DETERMINING PRODUCTION AND NUTRITIVE VALUE OF CROP RESIDUES AND AGRO-INDUSTRIAL BY-PRODUCTS AND IMPROVING THEIR UTILIZATION IN RUMINANT NUTRITION IN ERITREA

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university

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DEDICATION

This work is dedicated to my wife Freweini and our children Hiyab and Delina, and my father Haile and mother Amete.

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LIST OF ABBREVIATIONS / ACRONYMS

AOAC	Association of Official Analytical Chemists
ASB	Anseba
DBU	Debub
FAO	Food and Agricultural Organization
GB	Gash Barka
GDP	Gross Domestic product
HAC	Hamelmalo Agricultural College
ICRC	International Committee of the Red Cross
ILCA	International Livestock Centre for Africa
JKUAT	Jomo Kenyatta University of Agriculture and technology
MKL	Maekel
MoA	Ministry of Agriculture
NRS	Northern Red Sea
TLU	Tropical Livestock Unit
WRI	World Resources Institute

ABSTRACT

Livestock production plays important social and economic roles in Eritrea accounting for approximately 12.0% of the Gross Domestic Product. Despite the importance, animal productivity is low. This is attributed to poor quality feed characterised by fluctuations in quality and quantity within seasons and between years. Crop residues are an alternative feed resource that needs consideration for use in providing nutrients, however, there is need to determine the annual crop residues and agro-industrial by-products output, their respective chemical composition and nutritional values. Therefore, the overall aim of this study was to contribute to improved livestock production throughout the year in Eritrea through utilization of crop residues and agro-industrial by-products. The quantity of crop residues produced annually was estimated based on an eight years dataset (2007-2015) on the relevant crop production in five administrative zones of Eritrea. The chemical composition and degradation kinetics of nine cereal and seven legumes crop residues and seven agro-industrial by-products was determined. Crop residues were treated with urea and rations were formulated. Feeding trial was conducted using growing ram sheep. Findings indicated that approximately 1.3 million tonnes of crop residue is produced in Eritrea annually. Further analysis of the data obtained indicated that the crop residues accounted for 9.63 to 36.31% of the total annual maintenance feed requirements of the grazing ruminants. The contribution varied according to the land size set aside for crop production. Besides the crop residue the total amount of the agro-industrial by-products were estimated at between 19,604-19,788 tonnes and mainly comprised of brans, oilseed cakes and brewers grains. Generally, there was more ($P<0.05$) CP, ADL, ME and low ($P < 0.05$) NDF and ADF in legume straws with the exception for ADL in GNS than in cereal crop residues. The legume straws had higher value of degradability characterstics than cereals stover/straws. The nutritive value criteria were generally high in the agro-industrial by-products than in crop residue. Treating the crop residues with urea and/or supplementing with legume residues resulted in an increase in performancy of the sheep body weight gain in the growing lambs. Findings from this study indicate that crop residues and agro-industrial by-products hold huge potential in grazed animal feeding and/or supplementation in Eritrea

Keywords Chemical Composition, Nutritional Value, Crop Residues, Agro-Industrial By-Products

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Livestock plays important socio-economic roles both at household and national levels in Africa (Kosgey *et al*., 2003). The grazing stock play a complementary role of utilising the vast natural pasturelands where crop production is not feasible besides providing the poor rural households with milk, meat, manure, power, and cash flow (Jaitner *et al*., 2001; Baker & Rege, 1994).

In the greater horn of Africa, the region where Eritrea is located, the ruminant livestock population is about 277.36 million (Simpkin, 2005). According to the Government of the State of Eritrea in the National Livestock development Project (NLDP, 2007), Eritrea accounts for approximately 4% of the livestock in the region, that is approximately 1.9 million head of cattle, 2.1 million sheep, 4.6 million goats, 2.5 million chicken and 0.1 million camels. The statistics further indicated that though the number of livestock in the country is on the increase the rate at which it is occurring is slow given the projected potential.

