural pasture hay *ad libtum* + 350 g/day concentrate; T_2 = (67% Natural pasture hay + 33% SCT silage) *ad libtum* + 350 g/day concentrate; T_3 = (33% Natural pasture hay + 67% SCT silage) *ad libtum* + 350 g/day concentrate; T_4 = (67% Natural pasture hay + 33% SCT hay) *ad libtum* + 350 g/day concentrate; T_5 = (33% Natural pasture hay + 67% SCT hay) *ad libtum* + 350 g/day concentrate; DM= dry matter; CP = crude protein; OM = organic matter; NDF = neutral detergent fiber; ADF = acid detergent fiber; SEM= standard error of mean

4.4.4. Carcass and non-carcass characteristics

The carcass characteristics of experimental animals were not affected (P<0.05) by the substitution of natural pasture hay with SCT silage or hay (Table 27). The overall average for SBW, EBW, HCW, CCW, chilling loss, DP (%SBW), lean meat, fat and bone were 26.08 kg, 21.30 kg, 11.26 kg, 10.94 kg, 2.88%, 43.27% , 5.91 kg, 1.58 kg and 2.65 kg, respectively. Although the treatments did not vary significantly (P>0.05), the numerical values of DP were increased on the basis of empty body weight compared to the slaughter body weight and on the hot carcass than cold carcass basis.

Table 27. Carcass characteristics of Arsi-Bale lambs fed diets based on SCT silage/hay as a partial substitute for natural pasture hay

	Treatment (T)						
Parameter	T_1	T_2	T_3	T_4	T_5	SEM	*P*-value
SBW, kg	25.58	26.00	25.83	25.83	27.17	0.83	0.6958
EBW, kg	21.22	20.95	21.64	20.87	21.80	0.59	0.7455
HCW, kg	11.42	11.00	11.25	11.17	11.48	0.28	0.7633
CCW, kg	11.18	10.77	10.95	10.77	11.02	0.32	0.8921
ChLoss (%)	2.06	2.12	2.92	3.34	3.97	1.16	0.7357
*h*DP (%SBW)	44.78	42.37	43.56	43.23	42.42	0.99	0.4272
*h*DP (%EBW)	53.89	52.49	51.97	53.41	52.78	0.90	0.6002
*c*DP (%SBW)	43.82	41.47	42.30	41.70	40.69	0.90	0.1814
*c*DP (%EBW)	52.76	51.38	50.46	51.55	50.65	0.87	0.3860
Lean meat (kg)	6.03	5.66	5.89	5.87	6.09	0.23	0.7300
Fat (kg)	1.72	1.71	1.47	1.59	1.42	0.20	0.7878
Bone (kg)	2.77	2.63	2.74	2.49	2.62	0.12	0.4738

Means with different superscript letters in the same row differ significantly ($P<0.05$); T_1(control) = 100% Natural pasture hay *ad libtum* + 350 g/day concentrate; T_2 = (67% Natural pasture hay + 33% SCT silage) *ad libtum* + 350 g/day concentrate; T_3 = (33% Natural pasture hay + 67% SCT silage) *ad libtum* + 350 g/day concentrate; T_4 = (67% Natural pasture hay + 33% SCT hay) *ad libtum* + 350 g/day concentrate; T_5 = (33% Natural pasture hay + 67% SCT hay) *ad libtum* + 350 g/day concentrate; SBW = slaughter body weight, HCW = hot carcass weight; CCW = cold carcass weight; ChLoss = chilling loss; EBW = empty body weight; *h*DP = hot dressing percentage; *c*DP = cold dressing percentage; SEM = standard error of mean

Except for skin of lambs (expressed as %EBW), which was significantly ($P=0.0254$) lower in T_1 than T_2, the other non-carcass parameters did not vary ($P>0.05$) among the treatments (Table 28). The grand mean of the non-carcass parameters (%EBW, except for digesta as %SBW) were: 13.90 (skin), 8.87 (head), 4.95 (blood), 1.82 (liver), 0.35 (Kidney), 0.61 (Heart), 1.47 (Lung and trachea), 2.01 (Testis and penis), 0.21 (spleen), 2.96 (tail fat), 1.01 (Omental fat), 6.77 (gut total), 1.98 (empty gut) and 18.23(digesta).

Table 28. Non-carcass components of Arsi-Bale lambs fed diets based on SCT silage/hay as a partial substitute for natural pasture hay

Parameter	Treatment (T)					SEM	*P*-value
	T_1	T_2	T_3	T_4	T_5		
%EBW							
Skin	12.90[b]	14.93[a]	13.95[ab]	13.44[ab]	14.27[ab]	0.42	0.0254
Head	9.39	9.27	9.05	8.87	7.76	0.74	0.5607
Blood	5.36	4.83	4.73	5.14	4.67	0.49	0.8313
Liver	1.88	1.80	1.74	1.87	1.79	0.06	0.4061
Kidney	0.38	0.33	0.34	0.37	0.35	0.01	0.1243
Heart	0.60	0.66	0.57	0.63	0.59	0.05	0.7332
Lung with trachea	1.49	1.49	1.49	1.43	1.46	0.06	0.9458
Testis and penis	1.93	2.05	2.15	2.15	1.78	0.12	0.1634
Spleen	0.23	0.19	0.22	0.22	0.19	0.02	0.6229
Tail fat	3.27	3.36	3.02	2.64	2.51	0.44	0.5760
Omental fat	1.06	1.02	0.99	1.14	0.84	0.16	0.7756
Gut total(kg)	6.37	7.02	6.12	6.98	7.38	0.44	0.2708
Empty gut (kg)	2.00	1.97	1.92	2.02	2.01	0.07	0.8691
Digesta (%SBW)	16.92	19.29	16.18	19.08	19.68	1.07	0.1019

[a-b]Means with different superscript letters in the same row differ significantly ($P<0.05$); T_1(control) = 100% Natural pasture hay *ad libtum* + 350 g/day concentrate; T_2 = (67% Natural pasture hay + 33% SCT silage) *ad libtum* + 350 g/day concentrate; T_3 = (33% Natural pasture hay + 67% SCT silage) *ad libtum* + 350 g/day concentrate; T_4 = (67% Natural pasture hay + 33% SCT hay) *ad libtum* + 350 g/day concentrate; T_5 = (33% Natural pasture hay + 67% SCT hay) *ad libtum* + 350 g/day concentrate; SEM = standard error of mean; EBW = empty body weight

4.4.5. Meat quality attributes

Table 29 describes the chemical composition and cooking loss of *L*. dorsi muscle sampled from lambs fed the treatment diets. No significant difference ($P>0.05$) was observed among the treatments in meat moisture, ash, protein and fat contents and cooking loss, with the respective grand mean value of 74.1%, 1.3%, 20.6%, 5.1% and 36.4% .

Table 29. Chemical composition and cooking loss of *L. dorsi* muscle in Arsi-Bale lambs fed diets based on SCT silage/hay as a partial substitute for natural pasture hay

Parameter	Treatment (T)					SEM	*P*-value
	T_1	T_2	T_3	T_4	T_5		
Moisture (%)	74.28	73.50	74.20	74.31	74.23	0.59	0.857
Ash (% DM)	1.33	1.31	1.32	1.32	1.30	0.03	0.991
Protein (%DM)	20.53	21.50	20.43	20.07	20.28	0.63	0.566
Fat (%DM)	5.21	4.45	5.11	5.75	5.02	0.48	0.459
Cooking loss (%)	36.53	36.42	34.63	38.44	36.08	1.99	0.760

Means with different superscript letters in the same row differ significantly (P<0.05); T_1(control) = 100% Natural pasture hay *ad libtum* + 350 g/day concentrate; T_2 = (67% Natural pasture hay + 33% SCT silage) *ad libtum* + 350 g/day concentrate; T_3 = (33% Natural pasture hay + 67% SCT silage) *ad libtum* + 350 g/day concentrate; T_4 = (67% Natural pasture hay + 33% SCT hay) *ad libtum* + 350 g/day concentrate; T_5 = (33% Natural pasture hay + 67% SCT hay) *ad libtum* + 350 g/day concentrate; SEM= standard error of mean

4.4.6. Cost-benefit analysis

The results of the partial budget analysis for the feeding trial are shown in Table 30. The group fed the diet with higher level of SCT silage (T_3) achieved the highest positive net income (case I, 39.26 Birr/head; case II, 113.03 Birr/head) and profit margin (0.47, 0.72 Birr/head) over control (T_1), followed by lambs in T_5 with net income of 20.74 and 107.68 Birr/head and profit margin of 0.26 and 0.64 Birr/head over the control group (T_1). Lambs fed the diet with low SCT silage (T_2) had the lowest net income and profit margin. The net income (case I and II) of Birr 11.08 and 66.51; 113.08 and 186.85; 76.46 and 125.87; 94.56 and 181.5 were attained in T_2, T_3, T_4, T_5, respectively. The results of MRR analysis indicated that for one Birr extra cost per lamb, an additional income of -15.25, 0.47, 0.19 and 0.26 Birr/lamb over control when costs of SCT purchase were included and -0.14, 0.72, 0.82 and 0.64 Birr/lamb by excluding SCT acquisition cost in T_2, T_3, T_4 and T_5, respectively. In either case, a higher level of SCT silage and low to a high level of SCT hay replacing natural pasture hay had better economic performances over the control treatment.

Table 30. Economic parameters (Birr/lamb) of Arsi-Bale lambs fed diets based on SCT silage/hay as a partial substitute for natural pasture hay

Variable costs	Treatment (T)				
	T_1	T_2	T_3	T_4	T_5
Initial price of sheep	800	800	800	800	800
Hay cost	275.14	177.09	66.82	184.5	78.75
SCT purchase	0	47.43	73.77	49.41	86.94
Concentrate cost	179.63	178.52	179.21	178.78	179.46
Cost of molasses and urea	0	5.64	8.77	0	0
Silage/hay making costs	0	42.5	42.5	28.33	28.33
Labour cost for managing lambs	103.13	103.13	103.13	103.13	103.13
Medication cost	15.5	15.5	15.5	15.5	15.5
Selling price of lambs	1447.22	1388.89	1402.78	1436.11	1386.67
TR (A)	647.22	588.89	602.78	636.11	586.67
ΔTR	0	58.33	44.44	11.11	60.55
Case I. Cost of SCT included					
TVC (B)	573.4	569.81	489.7	559.65	492.11
ΔTVC	0	3.59	83.7	13.75	81.29
NI (A-B)	73.82	19.08	113.08	76.46	94.56
ΔNI (ΔTR-ΔTVC)	0	-54.74	39.26	2.64	20.74
MRR = ΔNI/ΔTVC	0	-15.25	0.47	0.19	0.26
Case II. Cost of SCT excluded					
TVC(c)	573.4	522.38	415.93	510.24	405.17
ΔTVC	0	51.02	157.47	63.16	168.23
NI (A-c)	73.82	66.51	186.85	125.87	181.5
ΔNI (ΔTR-ΔTVC)	0	-7.31	113.03	52.05	107.68
MRR = ΔNI/ΔTVC	0	-0.14	0.72	0.82	0.64

T_1 (control) = 100% Natural pasture hay *ad libtum* + 350 g/day concentrate; T_2 = (67% Natural pasture hay + 33% SCT silage) *ad libtum* + 350 g/day concentrate; T_3 = (33% Natural pasture hay + 67% SCT silage) *ad libtum* + 350 g/day concentrate; T_4 = (67% Natural pasture hay + 33% SCT hay) *ad libtum* + 350 g/day concentrate; T_5 = (33% Natural pasture hay + 67% SCT hay) *ad libtum* + 350 g/day concentrate; NI= net income; TR= total return; TVC=total variable cost; MRR= marginal rate of return; ETB= Ethiopian currency (Birr); Feed cost (Birr/kg) (natural pasture hay, 5; SCT, 1.07; concentrate mix, 5.63; urea, 10; molasses, 0.86)

5. DISCUSSION

In this section, the major findings of the survey work, SCT conservations, and sheep feeding experiment are discussed in detail by comparing and contrasting with reports of related studies.

5.1. Household Characteristics

In this survey, the observed higher male- than female-headed households (HHs) was in agreement with previous reports for rural (Zewdie and Yoseph, 2014; Diriba *et. al*., 2014; Tesfaye, 2016) and urban HHs (Duguma and Janssens, 2016) in the country. A relatively larger percent of female-headed farm HHs in urban than rural areas could be an indication of urban women's better access to management knowledge, financial sources and market for inputs and products.

The average age of a HH head in the present study was within the range of productive age group (15-64 years old) and close to 41.85 years reported by Selamawit *et al*. (2017), but lower than 45.5 years (Tesfaye, 2016) and 47.23 years (Diriba *et al.,* 2014) reported for the agricultural households. The average family size in the present study surpassed the national average (5.14 persons/HH; CSA, 2016), but was lower than the reported 9.5 (Zewdie and Yoseph, 2014) and 7.3 persons/HH (Diriba *et al*., 2014). The larger family size in the rural than urban HHs could be an indicator of less access to family planning education in the former, as a relatively larger proportion of illiterate HH heads were observed in rural Metehara. Regardless of location specific, larger percentage of household heads in the study areas were literate (at least able to read and write). The average proportion of illiterate HH heads was exceeded by the reported 18% (Zewdie and Yoseph, 2014), 40.05% (Tesfaye, 2016) and 43.7% (Selamawit *et al.,* 2017). Therefore, educating the farm HH heads is vital for the implementation and adoption of improved livestock husbandry practices in the areas.

A larger percentage of farm HHs relayed on crop production and animal fattening in Wonji-Shoa than Metehara, which could be due to favourable climate and soil factors for agriculture and better access to feed resources and markets for animal products in

the case of Wonji-Shoa. The proportion of urban HHs producing a crop in the study areas was lower than the national average (39.6%) for small towns, while the proportion for rural HHs was lower than the corresponding national average (90.3%; ERSS, 2013).

5.2. Land and Livestock Holdings

Total land holding per HH was higher in Wonji-Shoa than Metehara Sugar Estate varying greatly with the cultivated land holdings. The grazing land holding in Wonji-Shoa and Metehara Sugar Estates were lower than 1.3 ha reported for Adami Tullu Jidokombolcha district and 0.3 ha for Dugda Bora district of East Shoa Zone (Zewdie and Yoseph, 2014). According to Solomon *et al*. (2017), the private grazing land holding in Oromia region ranged 0.25-0.5 ha/HH. Except for 2.83 ha total land owned by a rural HH in Wonji-Shoa, the land allotted for other purposes and total land holdings were exceeded by the national average (1.06 ha/HH; CSA, 2016). On the other hand, the absence of private grazing land in rural Metehara was probably compensated by the presence of vast communal grazing lands.