Eritrea being a relatively young country having gained its independence in the last two decades has identified agriculture and animal production in particular as a priority area of focus considering that up to 80% of her population live in rural areas and are dependent on subsistence agriculture (NLDP, 2007). Despite the great potential held in the agricultural sector, the contribution in the Gross Domestic Product (GDP) from the sector has been in decline from 25% in 1993 to low of 12% in the year 2005.

The government and other stakeholders have been analysing the causes of the decline and/or the cause of slow growth rate in the sector and have identified a number of constraints including animal diseases, unimproved animal genetic resources, illiteracy and most important low quality and quantity feed resources (MoA, 2015). Much of the Eritrea is dry (arid and semi-arid; ASAL) and the main agricultural activity is keeping of grazed livestock. Livestock production is therefore very important component of Eritrea's national economy besides enhancing food and nutritional security of the country's human population. The FAO (2002) report estimated that 16,700 tonnes of beef and veal, 5,600 tonnes of mutton and lamb, 5,800 tonnes of goat meat, and 56,700 tonnes of milk are produced annually. Even where crop production is practiced, mixed crop-livestock production system is common as the crop residues are used in supplementing grazing animals to meet their nutritional requirements.

Despite the importance of livestock production in Eritrea, the animal productivity is low with feed resource supply and quality being identified as the major limiting factor. Crop residues from the mixed farming systems and the agro-industrial by-products from various industries have potential to increase and/or sustain livestock production through supply of nutrients. In order to optimally utilize the crop residues and the agro-industrial by-products, there is need to determine the annual crop residues and agro-industrial by-products output, their respective chemical composition, and nutritional values.

Various studies (Ben *et al*., 2002, Naser *et al*., 2011; Mugerwa *et al*., 2012) have shown that the availability of the nutrients from the residues and by-products can be enhanced through chemical treatment. For instance, urea treatment is reported to improve the nutritive value of cereal straws by increasing digestibility, palatability and CP content (Sharma *et al*. 1995; Chenost & Sansoucy, 1991; Badve, 1991; Israel & Pearson, 2000).

In this study, urea treated sorghum and millet stovers (most abundant crop residues in Eritrea) were used in formulating alternative diets whose effect on growth rate of young sheep were tested. This study was designed to present a holistic analysis of the availability, potential use, chemical composition, nutritional values and effects of feeding growing animals on urea treated sorghum and millet stovers. It is the first of its kind in Eritrea, a country that heavily rely on grazed livestock characterized by poor quality grazed pastures whose supply varies within and between years.

1.2 Statement of The Problem

Despite the importance of livestock production in Eritrea, the animal productivity is low. The problem is feed scarcity and fluctuation in quality and quantity within seasons and between years. Crop residues are invariably fibrous, of low digestibility and low in nitrogen (Preston, 2007). They are produced on the farm and therefore widely spread geographically. On small farms in developing countries they form the principal feed of ruminant livestock during the dry seasons. Agro-industrial by-products result from the processing of crops such as oilseeds, cereal seeds, sugar cane, sisal, citrus, pineapple and bananas; or the slaughter and processing of livestock and fish (Preston, 2007). They are geographically restricted to the factory sites. They are rich in protein (oilseeds and meals of animal origin) or sugar (molasses, citrus and pineapple pulps) and occasionally in starch (reject bananas, cassava peels) and usually low in fibre (Preston, 2007).

Identifying the locally available dietary resources which deserve better attention is one of the bases of the principles underlying the development of livestock feeding systems in developing countries, especially those in the tropics based on the available resources which are mainly crop residues, dry and/or mature pastures and agro-industrial by-products (Preston, 2007). However, in Eritrea the availability and utilisation efficiency by livestock of crop residue and agro-industrial by-products has not been established. In considering guidelines for research on by-products and residues, it is convenient to take into account the different objectives relating to the use of these feed resources (Preston, 2007). One of the objectives is to determine the chemical composition and nutritive value of different by-product or the fibrous crop residues (Preston, 2007).

No study has been carried out to understand the nutritional constraints associated with residues and by-products efficient utilization by ruminants in Eritrea. This is despite the fact that this is one of the bases of the principles underlying the development of livestock feeding systems based on the locally available resources. Farmer in Eritrea lack knowledge of how to efficiently and effectively use the available feed resources through treatment methods and/or supplementation despite there being established treatment methods that could increase availability of nutrients. This study thus evaluated the use of urea in improving the feeding qualities of the available crop residues and/or industrial by-products. Urea is readily available in Eritrea.