The total livestock holding (average, 5.6 TLU/HH) of the study area was close to 5.5 TLU reported for Basona Worana district (Hassen *et al*., 2010), but was lower than 16.2 TLU reported for the central Rift Valley areas (Zewdie and Yosef, 2014) and 13.9 TLU for central highlands (Fekede *et al*., 2013). However, it was higher than the report for Haramaya (4.06) and Gursum (2.15 TLU) districts (Freweini *et al*., 2014). The observed higher livestock holdings (5.33 TLU/HH) noted at lower land holdings (0.4 ha) in Metehara could be due to the use of communal grazing land, or better use of SCT and grass obtained from sugarcane fields. The higher local cattle, but lower crossbred cattle holdings in Metehara than Wonji-Shoa was possibly due to hot climate (not a comfort zone for exotic breeds) and limited access to inputs and services in the former. In agreement with the present results, higher indigenous cattle holdings than crossbred cattle holdings were reported (Fekede *et al.*, 2013; Zewdie and Yoseph, 2014; Selamawit *et al.*, 2017).

5.3. Feeds and Feeding Systems and Source of Water

Natural pasture and stubble grazing as the major feed resources in rural Metehara were attributed to the availability of communal grazing land and maize stover fields. Besides, green grasses from the rangelands and sugarcane plantation were notable feedstuffs. On the other hand, the feed use of crop residues (except maize stover), stubble grazing and small private grazing lands was common in Wonji-Shoa Sugar Estate, probably indicating the higher level of crop-livestock integration (Solomon *et al*., 2017). Crop residues as a major feed resource in the crop based farming system were also reported in previous studies (Tesfaye and Chairatanayuth, 2007; Hassen *et al*., 2010; Moti *et al*., 2015; Solomon *et al*., 2017). However, the nutritional quality of most crop residues is low, owing to low available protein and energy, low digestibility and intake (Adugna *et al*., 2012) and poor handling practices (Hassen *et al*., 2010).

The use of SCT as livestock feed by all of the surveyed HHs had indicated its abundant availability in the study areas. Contrary to Wonji-Shoa, the percentage of Metehara HHs using molasses as feed resource was low partly due to its alternative use for ethanol production and lack of awareness on its feed value. However, the use of improved forage crops in the surveyed areas was scant probably due to limited access to inputs (land and forage seeds) for production and lack of awareness (Tesfay *et al*., 2016;Yadessa *et al*., 2016) and underdeveloped livestock extension system. Similarly, the limited use of concentrate feeds in Metehara, particularly in rural areas could be due to shortage and poor marketing systems (Mesfin *et al*., 2014). Contrarily, most urban livestock farms in Wonji-Shoa Sugar Estate were market-oriented and have access to concentrate feeds.

In the study areas, the critical feed shortage period falls between December and May (dry season), when the market prices of available feeds rocket. The higher feed shortage in the dry season, particularly for rural Wonji-Shoa HHs could be due to limited grazing lands and lack of feed conservation practices. However, the feed supply shortage was partly resolved by conserving SCT and grass obtained from sugarcane fields.

The adopted free-grazing system by the majorities of rural HHs and stall feeding system by urban HHs explained the differences in resource acquisition (feed, land and capital, livestock size). The rural farm HHs largely relied on natural pasture, stubble grazing and crop residues available on-farm, while urban HHs relied mainly on purchased feeds. In agreement to the present study, a larger proportion of the rural HHs raised their livestock on free grazing (Yadessa *et al*., 2016), while the urban HHs on stall feeding (Duguma and Janssens, 2016). The combined stall feeding and free grazing systems adopted by the moderate proportion of urban farms of the study areas could be a management strategy to combat the temporal feed shortages and the rise in feed cost. In fact, the feeding system may vary with the farm production objectives and level of production.

Awash-river and irrigation scheme were the only sources of water for livestock farms in rural Metehara due to the lack of alternative water sources. River as a major source of water for rural livestock farms was also reported (Hassen *et al*., 2010). The pond water was used only by Wonji-Shoa rural HHs (43.7%), where there were no alternative water sources. The tap water development project initiated by the government had also served over 27% of rural farm HHs in Wonji-Shoa to water their livestock. Despite the presence of alternative water sources for livestock in the surveyed areas, farmers had disclosed that water available for livestock was not consistent in quantity and quality, especially in the dry season and at drought occurrence.

5.4. Household Feed Expenses and Consequences of Deficit

The detected difference in monthly feed expenses per farm HH of the two Sugar Estates could probably reflect the difference in feed supply and demand and its market price. Most of the urban HHs in Wonji-Shoa Sugar Estate adopted a stall feeding system (market-oriented dairying/fattening) with limited feeds produced on-farm, but relying largely on the purchased feeds. The relatively higher monthly feed expense in the urban than rural farms affects the likely benefits from livestock production and increases the market price of animal products. Studies have shown that the majority of urban and peri-urban livestock farms rely on purchased feeds

(Mesfin *et al.*, 2014), while most of the rural farms rely on on-farm produced feeds (Andnet *et al*., 2014). However, risks associated with feed shortage that the farm HHs faced (e.g., destocking, withdrawal from farm operation) were lower for urban than rural farms, which emanated from lack of good quality feeds and increase in market price. However, the urban HHs often tolerated the feed shortage problems by purchasing feeds with whatsoever price, which could be compensated by increasing the price of animal products. Reports of earlier work (Adugna *et al*., 2012; Mesfin *et al*., 2014; Demisse, 2017) have shown that feed comprised the largest share of livestock production costs in the country, impairing farm productivity at large.

5.5. Production and Utilization of Sugarcane Byproducts

There appeared differences in the production and utilization of SCT, molasses and bagasse in and around the Sugar Estates. The total annual production of the byproducts was directly proportional to area harvested and sugarcane yield (amount crushed and seedcane), which may also depend on the crushing efficiency of the factories. The available data and estimates had indicated a higher volume of the byproducts were generated in Metehara than Wonji-Shoa Sugar Estate. In both sugar Estates, the annual production volume of the byproducts was in the order of Baggase>SCT>molasees. In Wonji-Shoa, the increasing trend of the byproducts generation since 2014 was due to the high capacity of the plant at Dodota site and partly by the expansion of sugarcane farms by involving the smallholder sugarcane producers (“outgrowers”).

The production of green SCT was about 12.7 tonne (2.8 tonne DM) per ha for Wonji-Shoa and 16.1 tonne fresh (3.7 tonne DM) per ha for Metehara Sugar Estate (at 23% DM), which were lower than 5 tonne/ha DM (at 26% DM) suggested by Naseeven (1988). However, the current pre-harvest burning practice of sugarcane field has favoured the production of burnt SCT, which possibly resulted in the loss of DM from the leaf and sheath part. Except when seedcane is harvested that contributed about 1.3-2.7% to the annual SCT production estimate, the majorities of SCT were available in the burnt form. The burning practice of sugarcane field causes some dry matter and nutrient losses (Naseeven, 1988). Where no pre-harvest burning of sugarcane fields, a

range of 6.4-11 tonnes DM/ha SCT was obtained varying with sugarcane cultivars (Ripoli *et al*., 2005). In the present study, the observed differences in SCT yield between the two Sugar Estates could be attributed to differences in the amount of sugarcane yield, its variety and cutting stage, management level and soil factors. Suttie (2000) suggested that SCT account for about 15 to 25% of sugarcane biomass, which is equivalent to 8-10% of millable sugarcane (Deshmukh, 1983).

Based on data available (Table 10), about 31.4% of bagasse and 3.6 % of molasses were generated per unit of sugarcane milled in Wonji-Shoa, while about 28% bagasse and 3.41% molasses were generated in Metehara Sugar Estate. According to Mtunzi bagasse represents about 30% of sugarcane crushed (*et al.*,2012), however a wider range (22-38%) varying with fiber content of sugarcane and/or level of contamination before crushing was reported (Deshmukh, 1983). In the present study, unless for the amount of bagasse consumed by a boiler (representing 40-55% of what is generated at the sugar factories) and that sold to meet the domestic demands, the remaining part is removed by dumping or burning. It accumulates around sugar industries and often competes for space and causes environmental pollution. On the other hand, the excess production of bagasse and its availability at no cost around the sugar factories is an opportunity to exploit it as livestock feed through improving its quality.

Molasses production represented approximately 3.6% of the sugarcane crushed at Wonji-Shoa and 3.4% at Metehara, which were within the range (3–4%) reported by Deshmukh (1983). However, the annual production of molasses (over nine years) at Metehara sugar factory was lower than the reported 38500 tonnes/year (Adugna and Makkar (2018) that may attribute to difference in the number of production years and the amount of sugarcane crushed. Given that the present factories are operating at full capacity, the generation of SCT, molasses and bagasse at Wonji-Shoa and Metehara Sugar Estates would be about 168750, 59130, 516510 and 143100, 50490, 436590 tonnes per annum (fresh weight), respectively, indicating that the present level of production is far below potential.

The feed use of sugarcane byproduct in the study areas was favoured by their abundant availability and the livestock farms' proximity to the sugar industries.

Reports have shown that sugarcane byproducts are potential feed resources in the tropics (Preston and Leng, 1987) and their production and availability coincide with the feed shortage season (Da Costa *et al.*, 2015). However, the nutritive values of SCT and bagasse are low (Khanal *et al*., 1995; Suttie, 2000; Fouda, 2008). A report has also shown that SCT contributed about 0.5% to the annual available feed DM for livestock in Ethiopia (Adugna *et al*., 2012). Although bagasse is available in bulk at the sugar factories, its current feed use is negligible, due to to its low nutritive value and lack of technologies. Bagasse is high in fiber and low in protein content (Torres *et al*., 2003; Fouda, 2008). Generally, the sugarcane byproducts can be exploited for the development of Ethiopian red meat industry (PSRC, 2017). As a good start, Ethiopian Sugar Corporation has launched commercial cattle fattening operations in Wonji-Shoa Sugar Estate, which based sugarcane byproducts as a primary input.

5.6. Availability and Market Price of Sugarcane Byproducts

At the sugar factories, burnt SCT is available during the sugarcane harvesting period (October to June), while green SCT is available in seedcane planting season (December-March). Following sugarcane harvesting, SCT were collected by local livestock producers and some traders. According to Adugna and Makkar (2018), most of the SCT available at the sugar industries of the country are not used as livestock feed, but rather removed by burning. In the study areas, SCT were used mainly as a dry season feed. The farm households stored the surplus SCT for later use when their production ceases and feed supply is in scarce. Similarly, Funte *et al.* (2010) reported that SCT is mostly used as the dry season feed in southern Ethiopia. Quite a large number of small scale sugarcane farms exist in the country (Esayas *et al*., 2016), which produce SCT and green leaves for livestock feeding.

Farm HHs access to sugarcane byproducts was largely influenced by the distance of sugarcane fields from a homestead and transport availability. Distance to sugarcane harvesting sites within a wider area of sugarcane plantation fluctuates occasionally depending on the harvest calendar set by the factory. Although, most HHs (>50%) using SCT were found in the vicinity of the factories they often purchased SCT from collectors due to lack of their own labour and transport. A study conducted by

Tesfaye and Chairatanayuth (2007) also revealed that lack of transport and distance moved to the field challenge the collection of crop-residues by users. The local livestock producers and traders often competed for collecting SCT from the fields. The high competition for SCT has implications for its abundance, high demand, seasonal availability and absence of restriction to access sugarcane fields.

Unlike other crop-residues that are traded on formal markets elsewhere in the country, SCT was marketed only around the sugar industries. Previous reports (Adugna, 2007; Mesfin *et al*., 2014) had revealed that the bulky nature of SCT made it inconvenient for transportation and marketing to distant areas. However, upon agreement with livestock farms, collectors often brought SCT to the farm gate for selling. According to the respondents, the selling price of SCT was determined on the basis of distance moved from the field to the farm gate and the amount collected. The high price of SCT in Metehara than Wonji-Shoa was attributed to the longer distance to the field, low availability of transport and absence of the alternative roughages. The high price fetched by the burnt than green SCT could be related to its high demand (preference) by livestock farms. Higher DM is available per unit of burnt SCT than green SCT and spines are removed from leaf blades of the burnt SCT. Studies by Funte *et al.* (2010) and Jimma *et al.* (2016) have shown that SCT are a good source of roughage in areas where sugarcane is produced by smallholder farmers.

Despite the surveyed farm households are found close to molasses source sugar factories, its use as livestock feed was scant in Metehara and moderate in Wonji-Shoa Sugar Estates. At factories, the minimum amount of molasses sold was one quintal, which was not encouraging most resource-poor farmers and not convenient for transportation. The price of molasses at Wonji-Shoa sugar factory was increased from 47 Birr/qt in 2011 (Dawit *et al*., 2012) to 68 Birr/qt during the survey period. The use of molasses at the factory (Metehara) and by private enterprises for alcohol production might have adversely affected its feed use, availability and market price.

5.7. Preferences and Feeding Practice of Sugarcane Byproducts

Unlike the green SCT, the higher demand for burnt SCT in the study areas indicated its abundant availability at low cost and preference by users. According to the farm households, the pre-harvest burning practice of sugarcane fields removes SCT spines that otherwise can sore animal mouth during feeding. However, a mouth injury could also be resulted from feeding unchopped hard SCT stems. This may pre-dispose animals to other viral diseases (*e.g.*, foot and mouth disease). According to the respondent households, animals often select for the succulent bundle sheath (a soft part of SCT), leaving most of the stems with hard peels and leaves uneaten. This is an inefficient use of available SCT for livestock feeding. Farmers had shown preference to thin-stem SCT varieties that are juicy, soft and with less leaf proportion. However, the varieties that deserve high feed value at one time may not always available, as their sugar yield reduce with time and hence subjected to withdrawal from the production (*Industry expert, personal communication*). In the study areas, SCT were important roughage source for ruminants (mainly beef and dairy cattle). In agreement with the present finding, studies have also shown that SCT as important feed resource for large ruminants in sugarcane based farming (Naseeven, 1988; Suttie, 2000; McKenzie *et al*., 2007).

Molasses was widely used as supplemental feed for cattle, principally in Wonji-Shoa Sugar Estate. However, the limited feed use of molasses in Metehara Sugar Estate was partly attributed to the competition for ethanol production (Adugna and Makkar, 2018). Besides, poor marketing and distribution of molasses for domestic use and exporting it abroad have limited its feed use share (Mesfin *et al.,* 2014). Molasses is rich in soluble sugars (65-70% DM), major minerals (calcium, potassium, sodium, sulphur, magnesium) and trace minerals (copper, zinc, iron and manganese), but low in phosphorus and nitrogen (Adugna, 2007; Senthilkumar *et al*., 2016). Beyond its use as a source of nutrients, molasses improves palatability and intake of low quality roughages (Senthilkumar *et al*., 2016).

Farmers' experience in the amount of molasses fed varied with species, size and age of the farm animals. Large and older animals were supplemented with a higher level

of molasses (average 1.46 jug, or 2.3 kg/day) than the smaller and younger ones (average: 0.61 jug/day or ≈ 1 kg/day). In some farm households, the amount of molasses daily fed to animals exceeded the recommended range for cows (0.5-2 kg), beef cattle (0.5 kg), calves and heifers (0.1- 0.5 kg) and sheep/goat (0.1-0.2 kg) (Senthilkumar *et al*., 2016). Lack of knowledge and skill on the proper level of feeding molasses to animals often results in over- or under-feeding, which can upset animals' health and/or performances. The ratios of water to molasses adopted by most HHs of the study areas were close to 2:1-6:1 reported for optimum utilization (Senthilkumar *et al.*, 2016).

5.8. Processing and Preserving Sugarcane Tops

Farmers in the study areas processed SCT to improve its feed value. One such processing method was chopping SCT to a smaller size to increase its consumption, and reduce wastage and incidence of mouth injury. However, chopping was often operated manually, which is labour and time consuming practice for farmers. In this regard, the lack of mechanical chopper was a notable constraint. Chopping bulky roughages makes storage and transportation economical and improves utilization by animals (Osafo *et al*., 1997; Syomiti *et al*., 2011). The other SCT processing methods adopted by the farmers included feeding chopped SCT along with concentrate and other roughages and soaking them with a salt solution, molasses and water before feeding. Supplementation is the best strategy to improve the feed values of low quality roughage (Preston and Leng, 1987; Syomiti *et al*., 2011).

Livestock producers of the study areas conserved SCT as hay for later use. The intact SCT were often dried without chopping or turning during drying, which delayed moisture removal and makes the drying inadequate. Leaf tissue has a high surface-to-volume ratio and numerous stomata that favour rapid drying (Digman *et al*., 2011). However, with an increase in stem-thickness, the radial distance of stem core to the surface increases making the drying process difficult (Romero *et al*., 2015). Chopped thick-stem forages lose moisture at a higher rate and hence dry fast. However, farmers in the study areas chopped SCT right before feeding them to animals, but not for preservation purposes. Moreover, the SCT that stored in an open-air is liable to rain

and sunlight leading to quality loss. Hence the poor preserving method practiced by farmers coupled with low nutritive values of SCT reduces its feed use.

5.9. Chemical Composition of Sugarcane Tops

This study has revealed that the pre-harvest burning practice of sugarcane fields affected the nutrient composition of SCT. The loss of moisture and some organic matter (e.g., soluble sugars) due to burning sugarcane fields were notable changes. Loss of moisture probably increased the DM content, while the loss of OM raised the mineral compositions of burnt SCT samples compared to the unburnt ones. The change in the chemical composition of SCT is largely contributed by leaves and sheath parts as they are most likely affected by the flame. Similar to the present finding, a slight increase in DM, ash and hemicelluloses, but reduced NDF, ADF and ADL were reported in burnt than green SCT (Magaña *et al.,* 2009). On the other hand, Ramírez-Cathí *et al.* (2014) researched on green and burnt SCT of four mature sugarcane varieties and found no difference ($P>0.05$) in DM, CP, NDF, ADF, ash and *in-vivo* digestibility values among varieties and harvest types.

The average CP content (2.8%) of green SCT in this study was lower than the reported values by other studies (Khanal *et al*., 1995; Sharma *et al.,* 2012; Akinbode *et al*., 2017). However, Sharma *et al.* (2012) stated that various green SCT varieties, when sampled at 3rd stage of cutting, had CP content as low as 1.5%, while other researchers reported in a range of 2.5 to 3.6% CP (Alemayehu *et al.,* 2014; Anteneh, 2014; Ramírez-Cathí *et al.,* 2014). Generally, the CP content of SCT is below the minimum level (<70 g/kg DM) required to maintain an adequate ruminal fibrolytic activity (Sampaio *et al*., 2009). The variation in CP contents may be associated with differences in sugarcane varieties, stage of growth and/or nitrogen fertilizer application. Nevertheless, all of them had CP values below the optimum level for rumen fermentation. Similarly, the composition of fiber components (NDF, ADF and ADL) and EE were close to values reported in previous studies (Gendley *et al*., 2002; Sharma *et al*., 2012; Alemayehu *et al.,* 2014). However, significantly higher ADL contents (14%DM) of green SCT than the present results were reported by Akinbode

et al. (2017) and Anteneh (2014). The hemicelluloses and phosphorous content of green SCT in the present study were close to values reported by Gendley *et al.* (2002).

Molasses used in this study had higher CP, but comparable ash content reported by other studies (CP=2.5%, ash=14%; Eggleston *et al.*, 2017). Moreover, the nutrient contents of molasses fall within the range reported by Heuzé *et al.* (2015a): crude protein (2.1- 9.3%), NDF (0.2-2.8%), ADF (0-2.5%), (0.1-1.5%), ash (8.2-19.3) and calcium (0.68-1.26), but was higher in phosphorus (0.01-0.12 vs 0.9) content. The chemical composition of sugarcane molasses varies depending on sugarcane harvest location, varieties, processing efficiency (Eggleston *et al.*, 2017) and climate.

5.10. Physical Properties and Dry Matter Loss of Sugarcane Tops Silage

The low pH values observed in the green and burnt SCT ensiled without additive indicated that it had adequate soluble sugar for satisfactory fermentation. Similarly, low pH value of SCT silage ensiled without additive was reported (Khanal *et al*., 1995). Furthermore, Heikkilä *et al.* (2010) reported that wilting pre-ensiled grass to DM content above 30% restricted excessive fermentation resulting in well-preserved silage without additive. Except for the green SCT that ensiled with urea based additive, the rest of the silages had pH ranged 3.7- 5.0 that are acceptable for average quality silage (McDonald *et al*., 2010). The drop in pH at the end of the ensiling period compared to its values in the pre-ensiled forages could also be a consequence of adequate organic acids production (McDonald *et al*., 2010).

The similarity in pH between the control silage and that treated exclusively with molasses probably indicated SCT alone had the threshold soluble carbohydrate to trigger the production of lactic acid. However, urea used as sole additive raised the pH significantly over control (untreated silage), and beyond the normal range (3.7-4.5) indicating that urea might have reduced desirable fermentation and lactic acid production. During ensilage, the ammonia released from urea is slightly basic, causing a delay in pH drop and DM loss in grass silages (Kung and Shaver, 2001). Although no significant (P>0.05) difference in pH between SCT ensiled with urea alone and that with urea-molasses mix in the present study, Khanal *et al.* (1995) reported a

significant reduction in pH of green SCT ensiled with 1% urea and 3-12% molasses combinations compared with the green SCT ensiled with 1% urea alone. Similar to the result of the current study, increased pH were observed in green SCT (Khanal *et al*., 1995) and Napier grass (Samanta *et al*., 2001) ensiled with 1% urea and 1% urea + 4% molasses used as additives, leading to poor fermentation of silage.

The application of silage additives used in the present study had no beneficial effect in reducing total dry matter loss over control treatment. The higher TDML observation in urea based green SCT silage compared to molasses alone treated silage implies that undesirable microbes might have been favoured by urea than molasses addition. Paderoso *et al.* (2011) reported a 31% reduction in dry matter loss of sugarcane silage when ensiled with urea at a lower dose (0.5%) than the present dose. Up to 5% total DM loss occurring during fermentation is considered normal, presumably due to the loss of soluble nutrients (McDonald *et al*., 2010).

In this study, SCT silage temperatures were ranged from 26 to 29.8˚C. The silage temperatures of green (29.4˚C) and burnt SCT (29.0˚C,) ensiled without additive were higher than 26˚C reported for intact SCT silage after 42 days of ensiling (Akinbode *et al.*, 2017). According to Kung (2011), a core sample of silage temperature ranging from 24 to 32˚C for large silos and silage temperature of small silos similar to the ambient temperature or just a few degrees warmer is normal. The present SCT silage temperatures at the time of opening the silos were close to the ambient temperature (average, 28˚C), which probably indicated the occurrence of minimal aerobic deterioration that generated small heat. Excessive heat production due to aerobic oxidation leads to browning (Millard) reaction, forming protein and carbohydrate complex that inhibits digestion (Bolsen *et al*., 1996).

The physical properties of SCT silage (smell, colour, texture, moldiness and pH) were affected by the drying method and SCT type. The score values had indicated that the application of sole urea had undesirable effects on physical attributes and pH of SCT silage. Based on the scale used in this study, the average score values indicated SCT ensiled without additive, or that ensiled with molasses alone or molasses combined with urea had properties of good silage. Akinbode *et al.* (2017) reported that green

SCT ensiled without additive had a greenish-yellow color, pleasant smell and slightly moldy.

5.11. Nutrient Contents of Sugarcane Tops Silages

The additives had no effect on DM content of burnt SCT silage, however the addition of molasses alone increased the DM content of green SCT silage over the same forage treated with urea alone or 4% molasses + 1%urea. This can be explained by the minor fermentation loss noted in green SCT ensiled with molasses alone. On the other hand, the increased CP content of SCT ensiled with urea alone or urea - molasses solution indicates a strategy to enhance the nutritional quality of SCT conserved as silage. These results are in agreement with the research report of Pedroso *et al.* (2011), where urea addition increased CP content of sugarcane silage. In the contrary, Khanal *et al.* (1995) reported no difference in CP content between urea treated green SCT silages and control (no additive), but increased with molasses inclusion at 3-12% DM.

The lower (P<0.0001) NDF content in burnt SCT ensiled with a urea-molasses solution than with urea alone probably indicates molasses might have favoured lactic acid production that reduced high pH induced by sole urea addition and counteracted the bad fermentation. However, the reverse was true in green SCT silage, which could be partly due to the low acid condition of green SCT ensiled with urea based additives, resulting in reduced NDF solubility and/or increased loss of soluble nutrients. With an increase in silage acidity a decrease in NDF content was reported (McDonald *et al*., 2010). Remarkably, NDF content was lower in green than burnt SCT ensiled with molasses alone. The loss in soluble sugar arises from microbial fermentation that occurs during ensiling (McDonald *et al*., 2010).

The *in vitro* OM digestibility and ME content of SCT silages were favoured upon treated with urea-molasses solution, which could be related to the low fiber contents (NDF, ADF and hemicelluloses). In agreement with the present findings, Khanal *et al.* (1995) reported increased IVOMD of green SCT silage ensiled with urea-molasses solution compared to silage without the additives, however the addition of urea alone had no beneficial effect over control silage. The lowest ME content in green SCT

ensiled with urea alone probably indicated the highest nutrient loss. The ME value of intact SCT was reported to be 7.0 MJ/kg DM (McKenzie and Griffiths, 2007).

The higher NFC contents of silages made without additive, or with molasses based additives (except for green SCT) indicated the occurrence of good fermentation that preserved the soluble nutrients. In the contrary, the observed lower NFC contents in green SCT ensiled with urea based additives could also explain the occurrence of fermentation loss (total DM loss). Akinbode *et al.* (2017) reported that green SCT ensiled without additive had 13.9% NFC after 42 days of ensiling, which was close to that observed in green SCT silage (15.3%) in the present study. Moreover, Ferreira *et al.* (2004) reported that the fermentation characteristics of elephant grass low in NFC (3.2%) were greatly improved by the addition of cashew fruit *(Anacardium occidentale L.)* bagasse containing 11.9% NFC.

5.12. Drying Rate and Dry Matter Content of Sugarcane Tops

This study confirmed that the rate of moisture removal from SCT is influenced by drying methods. Chopping-and-sun-drying was superior to the other drying methods in reducing drying time to attain the optimum moisture (85% DM) for storage. However, the chopped SCT were not dried under-shed in this study since chopping increases the surface area and this along with the delay in moisture removal favours yeast proliferation on sugar, which results in enormous DM loss (mainly as alcohol). Undersander (2011) confirmed that chopping forages improves the drying rate as it breaks stem and damages the waxy cuticle, allowing more water removal. Contrarily, the sun or shed drying of intact SCT elapsed several days (45-68), during which plant respiration and microbial fermentation might be favoured, leading to nutrient loss. The sun and shed drying of intact SCT resemble farmers' practice (***see-*** survey results), which may indicate knowledge and skill gaps on SCT conservation practices.

The probable cause for the rise in the moisture loss rate of intact SCT between 18^{th} and 24^{th} days could be due to the drop in the relative humidity (RH) (<60%) and the rise in temperature during this period (Figure 2). Collins and Owens (2003) stated that attaining moisture content below 20% is difficult with thick-stemmed forages as the

greater radial distance between stem core and epidermis slows water movement for removal. The same authors suggested splitting or cracking and chopping the thick stem hasten the drying process. According to Undersander (2011), plant respiration rate was highest at cutting and decreases until the moisture content drops below 60%, while Rotz (2003) stated this effect persists at up to 40% moisture content. In this study, it appeared that the higher moisture contents of most intact SCT samples until day 24 (DM<60%, Figure 9) might have favoured plant respiration. For shed-dried green SCT samples, this effect persisted up to day 34th of drying time. Hence, management that foster the rapid drying of SCT is crucial to reduce plant respiration and preserve nutrients.

5.13. Effect of Drying Methods on the Quality of Sugarcane Tops Hay

In comparison to the chemical composition of fresh SCT samples (Table 18), a slight loss of CP (3.7%), ME (11.7%), EE (14.1%), NFC (7.6%) contents and reduced DM (11%) and OM (12.1%) digestibility, but increased fiber components (3.3% NDF, 0.6% ADF and 2% ADL) were observed due to hay making (regardless of SCT type and drying method). This could be partly due to the delay in moisture removal, which favours plant respiration and microbial fermentation leading to nutrient loss. Success in hay making depends on the extent of moisture loss, which influenced by plant factors, climatic condition and management type (Collins and Owens, 2003; Rotz and Shinners, 2007). As opposed to most herbaceous forage crops, SCT leaf shattering was not observed during hay making and could not be a cause for nutrient loss. In agreement, sun drying decreased CP, but increased NDF, ADF and ADL contents of natural grass and Brachiaria grass (Enoh *et al*., 2005). The green SCT dried under shed retained their original leaf color (green), but were bleached upon dried in the sun. According to Roberts (1995), color change through bleaching and excessive drying reduces the palatability of the hay and hence reduces feed intake.

The results of sample chemical analysis revealed that the drying methods and SCT types had variable effects on the nutrient composition of SCT hay. The higher proportion of NDF in the intact shed-dried burnt SCT indicated loss of soluble sugars (i.e., low NFC) with prolonged drying time since a delay in moisture removal favours

plant respiration and microbial fermentation (Dzowela *et al*., 1995). In addition, the higher proportion of NDF (lower NFC) in the chopped burnt SCT hay could be due to an increase in the surface area of SCT that favours yeast proliferation on sugar (Rotz, 2003), and nutrient loss by exposure to solar radiation. However, the similarity in fiber fraction between the sun-dried and shed-dried intact green SCT could be related to the minimum difference in micro-climate between the two drying sites (e.g., average ambient temperature: 26.6°C in the shed and 27.4°C outdoors). Yuangklang *et al.* (2005) reported that the chopped sugarcane tops dried in the sun for 3 to 4 days had higher content of CP (4.1%) and ash (15.3%), but low NDF (41.3%), ADF (23.2%) and ADL (3.4%) than the present results. In addition, the lower hemicellulose contents observed in the sun- and shed-dried intact SCT could be due to the effect of prolonged drying that might have favoured the decomposition of hemicelluloses to sugars. Generally, the sun-drying of chopped SCT is a preferred preservation method in terms of digestibility and metabolizable energy content.