1.3 Justification

The human population as well as living standards are on the rise in many parts of the world including Eritrea. This has led to increased demand for animal proteins. An increase in animal numbers to satisfy the increased demand is unsustainable as it has resulted in overgrazing and subsequent destruction of the production environment. Increasing productivity on per animal basis would be suitable and more so if the increase would be realised through more efficient utilisation of the crop residues and industrial by-products.

Crop residues are alternative feed resources but have limitation, hence the need for evaluation (nutritional profile, processing methods and feeding trials) of the residues and by-products available in the country as well as the available technologies that can be used to enhance their use in feeding livestock. This can only occur if a holistic study is carried out to determines the volumes of the crop residues and industrial by-products, their chemical composition and nutritional value as well as establishing their feeding value through performing feeding trials.

Basic chemical composition and nutritive value data available for most of crop residues and agro-industrial by-products available in Africa and Asia shows that, if appropriately used, they could satisfy the nutrition requirement of ruminant livestock (Chimwano, 1990; Aregheore, 2000; Abrar *et al*., 2004; Afshar & Naser, 2008; Naser *et al*., 2011; Mugerwa *et al*., 2012). In Eritrea, basic chemical composition and nutritive value data are not available for the crop residues and agro-industrial by-products produced in the country. Furthermore, utilization of these feed resources in a feeding program depends on their feeding value obtainable from feeding trials.

1.4 Objectives

The overall aim of this study was to contribute to improved livestock production throughout the year in Eritrea through utilization of crop residues and agro-industrial by-products.

The specific objectives were:

1. To determine the quantities of crop residues and agro-industrial by-products available for livestock feeding in Eritrea
2. To determine the chemical composition and nutritive values of cereal crop residues
3. To determine the chemical composition and nutritive values of legume crop residues
4. To determine the chemical composition and nutritive values of agro-industrial by-products
5. To determine the economics of using urea treated crop residues and growth rate of lambs fed on urea treated sorghum and millet stovers based rations

1.5 Hypotheses

The following null hypotheses that correspond to the specific objectives were tested:

1. There are no substantial quantities of crop (cereal and legume) residues and agro-industrial by-products available for use in livestock feeding in Eritrea
2. The chemical composition and nutritive values of different cereal crop residues produced in Eritrea are similar
3. The chemical composition and nutritive values of different legume crop residues produced in Eritrea are similar
4. The chemical composition and nutritive values of different agro-industrial by-products in Eritrea are similar
5. There is no difference in growth rate amongst lambs fed urea treated sorghum and millet stovers based rations

CHAPTER TWO

LITERATURE REVIEW

2.1 Livestock Feeding Systems

Integrating crops and livestock is critical in diversifying smallholder farmers' sources of income and employment (Rao & Hall, 2003). Livestock act as a storehouse of capital and an insurance against crop production risks, a coping mechanism against livelihood shocks as well as a vital source of dietary protein. In such production systems, crop residues constitute an important source of low-cost feeds (Smith, 1993; Tsopito, 2003), contributing between 40-60% of the total dry matter intake in many tropical countries (Rao & Hall, 2003).

Researches focusing on the potential use of local available non-conventional feed resources which are mainly crop residues, dry and/or mature pastures and agro-industrial by-products and examining strategies that can accelerate their utilization as feed constituents to bridge the wide gap existing between supply and demand for the feed in African countries, including Eritrea are capturing much attention. The first step in estimating the availability of crop residues for animal feed is to determine the crops grown and the proportions of the land area that are devoted to the predominant crops.

The importance of crop residues as potential livestock feed varies with the type of crops grown - cereals, grain legumes, roots/tubers - and also with the proportion of land under food crops and with the yields of the relevant plant parts. The output of crop residues tends to rise with rural population density. The proportion of total crop residues allocated as feed depends on such factors as livestock density and rules of access. These in turn are influenced by land tenure and the relative importance of livestock in the farming system.