5.14. Nutrient Intake, Digestibility and Growth Performances of lambs

The results of the feeding trial indicated that DM intake of sheep was affected by the partial replacement of natural pasture hay with SCT silage than with SCT hay. The observed lower DM intake at high silage inclusion might have probably associated with its high moisture content (65.8%), which might have increased rumen fill and hence reduced DM intake. In agreement with the present result, Salinas-Chavira *et al.* (2013) observed a decrease in DM intake of Pelibuey sheep fed on diets containing 5-10% SCT silage as a substitute for sorghum stover. Similarly, DM intake of Merino sheep was depressed as the maize silage portion of the ration increased from 20 to 70% (Beukes, 2013). Also, DM intake of dairy cattle was reduced by feeding a higher silage diet due to an increase in acetic acid concentration (Daniel *et al.*, 2018) and change in odor, taste and texture of silage (Rodríguez *et al*., 2015). Moreover, depression in voluntary feed intake of silage based diets was prominent in sheep than in cattle, especially with partially fermented silages containing high ammonia and butyrate (>1%) (Forbes, 2007 as cited in Beukes, 2013). In this study, since the intake of fiber fractions decreased at the higher silage inclusions, its negative role in reducing total DM intake might be attributed to the lower NDF digestibility at the

higher level of silage feeding (Table 26). The non-significant difference among treatments in SCT hay DM intake in the present study agreed with the research reports for Washera sheep supplemented with SCT hay (Anteneh, 2014) and goats fed on sugarcane and Guinea grass based diets (Bien, 1999). The lowest dietary CP intake at higher substitution rate (67%) of SCT hay could be attributed to its low CP content and the reduction in grass hay consumption.

The apparent DM and OM digestibility were not affected by the inclusion of SCT silage and hay. A report by Anteneh (2014) also confirmed no difference in DM, OM, CP and NDF digestibility among Washera sheep fed chopped dried SCT and grass hay as basal diet. According to Daniel *et al.* (2018), sugarcane based diets had low NDF digestibility, high rumen retention time and reduced feed intake in dairy cattle. However, the CP digestibility was higher than the present result. Suliman *et al.* (2013) observed a non-significant difference in DM, but lower CP and OM digestibility in Saidi rams fed SCT silage than the group fed berseem (*Trifolium alexandrinum*) hay. Moreover, feeding the dried-chopped SCT increased the digestibility of nutrients as compared to its pelleted form in beef cattle (Yuangklang *et al*., 2005). The low NDF and ADF digestibility at higher SCT silage feeding might have increased rumen retention time that reduced DM intake. However, earlier studies (Reddy and Prasad, 1982) have confirmed that SCT ensiled with urea had increased feed intake and nutrient digestibility in sheep. Aguirre *et al.* (2010) reported that CP content and IVDMD of SCT were improved by processing (grinding and fermenting with/without additives). The same authors also reported a non-significant difference in feed DM intake, ADG and FCE between Pelibuey lambs fed diet containing entire sugarcane and sugarcane field residue.

Growth performances of lambs were not affected by the inclusion of SCT silage or hay, which agreed with the sheep fed green SCT silage (Aguirre *et al*., 2010; Salinas-Chavira *et al.*,2013) and intact green SCT (Galina *et al*., 2007). Similarly, Julião *et al.* (2016) reported the partial (33-66%) substitution of sugarcane by SCT on high-concentrate diets for feedlot Nellore bulls did not affect the growth performances. However, the ADG of lambs in the present study was higher than 45-75 g reported for Washera sheep fed chopped SCT hay (120-360 g/day) and natural pasture hay

(Anteneh, 2014), but was lower than Pelibuey sheep fed SCT silage based diet (Salinas-Chavira *et al.,* 2013). However, the differences could also be related to the variation in the growth potential of breeds. In the present study, the non-significant difference (P>0.05) among the treatments in growth performances could be related to the similarity in the nutrient supply of the diets. Remarkably, lambs with low DM intake (T_3) had equivalent growth performances to the other treatment groups probably indicating the higher energy value of SCT silage over SCT hay or natural pasture hay used in this study. In agreement, Salinas-Chavira *et al.* (2013) observed no difference in ADG of Pelibuey sheep fed SCT silage replacing sorghum stover, although DM intake was decreased with silage inclusion.

5.15. Carcass and Non-Carcass Characteristics

The observed non-significant difference among treatments on most carcass traits has indicated the similarity in the nutritional value of the experimental diets for the feedlot sheep. The relatively higher dressing percentages of lambs when expressed on empty body weight than on slaughter body weight were due to the removal of digesta that accounted for 18.2% of SBW. The chilling loss had a minor effect in lowering the dressing percentage (DP). Higher SBW, HCW, CCW and DP were reported for Washera sheep supplemented with sun-dried chopped SCT than the unsupplemented group (Anteneh, 2014). However, Suliman *et al.* (2013) observed no difference in the proportion of lean meat, fat, bone and DP among Saidi rams fed SCT silage and berseem hay with concentrate supplementation. The values of SBW, HCW, CCW, DP observed in the current study were close to that reported for feedlot Arsi-Bale lambs (Abebe *et al*., 2010; Getahun, 2015) and pure Hararghe and Black Head Ogaden sheep, but was lower than the crossbred (50% local x 50% Dorper) (Tsegay *et al*., 2013). Girma *et al*. (2010) reported lower DP (36.2-38.5, %SBW) than the present for yearling Arsi-Bale lambs raised on pasture and in the feedlot. Moreover, the values of non-carcass parameters in this study were consistent with previous research reports for the same breed in feedlot management (Abebe *et al.,* 2010; Girma *et al*., 2010; Getahun, 2015).

5.16. Change in meat quality

The chemical composition of meat (*L. dorsi* muscle) samples from the experimental lambs was not influenced by SCT hay or silage inclusion as a partial replacement for natural pasture hay. In agreement with the present results, Beukes (2013) reported a non-significant difference in meat moisture, fat, ash and protein contents among Merino sheep finished on diets containing 0, 20, 50 and 70% of maize silage. The present findings are comparable in ash and protein, but low in moisture and fat contents with meat from Arsi-Bale goat finished on grass hay with concentrate supplementation (340 g/day) (Aberra *et al.*, 2016).

According to Tsegay *et al*. (2015), indigenous sheep meat (*L.dorsi*) sampled from local butcheries had 72.7% moisture. 19% protein, 6.4% fat and 1.1% ash, which were close to the present results. It also falls within the range reported for Menz sheep: moisture (64.06 to 74.18%), protein (18.26 to 25.12%), fat (3.80 to 13.71%) and ash (1.02 to 1.46%) (Said *et al*., 2018). Furthermore, it had higher moisture, but comparable protein and fat contents with indigenous sheep of Tanzania (67, 22.5 and 5.8%, respectively) (Shija *et al*, 2013). The deviation of the present results from the literature values could be due to the difference in the breed and age of sheep and/or level of feeding.

The observed non-significant difference among treatments in the cooking loss of meat (average: 36.42%) showed their similarity in water-holding capacity. However, the values were higher than the reported 29.9% for mutton (*L.dorsi*) samples from local butcheries (Abera *et al*., 2015). Comparable to the present findings, Aberra *et al*. (2016) reported a non-significant difference in cooking loss (36.7-39.1%) of meat (*L*.dorsi) from Arsi-Bale kids supplemented with or without moringa leaf. According to Mahala and Mokhtar *et al*. (2013a), meat from pure Kenana breed calves fed on diets containing 20 and 30% SCT had an equivalent cooking loss (average, 30.5%). However, it was higher (average, 33.25%) in meat from crossbred calves (50-75% Friesian-Kenana) fed on diets containing both low and high levels of SCT. Moreover, factors that were not covered in this study (species/breed, meat freezing and aging) can also affect the cooking loss of meat (Shija *et al.*, 2013)

5.17. Economic Benefits

Feeding SCT silage or hay to feedlot Arsi-Bale sheep at 33 and 67% replacement for natural pasture hay had a positive response on cost-benefit of production. Although all experimental lambs biologically performed equally, the diets with the higher proportion of SCT silage (T_3) and SCT hay (T_5) had remarkable economic benefits mainly due to the low cost of SCT, and reduced consumption of costly natural pasture hay. The study also disclosed that the economic benefit was increased by excluding the purchase cost of SCT, which is feasible for most livestock producers in and around sugar industries, who obtain it freely from sugarcane fields. In line with the present results, Anteneh (2014) reported increased net income and profit margin with increase in the level of chopped SCT hay offer for feedlot Washera sheep. Contrarily, Couto *et al.* (2016) reported that the partial (33-66%) substitution of whole sugarcane by SCT for feedlot Nellore bulls neither reduced the production cost nor increased the profit margin, but had an economic benefit at total substitution rate. The present study revealed that the partial replacement of natural pasture hay with chopped SCT silage or hay is cost-effective and increases income from yearling Arsi-Bale sheep.

6. CONCLUSION AND RECOMMENDATIONS

This segment of the dissertation encompasses an overview of research objectives, methodologies used to implement the study, a summary of the major findings and recommendations based on the findings.

6.1. Conclusion

Four successive studies were conducted: assessment on the production and utilization of the major sugarcane byproducts in Wonji-Shoa and Metehara Sugar Estates, evaluation for SCT (variety N-14) conservation as silage and hay, and performance evaluation of yearling Aris-Bale sheep fed natural pasture hay and SCT silage or hay as basal diets. In the survey work, quantitative and qualitative data were collected by interviewing 308 farm households. Secondary data were obtained from sugar factories in the study areas. In the silage experiment, 2 SCT types (green and burnt) x 4 silage treatment types (no additive, 4% molasses, 1% urea and 1% urea + 4% molasses) were evaluated in a completely randomized design (CRD). The forages were ensiled in mini-silos (5 replicates/treatment) for 45 days and evaluated for silage quality. In the hay experiment, 2 SCT types (green and burnt) x 3 drying methods (shed- and sun-drying of intact SCT and sun-drying of chopped SCT) were tested in CRD for hay quality. Each treatment had 5 replicates (initial swath density 4 kg/m^2/replicate) and dried to achieve the target DM (85%) for storage. Finally, adequate amounts of the burnt SCT silage and hay were made using the best methods (1% urea + 4% molasses as an additive, and chopping and sun-drying SCT) identified from results of the preceding experiments. Five feeding regimes were evaluated as fed to yearling Arsi-Bale lambs:T_1(control) = 100% Natural pasture hay *ad libtum* + 350g/day concentrate; T_2 = (67% Natural pasture hay + 33% SCT silage) *ad libtum* + 350g/day concentrate; T_3 = (33% Natural pasture hay + 67% SCT silage) *ad libtum* + 350g/day concentrate; T_4 = (67% Natural pasture hay + 33% SCT hay) *ad libtum* + 350g/day concentrate; and T_5 = (33% Natural pasture hay + 67% SCT hay) *ad libtum* + 350g/day concentrate.

Results of the survey indicated that natural pasture and stubble-grazing, crop residues, SCT, grass (green/hay) and concentrates were important feed resources of the study areas. Feed shortage was critical in the dry season, which peaked in April in Wonji-Shoa and in February in Metehara. The monthly feed expenditure per farm household of Metehara was 1036.21 Birr, while 18.7% less in Wonji-Shoa. The use of molasses as supplemental feed to livestock was moderate in Wonji-Shoa (53%), while baggase was barely used only in Metehara Sugar Estate (0.9%). The total production volume of sugarcane byproducts was proportional to the area harvested and sugarcane yield (amount crushed by factory and seedcane harvested), which was in the order of baggase>SCT>molasses. It was much higher in Metehara than Wonji-Shoa. The pre-harvest burning practice of sugarcane field favoured larger availability of burnt than green SCT, and the production season (November-June) coincided with the critical feed shortage period. The respective prices of burnt and green SCT (297.86 and 195.5 Birr/cart) in Metehara were three-fold more (P<0.001) than in Wonji-Shoa. The fixed price of molasses at the factory's gate was 82 Birr/qt in Wonji-Shoa and 68 Birr/qt in Metehara, while its prices at retailer shops averaged 141 and 120 Birr/qt, respectively. Sugarcane byproducts were fed principally to ruminants, varying in the amount offered and processing method used. Sugarcane tops contributed to year-round feed supply. Farmers preferred the burnt to green SCT, thin stem than thick stem varieties and SCT with low leaf proportion. The SCT were dried in the sun (Metehara- 98.2%; Wonji-Shoa- 80.8%) and in the shed (31.8, 40.4%) and stored mainly in an open-air (91.8, 85.9%). The factors limiting feed use of sugarcane byproducts by the farm households included: low nutritive quality of SCT (91.2%), health risks of feeding SCT (16.2%) or molasses (74.7%) and lack of labour and capital (11.7%), transport (26%), molasses supplier (85.1%) and technical supports (89%). In general, the surplus sugarcane byproducts produced and available in the study areas are not well-managed and utilized as livestock feed, hence calling for intervention.

In the silage experiment, the subjective scores of smell, colour, texture, moldiness and pH were highest for SCT ensiled without additive or with molasses. The desirable pH (3.7-5.0) was obtained in all silages, except in green SCT ensiled with urea based additives, while the lowest total dry matter loss (2.31%) and temperature (26˚C) were observed in green SCT ensiled with molasses alone. Silage CP content was enriched

(P<0.0001) with urea addition. The fiber fractions of burnt SCT were not affected (P>0.05) by the additives, while NDF increased by 17.5% with urea inclusion and ADF decreased by 15.7% with molasses based additive in green SCT silage. The highest (P<0.0001) IVOMD and ME contents were noted in burnt SCT ensiled with the urea-molasses solution. The NFC content was the lowest (P<0.0001) in green SCT ensiled with urea based additive. In general, the green SCT was best preserved as silage ensiling without additive or with 4% molasses, while the burnt SCT with the urea-molasses solution.

In the hay experiment, chopping and sun-drying of SCT increased the dehydration rate (burnt SCT, 19.8%; green SCT, 20.7% per day) and reduced the drying time (<3 days), while the shed-dried intact green and burnt SCT had the lowest dehydration rates (0.92 and 0.99% per day) taking the longest time to complete drying (68 and 60 days). The drying methods and SCT (harvest) type had interacted on the composition of hay ash, NDF, ADL, IVOMD, ME, NFC and P. The drying methods did not differ (P>0.05) in DM and CP contents of SCT hay. The NDF content was lower (P<0.001) in the sun-dried intact burnt SCT, and all green SCT hays. However, the ADF contents of sun-and shed-dried intact SCT were not different (P>0.05), but were higher (P<0.05) than the sun-dried chopped SCT. The sun-dried chopped SCT had the highest (P<0.0001) EE and hemicelluloses contents. The sun-dried chopped green SCT had lower (P<0.0001) NDF and ADL than the sun-dried chopped burnt SCT, however they were not significantly (P>0.05) different in OM digestibility and DM and ME contents. The NFC content was highest (P<0.0001) in the sun-dried intact burnt and green SCT and intact shed-dried green SCT. Generally, SCT can be best preserved as hay by chopping and sun-drying, which reduces drying duration (<3 days) and conserves nutrients.