Rough estimates of the crop residues supply have been made for individual countries, including Tanzania (Lwoga & Urio, 1987) and Malawi (Munthali & Dzowela, 1987). The usual procedure consisted of estimating the hectares of land devoted to each crop and using a crop residue: grain yield ratio to calculate national crop residues output. De Leeuw (1997) indicated that these ratios vary greatly and addressed the issue as follows.

Two kinds of ratio can be used to link grain and crop residues yield. The first is a simple one in which grain yield is divided by an agreed factor expressing the harvest index, or proportion of grain to total above-ground biomass (Kossila, 1988, Nordblom & Shomo, 1995). Crop residues: grain ratios usually decline with increasing grain yield and are therefore higher in Africa than in Asia (for wheat: 2.0 compared with 1.3) or South America (for maize: 3.0 compared with 2.0). However, to evaluate crop residues as a feed resource a second ratio is needed related to "edibility". To estimate the consumable fraction of a crop residue, data are required on such parameters as the likely removal rates by grazing animals or the refusal rates of stall-fed livestock

Potential supplies of crop residues in Africa can be approximated from country statistics on the proportion of land cultivated (e.g. World Bank, 1989; WRI, 1990), combined with yield estimates for the grains, tubers and so on of the major crops (World Bank, 1989). In the manner of Nordblom & Shomo (1995), these can then be expressed as a percentage of the total supply (assuming a given output for natural pastures and/or uncultivated land) and, by using data on livestock populations (Winrock, 1992), as the amount of feed available per tropical live weight unit (TLU) and year. These estimates can only be approximations. They would come closer to reality if appropriate ratios of grain to crop residues were available. Further caution is needed because data obtained in this way tend to ignore within-country heterogeneity in terms of eco-zones. As a result, estimates for small countries may be more realistic than for large ones like Nigeria, Ethiopia, Sudan or Tanzania (de Leeuw, 1997).

Stocking density on cropland vary widely, from 21 TLU per ha in arid/semiarid Somalia to 1.5 in Gambia and 0.9-1.1 TLU per ha in Sahelian countries such as Niger and Burkina Faso (de Leeuw, 1997). In countries where smallholder cropping is relatively important, density is lower mainly in the range of 0.35- 0.55 TLU per ha. Statistics on the production of major crops by country indicate a dominance of cereal crops in the drier eco-regions and highlands, and the increasing importance of roots and tubers (cassava, sweet potatoes, and yams) with increasing rainfall. In countries such as Togo, Benin, Rwanda and Uganda, tubers produce up to twice as much tonnage as cereals. Cash crops, in particular groundnuts and cotton, and legumes need to be included, since although smaller in amount their residues are important for their relatively high quality (de Leeuw, 1997).

Enormous quantities of different types of crop residues are produced as a renewable resource in integrated crop-livestock systems but most of them are being wasted, unused, undeveloped or poorly utilized (Makkar, 2002; Tingshuang *et al*., 2002). During dry season, the use of crop residues and agro-industrial by-products play an important role in reducing dry season feed stress, hence mitigating the otherwise heavy weight losses of animals and mortality due to inadequate nutrition (Simbaya, 2002). Numerous ways of crop by-product utilization exist amongst smallholder farmers (Preston, 1995). These may have a strong cultural and economic basis and may vary from society to society depending on the type of residue available (Tsopito, 2003). According to Williams *et al*., (1997), the fibrous by-products resulting from crop cultivation constitute a major source of nutrients for animal production in developing countries. On small farms, they form the principal feed of ruminant livestock during the dry seasons. Williams *et al*., (1997), after pointing out that concerns about inadequate utilization of available feeds have led to the establishment of research programs to improve the nutritive value and utilization of crop residues as ruminant feed, indicated that despite this, farmer uptake of research findings has been limited and to explains the reasons argues that the importance of crop residues as feed differs between production systems. Differences in production goals, resource endowments and socioeconomic conditions create different opportunities for the use of crop residues. Consequently, in designing research and extension projects that seek to improve use as livestock feed, it is pertinent to identify the main livestock production systems, farmers' production objectives and resource endowments, and determine the appropriate crop-residue-based diet for each system. In many developing countries, the feeding regimes aim to use crop residues and agro-industrial by-products as the principal component of the diet as these are the locally available and relatively cheap resources (Mugerwa *et al*., 2010).