The roughage and total DM intakes were lower (P<0.05) for lambs fed on the higher silage diet (T_3), but not affected (P>0.05) by the level of SCT hay. Lambs fed on a diet containing higher SCT hay (T5) had the lowest (P<0.0001) CP intake, while the intake of NDF and ADF were lower (P<0.05) in lambs fed higher silage diet. Treatments did not differ (P>0.05) in the apparent DM and OM digestibility, in lambs' growth performances, feed conversion efficiency, carcass characteristics, meat

chemical composition (average: moisture, 74.1%, protein-20.56%, fat-5.11%, Ash-1.32%) and cooking loss (36.2%). The final body weight, total gain, ADG and FCE were ranged from 26.58-27.63 kg, 7.25-8.23 kg, 80.55-91.42 g and 0.102-0.115, respectively. Lambs finished on the higher silage diet (T_3) fetched the higher positive net income (113.08 and 186.85 Birr/lamb) and profit margin (0.47 or 0.72 Birr/lamb) when purchase cost of SCT was considered and excluded, respectively, over the control treatment, followed by lambs fed a diet with the higher level of SCT hay (T5). In conclusion, the burnt SCT that ensiled with 1% urea + 4% molasses solution, or chopped and sun-dried substituted up to 67% of natural pasture hay for feedlot Arsi-Bale lambs at an economic benefit.

6.2. Recommendations

- Training farmers on proper feeding, processing and preservation of sugarcane byproducts are important to improve utilization and reduce feed cost.
- Availing appropriate chopper at an affordable price for farmers around the Sugar Estates should deserve attention.
- Improving the marketing/distribution of molasses to livestock producers is vital.
- Research on the role of the present conservation methods on SCT microbial load and quality change with prolonged storage is recommended.
- Further studies on evaluating the complete replacement of natural pasture hay with the preserved SCT hay or silage on performances of sheep is important.
- Research at incorporating (determining the inclusion level) of the byproducts into total mixed ration for livestock is needed.
- Options for nutritive value improvement and conservation of bagasse should be studied.
- Feeding packages based on SCT, bagasse and molasses for large ruminants (beef and dairy cattle) should be developed.

7. REFERENCES

AACCSA (Addis Ababa Chamber of Commerce and Sectoral Associations), (2015). Value Chain Study on Meat Processing Industry in Ethiopia. 37p. http://addischamber.c om/wp-content/uploads/2017/01/Value-Chain-study-on-Meat-Processing.pdf. Accessed on September 27, 2017.

Aaslyng, M. D., Bejerholm, C., Ertbjerg, P., Bertram, H. C., and Andersen, H. J. (2003). Cooking loss and juiciness of pork in relation to raw meat quality and cooking procedure. *Food Qual Prefer.*, **14**(4):277–288.

Abebe T., Solomon M. and Peters K.J. (2010). Supplementation with linseed (*Linum usitatissimum*) cake and/or wheat bran on feed utilization and carcass characteristics of Arsi-Bale sheep. *Trop. Anim. Health Prod.*, **42**(4): 677-685.

Aberra M., Sandip B., Degnet H., Aster A. and Amsalu S. (2016). Carcass and meat quality characteristics of Arsi-Bale goats supplemented with different levels of air-dried *Moringa stenopetala* leaf. *J. Agr. R. Dev. Trop. Subtrop*., **117**(2): 233–242.

Abule E., Girma A. and Engida O. (2017). Livestock feed resources in Southern Ethiopia: The case of Meskan district. *Livest. Res. Rural. Dev*. 29(11).

Adane K. and Berhan T. (2007). Effect of harvesting stage and nutrient levels on nutritive values of natural pasture in the central highlands of Ethiopia. *Agricultural Tropica Et Subtropical*. **40**(1):7-12.

Adugna T. (2007). Feed Resources for Producing Export Quality Meat and Livestock in Ethiopia. Examples from selected Weredas in Oromia and SNNP Regional States. 79p.

Adugna T. (2008). Feed resources and feeding management: A manual for feedlot operators and development worker.38p.

Adugna T., Alemu Y., Alemayehu M., Dawit A., Diriba G., Getnet A., Lemma G., Seyoum B. and Yirdaw W. (2012). Livestock feed resources in Ethiopia: challenges, opportunities and the need for transformation. Addis Ababa, Ethiopia: Ethiopian Animal Feed Industry Association, pp.5-36.

Adugna T. and Makkar H. (2018). Livestock feedings systems, available feed resources and the challenges and opportunities for enhancing utilization of the available feed resources in Ethiopia. *In*: Technological Innovation and Education Training in Animal Production with a Focus on Feeding and Feed Production. May 10-13, 2018 Nanjing, China.

AFIA (Australian Fodder Industry Association), 2011. Laboratory Methods Manual. Version 7: 80-81. http://www.afia.org.au.

Aguirre J., Maga˜na R., Martínez S., Gómez A., Ramírez J.C., Barajas R., Plascencia A., Barcena R. and García D.E. (2010). Caracterización nutricionaly uso de la ca˜na de azúcar y residuos transformados en dietas para ovinos (in Portugues) *Zoot. Trop*. **(28)**: 489–497.

Akinbode R.M., Isah O.A., Oni A.O., Arigbede O.M. and Ojo V.O.A. (2017). Nutritional evaluation of sugarcane tops ensiled with varying proportion of broiler litter. *Livest. Res. Rural. Dev.*, **29**(1).

Alcántara E., Aguilera A., Elliot R., Shimada A. (1989). Fermentation and utilization by lambs of sugarcane harvested fresh and ensiled with and without NaOH. 4. Ruminal kinetics. *Anim. Feed Sci. Technol*., **23**(4):323-331.

Alemayehu M. (2006). Country pasture/Forage resource profiles, Ethiopia. Addis Ababa: Ethiopia. FAO (Food and Agricultural Organization of the United Nations). 36p.

Alemayehu T., Fulpagare Y. G and Gangwar S. K. (2014). Effect of urea treatment on chemical composition and oxalate content of sugarcane tops. *Int. J. Sci. Nature (I.J.S.N)*. **5**(1):15-18.

Alemzadeh B. and Noroozy, S. (2006). Effect of different levels of sugarcane tops silage in milk production of dairy cattle. Buffalo Bulletin. **25**(3): 69-73.

Ameha S. and Bleich E. G. (2013)**.** Middle East's market feedback on Ethiopian meat and live animal export and market opportunities. *In*: A Proceeding of the National Workshop on Exploiting Market Opportunity for Value Added Milk and Meat Products, held at Holetta Agricultural Research Center, October 16-17, 2011, Holleta, Ethiopia. pp. 85-94.

Andnet D., Temesgen A., Zewdie W., Tibebu S., Jonse N., Abera A. and Adugna T. (2014). Assessment of livestock production system and feed resources availability at Melka watershed, Jeldu district, Ethiopia. 27p. https://cgspace. cgiar.org/ bitstream/handle/10568//56928/jeldu_feast_sep2014.pdf;seque nce =1.

Andy D., Macdonald E. and Clark A. (1987). Water and quality loss during field drying of hay. *Advances in Agronomy*. **41**:407-437.

Anteneh W. (2014). Effect of Different Levels of Dried Sugarcane Tops Inclusion on the Performance of Washera Sheep Fed a Basal Diet of Grass Hay. MSc Thesis. Haramaya University, Ethiopia. 45p.

AOAC (Association of Official Analytical Chemists), 1990. Official Methods of Analysis. 15th Edition. Arlington, Verginia, USA. pp.12-98.

AOAC (2000). Meat and Meat Products. Official Methods of Analysis. 17th ed. Association of Official Analytical Chemists, Gaithersburg, Arlington, VA.

Archimède H. and Garcia G.W. (2010). Sugarcane and SDFs in the feeding of ruminants. Pp. 47-66. *In*: A guide to the use of sugarcane and its by-products as animal feeds: a manual for farmers and livestock production specialists. 134p.

BAPH (Bureau of Animal Production and Health), 1996. Criteria for evaluation of maize stover silage. BAPH, Ministry of Agriculture, Bejing, China. FAO publication.

Bekele S. (1991). Crop-livestock interactions in the Ethiopian highlands and effects on sustainability of mixed farming: a case study from Ada district, Debre Zeit. MSc thesis submitted to Agricultural University of Norway, Oslo, Norway. 163p.

Beukes, J. A. (2013). Maize Silage Based Diets For Feedlot Finishing of Merino Lambs. MSc Thesis. Stellenbosch University, South Africa. 91p.

Bien L.D.L. (1999). Sugarcane as replacement for Guinea grass for growing goats. *Livest. Res. Rural. Dev*., **11**(1).

Bolsen K.K., Ashbell G. and Weinberg Z.G. (1996). Silage fermentation and silage additives. A review *Asian-Australas J. Anim. Sci*., **9**: 483-493.

Borys B., Borys A., Oprządek J., Przegalińska-Gorączkowska M. (2011). Effect of sex and fattening intensity on health-promoting value of lamb meat. *Anim. Sci. Pap. Rep*., **29** (4): 331-342.

Castenada C. and Birrch C. (2011). Preparation, Maintenance and Utilization of Maize Silage: A Review. 75p. Available: http://espace.library.uq.edu.au/view /UQ:9697. Accessed on January, 20 2017.

Chala M., Ulfina G., Tesfaw A. and Lemma F. (2014). Growth performance and harvest measures of horro rams under different management practices at Ambo University, Ethiopia. *In*: Proceedings of the 2nd Annual Conference of Ambo University, 24-26 July 2013.Ambo, Ethiopia. 2:28-35.

Charmley E. (2001).Towards improved silage quality: A review. *Can. J. Anim. Sci*. **81(**2): 157–168.

Chaudhry S.M. and Naseer, Z. (2008). Safety of ensiling poultry litter with sugarcane tops. *Pak. J. Agri. Sci.* **45(**2): 322-326.

Collins M. and Owens V. N. (2003). Preservation of Forage as Hay and Silage. *In* Forages: An Introduction to Grassland Agriculture. Barnes RF, Nelson CJ, Moore KJ, Collins M. (Eds). Vol. **1**, 6th ed., pp: 443–471.

CSA (Central Statistics Agency of Ethiopia) (2016). Agricultural sample survey. Vol. IV. Land utilization: Pivate peasant holdings in Ethiopia: Statistical bulletin 584.

CSA (2017a). Agricultural sample survey: Area and production of major crops: private peasant holdings," Statistical bulletin 584, Vol. I. Addis Ababa, Ethiopia.

CSA (2017b). Agricultural sample survey: Report on livestock and livestock characterstics (private peasant holdings) Ethiopia: Statistical bulletin 585, Vol. II. Addis Ababa, Ethiopia.

Da Costa D. A., Souza C. L.d., Saliba E. O. S. and Carneiro J. D. C. (2015). Byproductsof sugarcane industry in ruminant nutrition. *Int. J. Adv. Agric. Res.* **3**(1):1-9.

Daniel J.L.P., Jobim C.C. and Nussio L.G. (2018). A data analysis on the effect of acetic acid on dry matter intake in dairy cattle. *In*: Gerlach, K. and K.-H. Südekum (eds). *In*: Proceedings of the XVIII International Silage Conference, 24-26 July 2018, Bonn, Germany. pp.374-375.

Dawit A., Seyoum B. and Yirdaw W. (2012). Feed marketing and quality issues. *In:* Livestock Feed Resources in Ethiopia: Challenges, Opportunities and need for transformation. pp. 74- 89.

Delgado C, Rosegrant M, Steinfeld H, Ehui S, Courbois C. (1999). Livestock to 2020: the next food revolution. Food, Agriculture and the Environment Discussion Paper 28. Washington, DC: IFPRI/FAO/ ILRI. 83p.

Demisse N., 2017. Review on compound animal feed processing in Ethiopia: Condition, challenges and opportunities. *J.Nutri. Health*, **3**(2):1-5.

Deshmukh S.B. (1983). Prospects of Use of Byproducts. *In*: Gur and Sugar industry in Kolhapur district. A geographical analysis (Ed).Tawde, Mohan D. Shodhganga Shivaji University. 326p. http://hdl.handle.net/10603/140679.

Digman M., Undersander D., Shinners K. and Saxe C. (2011). Best practices to hasten field drying of grasses and alfalfa (A3927). University of Wisconsin-Extension, Co-operative Extension. 8p.Available:https://learningstore.uwex.edu/Assets/pdfs/ A3927.pdf. 8p. Accessed on January 12, 2016.

Diriba G., Mekonnen H., Ashenafi M. and Adugna T. (2014). Analysis of fluid milk value chains at two peri-urban sites in western Oromia, Ethiopia: current status and suggestions on how they might evolve. *Global Veterinaria* **12**(1): 104-120.

Duguma B. and Janssens G.P. J. (2016). Assessment of feed resources, feeding practices and coping strategies to feed scarcity by smallholder urban dairy producers in Jimma town, Ethiopia. *SpringerPlus*. **5**(1):717.

Dzowela B. H., Hove L. and Mafongoya P. L. (1995). Effect of drying methods on chemical composition and in vitro digestibility of multi-purpose tree and shrub fodders." *Tropical Grasslands*. **29**: 263-269.

EARO (Ethiopian Agricultural Research Organization), (2000). National Small Ruminants Research Strategy Document. EARO, Addis Ababa, Ethiopia. 59p.

Eggleston G., Legendre B. and Godshall M. A. (2017). Sugar and Other Sweeteners. *In*::Handbook of Industrial Chemistry and Biotechnology. Kent, James A., Bommaraju, Tilak, Barnicki, Scott D. (Eds.). pp. 933-978.

EMAPRM (Ethiopian Meat Animal Production Road Map), (2016). Ethiopian Policy Study and Research Center (Agricultural Modernization). A report. 142p.

Enoh M.B, Kijora C, Peters K.J., Tanya V.N. Fonkem D. and Mbanya J. (2005). Investigation on change of forage quality at harvesting, during hay making and storage of hay harvested at different growth stages in the Adamawa plateau of Cameroon. *Livest. Res. Rural. Dev*., **17**(5).

Ensminger M. E., Oldfield J. E.and Heinemann W. W. (1990). Feeds and Nutrition, 2nd ed. The Ensminger publishing company, USA. 433p.

ERSS (Ethiopia Rural Socioeconomic Survey) (2013). Survey Report. Central Statistical Agency and the World Bank. 65p. http://siteresources. World bank .org/

Esayas T., Firew M., Hussein S. and Mwadzingeni L. (2016). Sugarcane production under smallholder farming systems: Farmers preferred traits, constraints and genetic resources. *Cogent Food and Agriculture.* **2**(1):1191323.

Esayas T., Firew M. and Amsalu A. (2018). Sugarcane Landraces of Ethiopia: Germplasm Collection and Analysis of Regional Diversity and Distribution. Hindawi. *Advances in Agriculture*. https://doi.org/10.1155/2018/7920724.