2.2 Feed Analysis

The need for an alternative to the traditional methods of feed analysis was first raised at an Expert Consultation on New Feed Resources held in FAO Headquarters, Rome in November 1976 (Preston, 2007). At that meeting data were presented to show that the conventional feeding standards, derived from research with feeds of temperate country origin, were of limited value when applied to the crop residues, dry pastures and sugar-rich agro-industrial by-products which made up the feed inventory in most tropical countries. As a follow-up to this meeting a small network involving institutions from Cameroon, Nigeria and Senegal was set up by FAO to promote research on several locally available crop residues and agro-industrial by-products, and an FAO Seminar was organized in collaboration with the International Livestock Centre for Africa (ILCA), and held in Dakar, Senegal in September 1981. The conclusions and recommendations from the Dakar meeting were that there was a need to develop more appropriate procedures for evaluating crop residues and by-products, taking into account the limited laboratory facilities of most institutions in Africa; and the nature of the livestock production systems, where multipurpose traits such as draught power, ability to survive extended dry seasons and rural (transhumant) milk supply were of greater relevance than the technologies from industrialized countries which emphasize specialized meat and milk production.

The relevance of feeding standards for developing countries, particularly those in the tropics, has been questioned from the socio-economic (Jackson 1980) and technical (Graham 1983; Preston 1983) viewpoints. It has been apparent for many years that feeding standards based on assigned nutritive values (e.g.: net energy) are misleading when unconventional feed resources are used (Preston 1972; Leng & Preston 1976; Gaya *et al.*, 1981), since the levels of production achieved may be considerably less than the level predicted (Preston, 2007). More importantly this often led to the rejection of many available feed resources which apparently were too low in digestible energy to supply the energy needed for production. It also encouraged researchers to copy feeding systems used in temperate countries which are relatively "predictable", but which require feed resources that are unavailable and/or inappropriate on socio-economic grounds, in most developing countries. So, the need for an alternative approach to develop feeding system for ruminants not based on conventional “feeding standards”.

According to Preston (2007) the justification for a new approach to the development of feeding systems for ruminants, not based on conventional “feeding standards”, is that: The efficiency of the rumen ecosystem cannot be characterized by any form of feed analysis. Feed intake on some diets bears no relationship to digestibility and is much more influenced by supplementation. Availability of amino acids cannot be inferred from the crude protein content of the diet. The energy value of a diet and the efficiency of its utilization, are largely determined by the relative balances of glucogenic energy, long chain fatty acids and essential amino acids absorbed by the animal.

2.3 Assessing Nutritive Value

In discussing guidelines for research on by-products and residues it is convenient to consider the different objectives relating to the use of these feed resources. For example, the following questions should be addressed. What is the feed value of a relatively unknown by-product or fibrous residue? How can an improvement in nutritive value caused by chemical, physical or biological treatment be measured? How can the product be used best in feeding systems with other locally-produced feeds or by-products/residues? How can rumen degradability be best measured within the context of a feeding system? How can responses to protein and other supplementary nutrients be measured in animals? How can crop residues and agro-industrial products be integrated into feeding systems for non-ruminant herbivores? (Preston, 2007)

Considering a residue/by-product, non-conventional feed resources, about which relatively little is known, the most appropriate first assessment of feeding value would be by incubating it in nylon bags in the rumen of fistulated animals given a standard diet well balanced in terms of availability of nutrients for efficient rumen function and the animal (Preston, 2007). In recent years the nylon bag technique, as a tool for studying rumen digestion, has become more widely used, and it is recommended as a means for evaluating tropical feeds (Preston, 2007).