ESGPIP (Ethiopia Sheep and Goat Productivity Improvement Program). 2011. Short Term Intensive Fattening of Sheep and Goats for Rapid Improvement in Weight and Condition and also Producer Incomes. Technical Bulletin No.11. 11p.

Fekede F., Prasad S., Getnet A., Getu K. and Seyoum B. (2013).The status of production, conservation and utilization of natural pasture hay for feeding dairy cattle in the greater Addis milkshed, central highlands of Ethiopia. *J. Agric. Res. Dev*., **3**(6):082-093.

Fekede F., Prasad S., Getnet A., Seyoum B., Getu K., Aemiro K. and Gezehagne K. (2014). Dynamics in nutritional characterstics of natural pasture hay as affected by harvesting stage, storage method and storage duration in the cooler tropical highlands. *Afr. J. Agric. Res.* **9**(43):3233-3244.

Fentie B. and Solomon M. (2008). Feed utilization and live weight change of Farta sheep supplemented with *noug* seed (*Guizaotia Abyssinian*) cake, Wheat bran and their mixtures. *Tropical Animal Health and Production,* **40**(8):597-606.

Ferreira A.C. H., Neiva J. N. M., Rodriguez N. M., Lôbo R. N. B., Vasconcelos V. R. (2004). Nutritive value of elephant grass silage added byproducts from the Cashew Juice Industry. *R. Bras. Zootec*., **33**(6):1380-1385.

Fluid Surveys Team (2014). Calculating the right survey sample size. http://fluidsurveys.com.

Fouda, S. M. I. (2008). Studies of Nutrition on Sugarcane Bagasse Previous Treated of Some Chemical and Biological Treatment. PhD Thesis, Faculty of Agriculture. Al-Azhar University, Egypt. 191p.

Freweini A., Getachew A. Yoseph M. and Mengistu U. (2014). Assessment of the feeding potential and utilization of *Erythrina burana* and *Casimiroa edulis* in Eastern Harerghe zone of Ethiopia. *Livest. Res. Rural. Dev*., **26(**5).

Funte S., Negesse T. and Legesse G. (2010). Feed resources and their management systems in Ethiopian highlands: The case of Umbulo Wacho watershed in southern Ethiopia. *Tropical and Subtropical Agroecosystems*. **12** (1):47-56.

Galina M. A., Guerrero M. and Puga C. D. (2007). Fattening Pelibuey lambs with sugarcane tops and corn complemented with or without slow intake urea supplement. *Small Rum. Res.* **70**(2-3):101-109.

Gendley M. K., Singh P. and Garg A. K. (2002). Performance of crossbred cattle fed chopped green sugarcane tops and supplemented with wheat bran or lentil chuni concentrates. *Asian-Aust. J. Anim. Sci.* **15**(10): 1422-1427.

Gendley M.K., Singh P., Garg A.K., Tiwari S.P., Kumari K. and Dutta G.K.(2009). The studies on nutrient balances in crossbred cattle bulls fed chopped green sugarcane tops supplemented with some agro industrial byproducts. *Trop. Anim. Health Prod*. **41**: 943–949.

Getahun K. (2015). Optimum dietary crude protein level for fattening yearling Arsi-Bale lambs. *Animal and Veterinary Sciences*. **3**(5):144-148.

Girma A., Kannan G. and Goetsch A.L. (2010). Effects of small ruminant species and origin (highland and lowland) and length of rest and feeding period on harvest measurements in Ethiopia. *Afr. J. Agric. Res.* **5**(9): 834-847.

Gryseels G., (1988). The Role of Livestock in the Generation of Smallholder Income in Two Vertisol Areas of the Central Ethiopian Highland; *In*: S.C.Jutzi,I.

Haque, J. MacIntire, J.E.S. Stares (eds). Management of Vertisols in Sub-saharn Africa. ILCA, Addis Ababa.

Hall M.B (2000). Neutral detergent-soluble carbohydrates. Nutritional and relevance analysis. Florida: University of Florida. Bulletin 339.

Hassen A., Abule E., Mohammod K. and Treydte A C. (2010). Livestock feed resources utilization and management as influenced by altitude in the central highlands of Ethiopia. *Livest. Res. Rural. Dev*., **22** (12).

Heikkilä T, Saarisalo E, Taimisto A-M and Jaakkola S (2010). Effects of dry matter and additive on wilted bale silage quality and milk production. *Grassland Science in Europe*.**15**:500–502.

Heuzé V., Tran G., Archimède H., Renaudeau D., Lessire M. and Lebas F.(2015a). Sugarcane molasses. Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. https://www. feedipedia.org/node/561. Accessed on October 21, 2017.

Heuzé V., Tran G., Baumont R., Noblet J., Renaudeau D., Lessire M. and Lebas F.(2015b). Wheat bran. Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. http://www. feedipedia.org/node/726. Accessed on January, 10, 2016.

Heymann, H., Hedrick, H. B., Karrasch, M. A., Eggeman, M. K., and Ellersieck, M. R. (1990). Sensory and chemical characteristics of fresh pork roasts cooked to different centre temperatures. *J. Food Sci.*, **55**(3):613–617.

Hirut Y., Solomon M. and Mengistu U. (2011). Effect of concentrate supplementation on live weight change and carcass characteristics of Hararghe highland sheep fed a basal diet of urea-treated maize stover. *Livest. Res. Rural. Dev*., **23**(12).

Huhtanen P., Khalili, H. and Nousiainen J. (2002). Prediction of the relative intake potential of grass silage by dairy cows. *Livest. Prod*. **73**:111–130.

ILCA (International Livestock Centre for Africa), (1990). Livestock systems research manual. Working Paper 1, Vol. 1. ILCA, Addis Ababa, Ethiopia. 287p.

Jemal D., Chala M., Diriba G., Ulfina G., Diriba D., Adane H. and Temesgen J. (2004). Weight gain, carcass characteristics and economic evaluation of Horro ram supplemented with different substitution levels of maize grain and molasses. *In*: Proceedings of the 13th Annual conference of the Ethiopian Society of Animal Production (ESAP), August 25-27, 2004. Addis Ababa, Ethiopia. 244 pp.

Jimma A., Tessema F., Gemiyo D. and Bassa Z. (2016). Assessment of available feed resources, feed management and utilization systems in SNNPRS of Ethiopia. *J. Fisheries Livest.Prod.* **4**:183. doi: 10.4172/2332-2608.1000183

Julião R. L. Couto, Severino D. J. Villela, Mário H. F. Mourthé, Adalfredo R. Lobo-Jr, Roseli A. Santos and Paulo G. M. A. Martins, 2016.. Sugarcane tops as a substitute for sugarcane in high-concentrate diets for beef bulls. *Animal Production Science.* **57**(3):563-568.

Kevelenge J.E.E., Said A.N. and Kiflewahid B. (1983). The nutritive value of four arable farms by products commonly fed to dairy cattle by small scale farmers in Kenya. III. Nitrogen and mineral retentions by weather. *Tropical Animal Production*. **8**:180–186.

Khanal R. C., Perera A. N. F. and Perer E. R. K. (1995). Ensiling characterstics and nutritive value of sugarcane tops. *Tropical Agricultural Research*. **7**:177-185.

Knapik J., Ropka-Molik K., Pieszka M. (2016). Genetic and nutritional factors determining the production and quality of sheep meat – a review, *Ann. of Anim. Sci.*, **17**(10): 23-40.

Kung L. and Shaver R. (2001). Interpretation and use of silage fermentation analysis reports. *Focus on Forage*. **3**(13):1-5.

Kung L. (2011). Silage temperatures: how hot is too hot? Department of Animal and Food Sciences.Available on line at: https://cdn.canr.udel.edu/wp-content/ uploads /2014/02/HowHotisTooHot-2011pdf. Accessed on July 24, 2016.

Kung L., Stokes M. R. and Lin C. J. (2003). Silage additives. *In:* Silage Science and Technology. Gronomy Monograph no. 42. pp. 305-360.

Lawrie R.A. and Ledward D.A. (2006). *In*: Lawrie's Meat Science (7th ed.). Woodhead Publishing Limited, Abington, Cambridge, England. pp. 34-36.

Leme P. R., Silva S. L., Pereira A. S. C., Putrino S. M., Lanna D. P. D. and Nogueira Filho J. C. M. (2003). Levels of sugarcane bagasse in diets with high concentrate for Nellore steers in feedlot. *R. Bras. Zootec.* **32**(6):1786-1791.

Magaña R, Aguirre J, Aguirre A, Gómez A, Martínez S, Lemus C, Ulloa R and Ly J (2009). Entire sugarcane or sugarcane residues for feeding sheep. Performance traits of hairless sheep. *Livest. Res. Rural. Dev.*, **21**(2).

Mahala A.G. and Mokhtar A.M.S. (2013a). Nutritive evaluation of sugarcane tops and meat parameters of dairy calves, crossbred and pure local (Kenana Breed - Sudan). *World Vet. J*., **3**(1): 21-28.

Mahala A.G., Mokhtar A.M.S., Amasiab E.O. and AttaElmnan B.A. (2013b). Sugarcane tops as animal feed. *Int. Res J. Agric. Sci. Soi. Sci.* **3**(4):147-151.

Mashego D. V. (2016). Preparation, Isolation and Characterization of Nanocellulose from Sugarcane Bagasse. MSc Thesis. Durban University of Technology, Durban, South Africa. 140p.

McDonald P., Edwards R.A, Greenhalgh J. F. D., Morgan C.A., Sinclair L.A and Wilkinson R.G. (2010). Animal Nutrition. 7th Ed. Ashford Color Press Ltd., England. pp. 499-520.

McGechan M.B. (1990). A review of losses arising during conservation of grass forage: Part 2, storage losses. *Journal of Agricultural Engineering Research*.**45**:1-30.

McKenzie J. and Griffiths C. (2007). Sugarcane tops as cattle fodder. New South Wales Department of Primary Industries, Primefacts, No. 314.

http://www.dpi.nsw. gov. au/_data/assets/pdf_file/0009/110160/cane-tops-as-cattle-fodder.pdf. Accessed on July 13, 2016.

Mesfin D., Seyoum B., Dawit A., Getu K., Aemiro K., Getnet A. and Getaw T. (2014). Livestock feed marketing in Ethiopia: challenges and opportunities for livestock development. *Journal of Agricultural Science and Technology* **4**:155-168.

Misra A. K., Pathak P.K., Raootrn S. and Singw A. P. (1997). Effect of processing and weather condition on drying rate and chemical composition of berseem. *Ind. J. Anim. Sci.* **67**(2):168-169.

Moti J., Menale K. and Erenstein O. (2015). Determinants of maize stover utilization as feed, fuel and soil amendment in mixed croplivestock systems, Ethiopia. Elsevier Ltd. *Agricultural Systems* **134**:17–23.

Mtunzi B., Mampwheli N., Meyer E. and Wilson Mungwena, 2012. Bagasse-based cogeneration at Hippo Valley Estates sugar factory in Zimbabwe. *Journal of Energy in Southern Africa***, 23** (1): 15-22.

Muck R.E. (2004). Effects of corn silage inoculants on aerobic stability. *American. Society of Agricultural Engineering.* **47**(4):1011–1016.

Naseeven R. (1988). Sugarcane Tops As Animal Feed. *In*: Sugarcane as feed. Sansoucy, R., Aarts, G. and Preston T.R. (eds.) FAO Animal Health and Production Paper No.72, 106-122.

NRC (National Research Council), (1985). The Nutrient Requirements of Sheep. National Research Council (6^{th} edition). ASA-National Academy Press. Washington, D C, US.

Nguyen T.M., Preston T.R, Dinh V.B., Le V.L. and Ohlsson I. (1996). Effect of management practices on yield and quality of sugarcane and on soil fertility. *Livest. Res. Rural. Dev.,* **8**(3):51-60.

Ning T., Huili W., Mingli Z., Dongze N., Sasa Z. and Chuncheng X.(2017). Effects of microbial enzymes on starch and hemicellulose degradation in total mixed ration silages. *Asian-Australas J. Anim. Sci.* **30**(2):171-180.

Ortiz-Rubio M.A., Ørskov E.R., Milne J. and Galina H.M.A. (2007). Effect of different sources of nitrogen on *in situ* degradability and feed intake of Zebu cattle fed sugarcane tops (*Saccharum officinarum*). *Anim. Feed Sci. Technol*. **139** (3-4):143–158.

Osafo E. L. K., Owen E., Said A. N. and Gill. M. (1997). Effects of amount offered and chopping on intake and selection of sorghum stover by Ethiopian sheep and cattle. *Journal of Animal Science*. **65**(1):55-62.

Ososanya T. O. and Olorunnisomo O. A. (2015). Silage characteristics and preference of sheep for wet brewer's grain ensiled with maize cob. *Livest. Res. Rural. Dev.*, **27**(1).

Pedroso A.F, Rodrigues A.A., Júnior W.B. and Souza G.B. (2011). Fermentation parameters, quality and losses in sugarcane silages treated with chemical additives and bacterial inoculants. *R. Bras. Zootec*. **40**(11):2318-2322.

Pedroso A.F., Pedroso A. M., Júnior W. B. and de Souza G.B. (2014). Evaluation of sugarcane laboratory ensiling and analysis techniques. *R. Bras. Zootec*., **43**(4):169-174. http://dx.doi.org/10.1590/S1516-35982014000400002.

Pereira R. A. N., Ferreira W. M. and Garcia S. K. (2008). Digestibility of sugarcane bagasse after a NaOH treatment in growing rabbit diets. *Ciênc. Agrotec.* **32**(2):573-577.

Pitt R.E. (1990). The biology of silage preservation. *In*: Silage and Hay Preservation. National Resource, Agriculture and Engineering Service, Ithaca, NY. pp.5-20. https://cpb-us-e1.wpmucdn.com/blogs.cornell.edu/dist/e/1628/files/2016/03/Sila ge-Hay-Preservation-wgxus9.pdf

Preston T. R. and Leng R. A. (1991). Matching Ruminant Production Systems with Available Resources in the Tropics and Sub-tropics. 265p. https://www. cabdirect. org/cabdirect/abstract/19886768351

PSRC (Policy Study Research Center) (2017). Road map of Ethiopian meat animal production development. Federal Democratic Republic of Ethiopia. Addis Ababa, Ethiopia. 144p. www.psrc.gov.et.

Ramírez-Cathí H., Aida C.C., Salcedo F. B., Lucero F.A., Alicia C., Marcof C. and Martínez J. C. (2014). Bromatological and morphological characterization and yield of sugarcane tops in Huasteca Potosina, Mexico. *Cuban J. Agric. Sci.*, **48**(4).

Reddy R.R. and Prasad D.A. (1982). Studies on improving nutritive value of sugarcane tops with urea, or dried poultry waste by ensiling techniques and development of complete rations for growing Nellore lambs. *Indian J. Anim. Sci.*, **76**:805-807.