2.4 Improving the Nutritional Value of Crop Residues

The major classes of by-products from agriculture, such as straws, stalks, bagasse, legume hulls, and leaves, are not utilized efficiently due to their low digestibility and voluntary intake by ruminants. The low digestibility and intake is due mainly to their highly lignified cell wall and low protein components (Srivastava *et al*., 2012)

Despite their demonstrated role in ruminant nutrition, crop residues are however high in fibre and low in metabolized energy and crude protein (Devandra, 1991; Warambwa & Ndlovu, 1992; Preston, 1995; Tingshuang *et al*., 2002) that may result in low degradability in rumen.

It was reported that rice straws and maize stovers are bulky and of poor quality due to a high concentration of lignin (36.4 - 45.3% crude fibre), but are medium energy sources (12.2 – 13.4 GE MJ/kg) in ruminant rations, and they are also low in protein (4.6 – 5.0% CP), vitamins and minerals (Aregheore, 2000).

Improving the nutritional value of straws and the efficiency of their use in mixed diets is an attractive option for increasing livestock production (Ben *et al* 2004). If cereal crop residues are used strategically, these feed resources could save up to 186 million Kg of livestock weight during dry season (Amaning, 1992).

The constraints to livestock production from feeding large quantities of fibrous by products are known, as are intervention which can ameliorate them. Considerable research effort has gone into improving their nutritional value through crop management, breeding and physical, biological and chemical treatment of residues as well as supplementation through high protein oil cakes, green fodder, and tree leaves (Preston, 1995; Kristjanson & Zerbini, 1999; Kristjanson *et al*., 2001). In recent years, there has been increased research interest to improve the nutritive value of low-quality farm by-products and residues from agro-industries by utilizing different processing approaches involving physical, chemical, and microbiological treatments. The most significant effect of these processes has been on increasing the rate and extent of cellulose and hemicellulose digestion and, consequently, increasing voluntary intake and live-weight gain by ruminants (Ben *et al*., 2002, Naser *et al*., 2011; Mugerwa *et al*., 2012).

2.4.1 Types of Chemical Treatment

Technology for the chemical treatment of crop residues likely stems from paper making techniques, which were in place as early as the 12th century. Chemical treatment of straw with NaOH began in Germany in the 1880s with the development of the Beckmann method (Homb, 1984). This process, while effective in increasing organic matter digestibility (45.7% in untreated to 71.2% treated with 1.5% NaOH), led to losses of approximately 20% of the dry matter (due to washing off excess NaOH) and produced significant amount of environmental pollution (Fingerling &Schmidt, 1919). Since that time, a variety of methods have been developed to improve the treatment of fibre. These methods can be grouped by their mode of action. Mostly, chemical treatment occurs by hydrolytic or oxidative means. Physically treatments such as particle size reduction (Thomas *et al*., 1980), steam treatment (Garrett *et al*., 1980), or irradiation (Pritchard *et al*., 1962; Yu *et al*., 1975) have also been used. Combinations of chemical and physical treatment are possible as well. Owen *et al*., (1984) identified that an ideal chemical would: 1) be effective in increasing intake or digestibility, 2) benefits that outweigh the costs associated with treatment, 3) have non-toxic effects on animals or the environment, 4) provide an essential nutrient to the animal or as fertilizer, 5) be non-hazardous to handle.

2.4.2 Hydrolytic Treatment

Hydrolytic agents improve digestibility by action of –OH groups disrupting cell wall structure and increased swelling resulting increased microbial attachment (Fahey *et al*., 1993). Core lignin is usually not affected by hydrolytic treatment but bonds between lignin and hemicellulose are broken. Klopfenstein (1978) postulated that the mode of action of hydrolytic agents were primarily related to (1) solubilisation of hemicellulose, (2) increased rate and (3) increased extent of digestion of hemicullose and cellulose. Sodium hydroxide has been the principal base produced by the chemical industry. As a chemical treatment agent, it is often the standard by which other treatments are compared to. Fahey *et al*., (1993) reviewed 24 studies which fed cattle or sheep crop residues (included at ≥ 60% of diet DM) treated with NaOH and found an average improvement in DMI of 22%. In the same review, chemical treatment with NaOH led to an average of 30% improvement in DM digestibility from 32 studies by lambs or cattle.

Sodium content of treated feeds is largely the biggest drawback of NaOH treatment. Effects of high sodium intakes on rumen fermentation have been studied (Berger *et al*., 1979b). The notion that sodium might be influencing digestion was conceived by the difference in digestibility between *in vitro* and *in vivo* techniques (Klopfenstein *et al*., 1972; Berger *et al*., 1979b).

Ammunition using ammonia gas has also been used as a hydrolytic agent in chemical treatment of crop residues. NaOH and NH_3 are the two most effective treatment chemicals.

Urea has also been considered as a source of NH_3in treatment. Urea is cheaper compared to NaOH and NH_3. It is easily available as a fertilizer grade urea. It is not hazardous to use compared with NaOH and NH_3 and it has the added advantages of increasing the nitrogen content of crop residues in form of NPN, which could be used by the rumen micro flora to synthesize microbial protein; other condition in the rumen being right (Sharma et al 1995; Chenost and Sansoucy 1991; Badve 1991; Ranjhan 1999; Israel and Pearson 2000). Daily DM intake can be improved by ammonia, urea and urea plus cattle waste treatments of corn stover (Ali *et al*., 2009).

There are well established treatment methods that could increase availability of nutrients and supplementation techniques to correct nutrient deficiencies, and thereby improve the utilization of crop residues (Owen and Jayasuriy, 1989; Ben salem *et al*., 2004; Ali *et al*., 2009).

Many of the agro-industrial by-products are known to have high nutritive value. Brewer's grains are considered to be good sources of un-degradable protein and water-soluble vitamins (Ulfina *et al*., 2013). Milling by-products such as bran, wheatling and screenings are important by-product which along with palm kernel cake and copra meal could form important raw materials in the production of formulated ruminant diets (Aregheore, 2000).

Agro-Industrial by-products are important source of protein supply for livestock and their use as a part of feed for livestock reduces the cost of production, improve the quality of feed, ensure regular feed supply even during slump period and ultimately increase the profit margin of livestock farmers (Abrar *et al*, 2004). According to Abrar *et al.* (2004), the digestibly crude protein value of groundnut straw is superior to that of non-leguminous hays and is comparable to that of leguminous hay of cowpea. Groundnut hay has higher nutritive value and has been found to improve utilization of stovers (Ndlovu & Hove, 1989). However, low nitrogen diet supplemented with legume still need a source of readily fermentable nitrogen to ensure adequate concentration of ammonia in the rumen (Preston, 2007). Urea used as a feed supplement, even in small amount, can increase fermentable nitrogen. There may also be a need to supply animals with ‘by-pass” energy in the form of lipids. Sunflower seeds contain about 20% crude protein and 40% oil and its use in crop-residue-based diet could be beneficial (Warambwa & Ndlovu, 1992).

The results of research on effect of feeding hydrated teff straw and protein sources on teff straw voluntary intake and growth of young Horro Sheep grazing native pasture during the dry season demonstrated that home- grown Leucaena supplements can improve the productivity of small ruminants during dry period when feed supplies are limited (Gizachew & Tadesse, 1992). Amaning (1992) in his research on sustainable dry-season feeding of ruminants in Ghana showed that the use of crop residues and leguminous shrubs as feedstuff suggested that feeding urea-treated low-quality roughages supplemented with leguminous browses is the key to solving dry-season feeding problem for the small holder livestock farming system in Ghana. The results of research on the use of *Leucaena Leucoephala* supplementation to improve the utilization of maize stover by sheep indicated that intake and rumen degradation of maize stover in sheep could be improved by supplementing the animals with up to 6 g DM per Kg live weight per day of leucaena hay (Kimamba, *et al*., 1992). Ngwa & Tawah (1991) in their research work on effect of legume crop-residues and concentrate supplementation on voluntary intake and performance of Kirdi sheep fed a basal diet of rice straw indicated that cotton seed cake was the most effective supplement, in terms of both live weight gains and intake of rice straw.

Ali *et al.* (2009) reported that ensiling fibrous crop residues with poultry litter increased the DM intake of corn stover. They also indicated that animals fed with basal diet mixed with stover treated with 5.8% urea or 5.8% urea + 10% cattle wastage showed improved dry matter intake compared to untreated control group.