Ripoli M.L.C., Franco F.N., Ripoli T.C.C.and Gamero A.C. (2005). The sugarcane crop residues unloaded in the sugar mill: operational costs and physical characteristics. *Engenharia Rural* **16**: 17-23.

Roberts C.A. (1995). Microbiology of stored forages. *In*: Moore K.J. and Peterson M.A. (ed.) Post-harvest physiology and preservation of forages. CSSA Spec. Publ. 22. ASA and CSSA, Madison, WI. pp. 21–38.

Rodríguez A.A., Luciano D., Galván M., and Solórzano L.C. (2015). Effects of aerobic exposure on fermentation end-products of corn and sugarcane silages and intake by goats. *In*: Proceedings of the XVII International Silage Conference. July 1-3, 2015. Piracicaba, São Paulo, Brazil.

Romero J.J., Castillo M. S., Burns J. C., Moriel P. and Davidson S. (2014). Forage quality: concepts and practices. AG-792. Raleigh, NC:hNorth Carolina Cooperative Extension Service. https://content.ces.ncsu. edu/static/publication

/js/pdfjs/web/viewer.html?slug=forage-quality-concepts-and-practices. Accessed on June 8, 2016.

Romero J. J., Castillo M., Burns J. C, Mueller P. and Green J. (2015). Forage conservation techniques: Hay production. Crop and soil sciences. Available online at: https://content.ces.ncsu.edu /forage-conservation-techniques-hay-produ ction. Accessed on June 8, 2016.

Rotz C.A. (2003). How to maintain forage quality during harvest and storage. *Advances in Dairy Technology*: **15:** 227-236.

Rotz C. A. and Shinners K. J. (2007). Hay Harvest and Storage. *In*: Forages: The Science of Grassland Agriculture, edited by R.F. Barnes, C.J. Nelson, K.J. Moore and M. Collins. Ames, IA: Blackwell Publishing. pp. 601–616.

Said M., Tewodros K. and Getachew K. (2018). Meat quality and morphology to meet the patency of Menz sheep (*Ovis aries*) in North Shewa Zone, Ethiopia. *Int. J. Livest. Prod.* **9**(2):17-23.

Salinas-Chavira J., Almaguer L.J., Aguilera-Aceves C.E., Zinn R.A., Mellado M. and Ruiz-Barrera O. (2013). Effect of substitution of sorghum stover with sugarcane tops silage on ruminal dry matter degradability of diets and growth performance of feedlot hair lambs. *Small Rum. Res.*, **112**:73– 77.

Samanta A K, Singh K K, Verma N C.and Misra A.K (2001). Effect of additives on silage quality of Napier ensiled in plastic bag. *Indian J. Anim. Sci*. **71**(9):881-882.

Sampaio C. B., Detmann E., Lazzarini I., Souza M. A., Paulino M. F. and Valadares F.S. C. (2009). Rumen dynamics of neutral detergent fiber in cattle fed low-quality tropical forage and supplemented with nitrogenous compounds. *Rev. Brasil. Zootec*. **38** (3): 560–569.

Santos-Silva, J., Mendes, I. A., and Bessa, R. J. B. (2003). The effect of genotype, feeding system and slaughter weight on the quality of light lambs:1. Growth, carcass composition and meat quality. *Livest. Prod. Sci.*, **76**(1–2):17–25.

SAS (Statistical Analysis System). 2004. Version 9.1. SAS Institute. Inc., Cary, NC, USA.

Selamawit D., Yeshambel M. and Bimrew A. (2017). Assessment of livestock production system and feed balance in watersheds of North Achefer District, Ethiopia. *J. Agric. Env. Int. Dev.*, **111**(1): 175-190.

Senthilkumar S., Suganya T., Deepa K., Muralidharan J. and Sasikala K. (2016). Supplementation of molasses in livestock feed. *Int. J. Sci. Env. Tech.*, **5**(3):1243–1250.

Seyoum.B and Fekede F. (2008). The status of animal feeds and nutrition in west-shoa zone of Oromia, Ethiopia. *In*: Kindu M., Glatzel G. and Habermann, B. (eds.) (2008) Indigenous tree and shrub species for environmental protection and agricultural productivity. *In*: Proceedings of the Workshop 'Indigenous Tree and Shrub Species for Environmental Protection and Agricultural Productivity', November 7-9, 2006, Vienna, Austria.

Shapiro B.I., Gebru G., Desta S., Negassa A., Nigussie K., Aboset G. and Mechale H. (2017). Ethiopia livestock sector analysis. ILRI (International Livestock Research Institute) Project Report. Nairobi, Kenya. 103p.

Sharma V.K., Tomar S.K., Kundu S.S., Pankaj J., Pankaj J., Muneendra K. and Manju L.(2012). Chemical composition and effect of feeding different levels of sugarcane tops with concentrate mixture/mustard cake on digestibility in Buffalo calves. *Indian J. Dairy Sci*. **65**(5).

Shija D.S., Mtenga L.A., Kimambo A.E., Laswai G.H., Mushi D.E., Mgheni D.M., Mwilawa A.J., Shirima E.J. M. and Safari J.G. (2013). Chemical composition and meat quality attributes of indigenous sheep and goats from traditional production system in Tanzania. *Asian-Aust. J. Anim. Sci.* **26**(2):295-302.

Sindhu A. A., Khan M.A., Mahr-Un-Nisa and Sarwar M. (2002). Agro-industrial byproducts as a potential source of livestock feed. *Int. J. Agri. Biol.* **4**(2): 307-310.

Siqueira, G.R., R.A. Reis, R.P. Schocken-Iturrino, T.F. Bernardes, A.J.V. Pires, M.T.P. Roth R.C. Amaral. (2009). Effect of chemical and bacterial additives on chemical composition of burnt and unburnt sugarcane silage. *Arch. Zootec.* **58** (221): 43-54.

Siqueira G.R., Reis R.A., Schocken-Iturrino R.P., Bernardes T.F., Pires A.J.V., Roth M.T.P. and Roth A.P.T.P. (2007). Chemical and bacterial additives association on the sugarcane ensilage. *Revista Brasileira de Zootecnia.* **36**(4):789-798.

Solomon B., Solomon M. and Alemu Y. (2008). Potential use of crop residue as livestock feed reduces under small holder farmers conditions in Bale highland of Ethiopia. *Tropical and subtropical Agro ecosystems*. **8**:107-114.

Solomon G., Abule E., Yayneshet T., Zeleke M., Yosef M., Hoekstra D., Berhanu G. and Azage T. (2017). Feed resources in the highlands of Ethiopia: A value chain assessment and intervention options. LIVES Working Paper 27. Nairobi, Kenya: ILRI. 40p.

SPSS (Statistical Package for Social Sciences), (2011). SPSS Version 20 for Windows.Inc. Chicago, Illinois.

Suárez R, Mejía J, González M, García D.E and Perdomo Y D.A (2011). Evaluation of mixed silages of *Saccharum officinarum* and *Gliricidia sepium* using additives. *Pastos Forrajes*. **34**(1): 69-86.

Suliman A. I. A., Baiomy A.A. and Awad-Allah M.A.A. (2013). Productive performance of growing lambs fed silages of sugarcane tops, sugar beet leaves and green maize stems. *Egyptian Journal of Animal Production*, **50**(2):59-67.

Suliman A.I.A, Azza M.M. B. and Ebtehag I.M. (2016). Performance of lambs fed on biologically treated silages. *International Journal of Chem. Tech. Research*. **9**(5):151-160.

Suttie J M (2000). Hay And Straw Conservation for Small-Scale Farming and Pastoral Conditions. FAO Plant Production and Protection Series No. 29, FAO, Rome. 303p.

Syomiti M., Wanyoike M., Wahome R.G. and Kuria J.K.N. (2011). The status of maize stover utilization as feed for livestock in Kiambu and Thika districts of Kenya: Constraints and opportunities. *Animal Science Journal*, **8**:9-13.

Tegene N., Makkarb H.P.S., Beckerb K. (2009). Nutritive value of some non-conventional feed resources of Ethiopia determined by chemical analyses and an *in vitro* gas method. *Anim. Feed Sci. Technol.*, **154** (3-4):204–217.

Tesfay Y., Gebrelibanos A., Woldemariam S. and Tilahun H. (2016). Feed resources availability, utilization and marketing in central and eastern Tigray, northern Ethiopia. LIVES Working Paper 11. Nairobi, Kenya: ILRI.

Tesfaye A. and Chairatanayuth P. (2007). Management and feeding systems of crop residues: the experience of East Shoa Zone, Ethiopia. *Livest. Res. Rural. Dev.*, **19** (3).

Tesfaye M (2016). Assessment of beef cattle production, assessment of beef cattle production, management practices and marketing system in Lume district, East shoa zone. MSc Thesis. Hawassa University, Ethiopia. 109p.

Tilley J. and Terry R A (1963). A two stage technique for the *in-vitro* digestion of forage crops. *Journal of British Grassland Society*, **18**:104–111.

Torres L. B., Ferreira M. A., Véras A. S. C., Melo A. A. S. and Andrade D. K. B. (2003). Sugarcane bagasse and urea as replacement of soybean meal in the growing dairy cattle diets. *R. Bras. Zootec*. **32**(3):760-767.

Tsegay L., Mohammed B. and Sandip B. (2015). Meat quality assessment at Hawassa city in Southern Ethiopia. *World Journal of Multidisciplinary and Contemporary Research*. **1**(2):1- 9.

Tsegay T., Yoseph M. and Mengistu U. (2013). Comparative evaluation of growth and carcass traits of indigenous and crossbred (Dorper × Indigenous) Ethiopian sheep. *Small Rum. Res.,* **114**: 247–252.

Undersander D. (2011). Hay drying, preservatives, conditioning, ash content. *In*: Garry L, Christi F (*eds*), 31st Kentucky Alfalfa Conference, 24 February 2011, Fayette County Extension Office, Lexington, Kentucky. pp. 14–21.

Upton M. (1979). Farm Management in Africa: The Principle of Production and Planning. Oxford University Press, Great Britain.**28:** 298p.

Van Soest P.J. and Robertson J. B. (1985). Analyses of Forage and Fibrous Foods. A laboratory Manual for Animal Science 613. Cornell University, Ithaca, New York, USA.

Yadessa E, Ebro A, Fita L and Asefa G. (2016). Feed resources and its utilization practices by smallholder farmers in Meta-Robi District, West Shewa Zone, Oromiya Regional State, Ethiopia. *Acad. Res. J. Agri. Sci. Res*. **4**(4): 124-133.

Yihalem D., Berhan T. and Solomon M. (2006). Effect of harvesting date on composition and yield of natural pasture in north western Ethiopia. *Tropical Science* **45**(1):19-22.

Yuangklang C., M. Wanapat, and C. Wachirapakorn, 2005. Effects of pelleted sugarcane tops on voluntary feed intake, digestibility and rumen fermentation in beef cattle. *Asian-Aust. J. Anim. Sci.* **18**(1):22-26.

Zewdie W. and Yoseph M. (2014). Feed resources availability and livestock production in the central Rift Valley of Ethiopia. *Int. J. Livest. Prod.,* **5**(2):30-35.

8. APPENDICES

Appendix Table 1. Chemical composition (% DM basis) of roughage refusal samples of sheep feeding trial

	T_1	T_2	T_3	T_4	T_5
DM%	87.0	57.7	42.8	87.2	87.5
CP	4.3	4.5	4.6	3.4	3.3
Ash	9.6	10.6	11.0	11.6	11.2
NDF	71.4	71.6	70.3	66.4	69.7
ADF	46.4	47.6	48.9	49.3	49.3
ADL	10.6	10.1	10.5	10.3	10.4

T_1(control) = 100% Natural pasture hay *ad libtum* + 350 g/day concentrate;
T_2 = (67% Natural pasture hay + 33% SCT silage) *ad libtum* + 350 g/day concentrate;
T_3 = (33% Natural pasture hay + 67% SCT silage) *ad libtum* + 350 g/day concentrate;
T_4 = (67% Natural pasture hay + 33% SCT hay) *ad libtum* + 350 g/day concentrate;
T_5 = (33% Natural pasture hay + 67% SCT hay) *ad libtum* + 350 g/day concentrate

Appendix Table 2. Determinants of market price for molasses and SCT in the study areas (% of respondents)

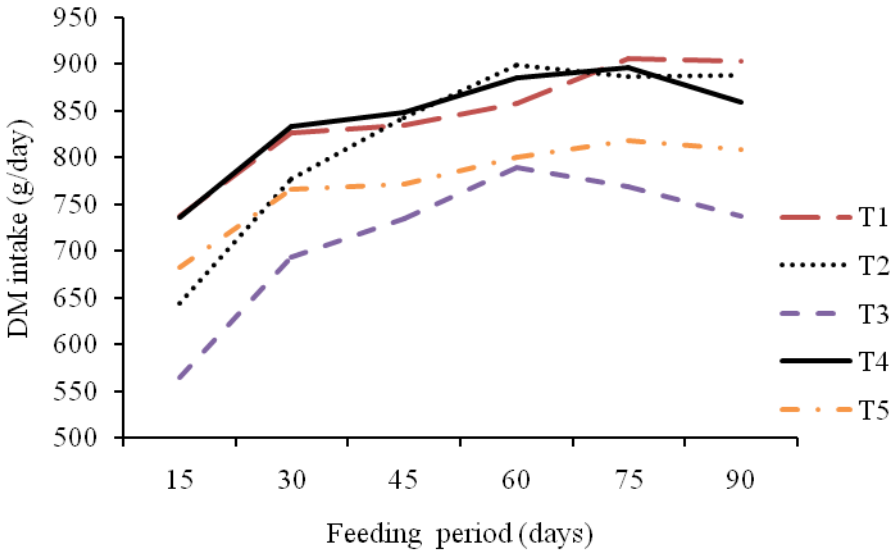
Price determinants	Molasses				SCT			
	Metehara (*n*,110)	Wonji-Shoa (*n*,198)	Total (*n*,308)	*P*-value	Metehara (*n*,110)	Wonji-Shoa (*n*,198)	Total (*n*,308)	*P*-value
Distance from factory/source	0.0	10.6	6.87	<0.001	41.8	33.8	36.7	-
Lack of transport	0.9	9.1	6.2	0.004	0	3.0	1.9	0.065
Low availability	0.9	3.5	2.6	0.165	3.6	5.1	4.5	0.568
High competition	0	3.5	2.3	0.046	4.5	6.6	5.8	0.469
Lack of labour	0	4.5	2.9	0.023	0	4.5	2.9	0.023
Type, variety and quality	-	-	-	-	32.8	1	14.3	<0.001
Season of the year	-	-	-	-	2.7	1.5	1.9	0.461
Limited access to fields	-	-	-	-	0	0.5	0.3	0.455
Drought occurrence	-	-	-	-	19.1	0.5	7.1	<0.001
Size of a horse cart (for SCT)	-	-	-	-	13.6	1.5	5.8	<0.001

P-value compares within a row for the two Sugar Estates and for each byproduct*; n* = number of respondents; SCT = sugarcane tops

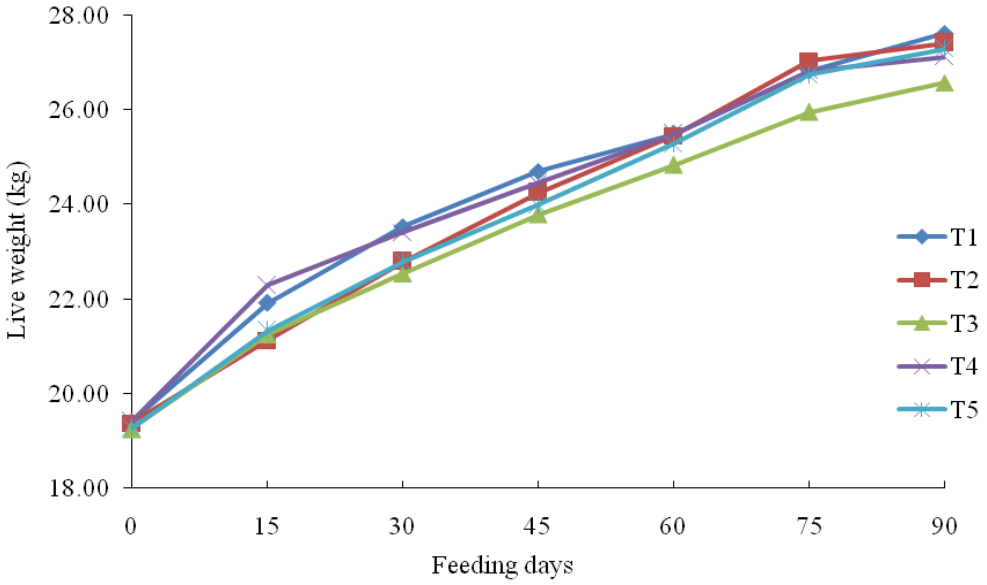
Appendix Table 3. Chemical composition (mean, %DM) of the major feedstuffs used by the surveyed farm households in the study areas

Sugar Estate	Feed items	DM	CP	Ash	NDF	ADF	ADL
Metehara	Burnt SCT	94.57	2.31	7.17	61.65	38.46	5.16
	Seedcane tops	96.77	3.75	10.96	63.08	50.03	6.22
	Molasses	73.99	3.56	13.57	0.57	0.32	0.21
	Grass hay	95.68	3.99	6.21	70.35	30.64	5.90
	Bagasse*	43.05	2.18	2.7	84.46	60.02	13.37
Wonji-Shoa	Burnt SCT	95.69	2.45	7.42	68.40	46.41	6.70
	Seedcane tops	95.36	2.70	7.19	68.07	41.70	4.61
	Molasses	75.07	3.15	14.04	0.30	0.11	0.12
	Grass hay	96.03	4.09	6.14	72.29	52.08	6.49
	Bagasse*	41.46	2.0	6.2	83.7	63.9	12.4
Concentrate	Maize grain	94.49	6.14	1.06	70.47	5.63	4.93
	Noug cake	96.00	30.38	9.78	30.13	23.33	9.51
	Wheat bran	94.98	12.07	4.53	49.37	15.06	1.23

*Sampled from sugar factories; DM = dry matter; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin



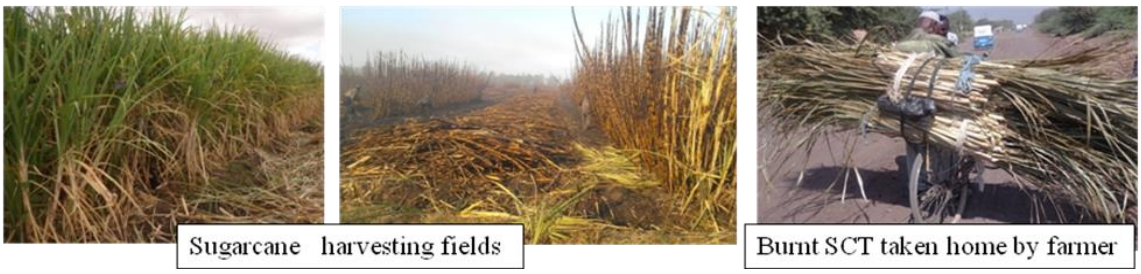
Appendix figure 1.Trend of total dry matter intake for experimental lambs



Appendix figure 2. Trend of body weight change of lambs as affected by the experimental diets

Where, T_1(control) = 100% Natural pasture hay + 350 g/day concentrate; T_2 = (67% Natural pasture hay + 33% SCT silage) + 350 g/day concentrate; T_3 = (33% Natural pasture hay + 67% SCT silage) + 350 g/day concentrate; T_4 = (67% Natural pasture hay + 33% SCT hay) + 350 g/day concentrate; T_5 = (33% Natural pasture hay + 67% SCT hay) + 350 g/day concentrate

Appendix figure 3. Pictures taken during the research implementation








Silage making trial and evaluation



Hay making trials



Silage preparation for the feeding trial



Sheep feeding trial and carcass analysis

Appendix 1. Questionnaire for formal survey

1. General information

1.1. Enumerator's name_____Date of interview___/___/ _____

1.2. Sugar Estate _____ Zone_____District_____

PA_____ Town_____ Camp_____

2. Household characteristics:

2.1. Sex of HH head 1) Male 2) Female :Age_____ Phone: _____

2.2. Education of HH head: 1) Illiterate 2) Write and read 3) Completed grade____

4) other____

2.3. Family size: Male_____ Female _____

2.4. Land holdings and use since 2008 E.C: (ha, 'Kert', m^2):

1) Cultivated land _____ 2) Grazing land_____ 3) Residence compound land_____ 4) Others (specify)_____ 5) Total _____

2.5. Main livelihood activity:

1) Livestock production: 1) Dairying 2) Fattening (cattle/sheep/goat)

2) Crop production 3) Trade 4) Employee 5) Retired 6) Other_____

3. Livestock holdings and herd structure

		Cows	Bull/oxen	Heifers	Calves
Cattle	Local		___/____		
	Crossbred		___/____		
Sheep	Local	Ewe_____	Ram____	Yearling___	Lambs___
Goat	Local	Doe _____	Buck____	Yearling___	Kids_____
Horse	Local	Adult_____	Young____	-	-
Donkey	Local	Adult_____	Young____	-	-
Mule	Local	Adult_____	Young____	-	-
Camel	Local	Adult_____	Young____	-	-
Chicken	Local	Pure exotic___	Crossbred___	-	-

NB: Young animal = 3 < years old; Adult animals = >3 years old

4. Feed resources and feeding system

4.1. Major feed resources available and used (Most important = 1; least important =7)

List of available feeds	Season used (wet=1; dry = 2; both= 3)	Source (Own farm=1; Purchase = 2 Gift =3; other =4___)
Roughages:		
Concentrates:		
Others (if any):_____		

4.2. Livestock feeding system (Tick " √ ")

1) Free grazing alone 3) Grazing and stall feeding

2) Stall feeding/Zero grazing 4) Tethered grazing

4.3. Source of water for livestock

1) River 2) Tap water 3) Well water 4) Irrigation water

5) River and tap water 6) Other (if any)_____

4.4. Do you face feed supply shortage? 1) Yes 2) No

4.5. If "Yes", in which months of the year do you face feed supply shortage? _____

4.6. What is your average monthly expense for feed purchase (Birr)? _____

4.7. What is the impact of feed shortage or its high cost on your farm?

1) Low milk yield/bodyweight gain of animals

2) Animal loss through death 3) Destocking 4) Low profit

5) Withdrawal from farm 6) Other (if any) _____

4.8. Do you conserve feeds? 1) Yes 2) No.

4.9. If you conserve/store forages, list them_____

4.10. Did you receive extension services related to feed production, utilization and improvement? 1) Yes 2) No

5. Sugarcane byproducts

5.1. Which sugarcane byproduct do you use?

1) Molasses 2) Sugarcane tops (SCT) 3) Bagasse 4) Other (specify)_____

5.2. For what purposes do you use sugarcane byproducts? (Tick)

	Animal feed	Fuel source	Construction /*e.g.*,fence roof/	Bedding barn/stall	For sale (cash)	Other _____
Molasses						
SCT						
Bagasse						

5.3. Where do you get sugarcane byproducts? (choose or Tick " √")

	1.Own farm 2.Collecting freely from factory	buying from					
		factory	local collectors	market	Retail shops	in group with farmers	Agricultural office (Gov.)
Molasses							
Bagasse							
SCT							

5.4. Which type of sugarcane tops do you get? (Encircle)

1) Burnt SCT 2) Green SCT 3) both

5.5. How far is the source of sugarcane byproducts from homestead? (km)

molasses/bagasse_____ SCT_____

5.6. Indicate the seasonal abundance of sugarcane byproducts. (3=highest, 2= moderate,1=lowest)

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug
Molasses												
Bagasse												
SCT: burnt												
green												

6. Costs of sugarcane byproducts:

6.1. If you buy sugarcane byproducts, what was its price in 2008 E.C?

(SCT- Birr/horse cart; Molasses (qt)

Byproducts	At factory	Retailers/ collectors
Molasses		
Bagasse		
SCT: burnt		
green		

6.2. What factors contribute to the price variation:

a) Molasses?_____

b) SCT?_____

6.3. Is the transportation/distribution of molasses in your area adequate?

1) Yes 2) No

6.4. If "No", what do you suggest to improve?_____

7. Utilization of sugarcane byproducts as livestock feed

7.1. Which SCT type do you prefer for your animal?

1) Burnt SCT 2) Green SCT 3) Thin stem

4) Thick stem 5) more leaf 6) less leaf Why?_____

7.2. How do you differentiate feed value (quality) of SCT?

1) By sugarcane variety 2) SCT Type (burnt /green) 3) Palatability to animal

4) Leaf to stem proportion 5) Color 6) Other_____

7.3. If you differentiate SCT by "sugarcane variety", which varieties are preferred as feed?_____ ; and which are not good?_____ Why?_____

7.4. To which animal do you offer sugarcane byproducts ("√")

	Dairy cows (1=Lactating 2= Dry 3=Pregnant)	Fattening Ox/bull	Draught oxen	Fattening Sheep/ goat	Heifers	Calves	Equines	Camel
Molasses								
Bagasse								
SCT:burnt								
green								

7.5. Feeding practices of sugarcane byproducts to animals daily?

Class of animal	Type of sugarcane byproducts	Amount fed (unit/day/animal	Feeding frequency 1) once 2) twice 3) thrice 4) *ad libtum*
Cow	Molasses		
	Bagasse		
	SCT		
Calves	Molasses		
	Bagasse		
	SCT		
Oxen/bull	Molasses		
	Bagasse		
	SCT		
Heifers	Molasses		
	Bagasse		
	SCT		
Sheep/goat	Molasses		
	Bagasse		
	SCT		

7.6. How do you feed molasses to your animals? (Encircle)

1) Feeding alone

2) By mixing with water alone

3) By mixing with concentrate

4) By mixing with crop residues

5) By mixing with water and sprinkling on crop residues

6) For straw-urea treatment /silage /UMB

7.7. If you mix molasses with water, how much is the proportion?

(water: molasses =_____/____)

7.8. How you process sugarcane tops and feed it to the animals?

1) Intact feeding alone

2) Chopping and feeding alone

3) Intact mixing with other roughages

4) Chopping and mixing with other roughages

List of the roughages _____

5) Chopped and mixed with concentrates

List of the concentrates _____

6) Chopping and wetting with water

7) Chopped and sprayed/mixed with salt, molasses and atela

8) Intact mixing with salt, molasses and atela

9) Other method_____

7.9. What desirable and undesirable symptoms do you observe on your animals feeding sugarcane byproducts?

Molasses_____

SCT_____

Bagasse_____

7.10. Do you preserve sugarcane byproducts? 1) Yes 2) No

7.11. If you process SCT, which processing/treatment method do you apply?

1) Manual chopping 4)Machine chopping

2) Treating with EM 5) Chemical treatment (*e.g.*,urea)

3) Don't process 6) Other_____

7.12. Which type of SCT do preserve for later use?

1) Burnt SCT 2) Green SCT 3) Both 4) Do not preserve

7.13. Which preserving method do you apply for SCT? (Encircle)

1) Sun drying 2) Under shade drying 3) Ensiling 4) Don't preserve

7.14. For how long do you sun-dry or, under shade dry SCT before storing?

1) Whole burnt SCT _____ days/week 3) SCT leaf _____ days/week

2) Whole green SCT_____ days/week 4) SCT stem _____days/week

7.15. Storage condition of SCT

1) Stacked in an open air 3) Stacked under shade/roofed barn/house

2) Stacked along fences/trees 4) Do note store

7.16. For how long do you store SCT? _____Molasses?_____ (weeks/months).

7.17. Did you encounter quality deteriorations of SCT upon storage?

1) Yes 2) No

7.18. If yes, what are the major indicators in the quality loss of SCT?

1) Bad smell 2) Color change 3) Moldy 4) Rough texture 5) Not edible

7.19. Did you receive any training service/technology on improved production and use of sugarcane byproducts? 1) Yes 2) No

7.20. Major constraints in using sugarcane byproducts as livestock feed

1) Molasses_____

2) Bagasse_____

3) SCT_____

Appendix 2. Questionnaire/formats for sugar factories

1. Name of sugar factory_____ Year established _____

2. Total area (ha)_____ Area under sugarcane plantation (ha)_____

3. Potential crushing capacity (tonne/day)_____Current capacity(t/day)_____

4. List out sugarcane varieties on production in the factory?_____

5. What are the byproducts available from the factory?_____

6. What amounts of the byproducts are produced daily at the moment? (tonne/day)

a) Molasses_____ b)Bagasse_____ c) SCT_____

7. What is the ratio of the byproduct produced to the amount of crushed sugarcane?

Molasses	Bagasse	SCT	Others _____

8. What is the current price of molasses ?_____Bagasse?_____ (Birr/kg/qt).

9. Who are your customers for molasses/bagasse purchase?

	Current	5 years ago	10 years ago
1. Individual livestock farmers			
2 . Retailers			
3. Farmers unions/cooperatives			
4. Alcohol producers			
5. Others_____			

10. Is there surplus production/availability of molasses? 1. Yes 2. No

11. What is the mechanism of distribution and transportation of molasses to users?

_____.

12. Sugarcane byproduct production during 2008-2016 at the sugar factories

Descriptions	2008	2009	2010	2011	2012	2013	2014	2015	2016
Area of sugarcane field harvested (ha)									
Sugarcane yield/ harvested (qt)									
Molasses yield (qt)									
Bagasse yield (qt)									
Sugarcane tops yield(qt) (if any)									

13. Sugarcane byproducts utilization at each factory

Type of byproduct	Production (tonne)	Amount used			Amount dumped
Molasses		Ethanol Prod.	Sold abroad	Domestic sale	
2008					
:					
2016					
Bagasse		As fuel	As feed	Other uses	
2008					
:					
2016					