On study conducted on farmers' adoption of urea treatment of cereal straw for feeding of dairy animals (a success in Mathilamilkshed, India) it was indicated that the farmers reported increase in milk production with a range of 0.5 to 2 litres per animal. Also, they reported increase of milk production and fat percentage and decrease in wastage of fodder by feeding urea treated straw. Some farmers informed improvement in breeding efficiency and that animals developed shining coat, and feel that feeding of urea treated straw to their animals resulted in decrease in cost of milk production as they reduce feeding of concentrates (Sabyasachi & Rangnekar, 2006). If urea treated straw is fed straight away, then straw digestibility is increased by about 5 units, whereas if it is ensiled for ten days, the increase in digestibility is twice this (Signgh & Chandramoni, 2010).

By treating rice straw with urea or calcium hydroxide or by supplementing rice straw with protein, intake, degradability and milk yield can be enhanced, compared to feeding untreated rice straw alone (Elseed , 2005; Wanapat *et al*, 2009).

Treatment of straw with anhydrous and aqueous ammonia, urea or other ammonia-releasing compounds has been widely investigated to improve degradability (Abou-EL-Enin *et al*, 1999; Selim *et al*, 2002; Elseed *et al*., 2003).

The nutritive value of the crop residues could be enhanced through physical and/or chemical treatment and/or supplementation with concentrate agro-industrial by-products or forage legume (Ben *et al*, 2004). Vadiveloo (2003) reported that rice varieties with a low degradability responded better to urea treatments than higher quality straw, increasing the *in vitro* dry matter degradability from 45 to 55-62%. Urea treatment may therefore be most suitable for small-scale farmers to improve the quality of straws, particularly varieties showing a low degradability.

CHAPTER THREE

GENERAL MATERIALS AND METHODS

3.1 Sampling procedure

A total of sixteen major crop residues (cereals and legumes) found in different agricultural zones, including Maekel, Debub, Anseba, Gash Barka and Northern Red Sea in Eritrea were collected for analysis. In addition seven agro industrial by-products were collected from their respective industries found in zoba Maekel and Gash Barka.The cereal crop residues collected included the sorghum stovers (SS) and its threshed head residues (STH), millet stovers (MS) and its threshed head residues (MTH), corn stover (CS), barley (BS), wheat (WS) and Teff (TS) straws and teff threshed head residues (TTH).The legume crops residues collected were the chickpea (CPS), field-pea (FPS), horse-bean (HBS), groundnut (GNS), vetch (VS) and Lentil (LS) straw and groundnut hull (GNH).The agro-industrial by-products were wheat bran, short and middling from the only milling industries in Maekel and Debub Zones, brewers grain, hop and yeast from the only Asmera beer factery in Maekel Zone and sesame cake from yhe only oil industries in Gash Barka Zone

In collecting crop residues samples, four sub-zones from each zone and eight farmers' farm in each sub-zone were randomly selected. Two kg of samples of each collected feedstuff from each farmer in a zone were chopped (1-2 cm length), pooled, sub-sampled and ground. The feed samples for chemical analysis were ground to 1mm and for *in situ* degradation to 3 mm.The ground samples were tightly packed in plastic bag for laboratory analysis. The chemical analysis and *in situ* degradation procedure was conducted at the University of Nairobi, Departement of Animal Productions' Animal Nutrition Laboratory.

3.2 Describtion of The Main Crop Production Zones

Figure 3-1 shows the map of Eritrea with areas for which an estimate of crop residue production was determined and from which samples of different crop residues were collected. Eritrea has six administrative zones also referred to as Zoba. The main crop production and subsequently crop residues are Maekel (MEK), Debub (DEB), Anseba (ASB), Gash Barka (GB) and Northern Red Sea (NRS).

Figure 3-2 shows the agro-ecological zones of Eritrea. Based on the information product of FAO (2006) and the map (Figure 3-2) it can be indicated that the agricultural area of the Zobas are characterized by agro-ecological condition of highland and midland with integrate crop-livestock farming system and lowland with sedentary and semi-sedentary agro-pastoralism, mechanized large-scale rain-fed cultivation of sorghum and sesame and small-scale irrigated horticultural based system.

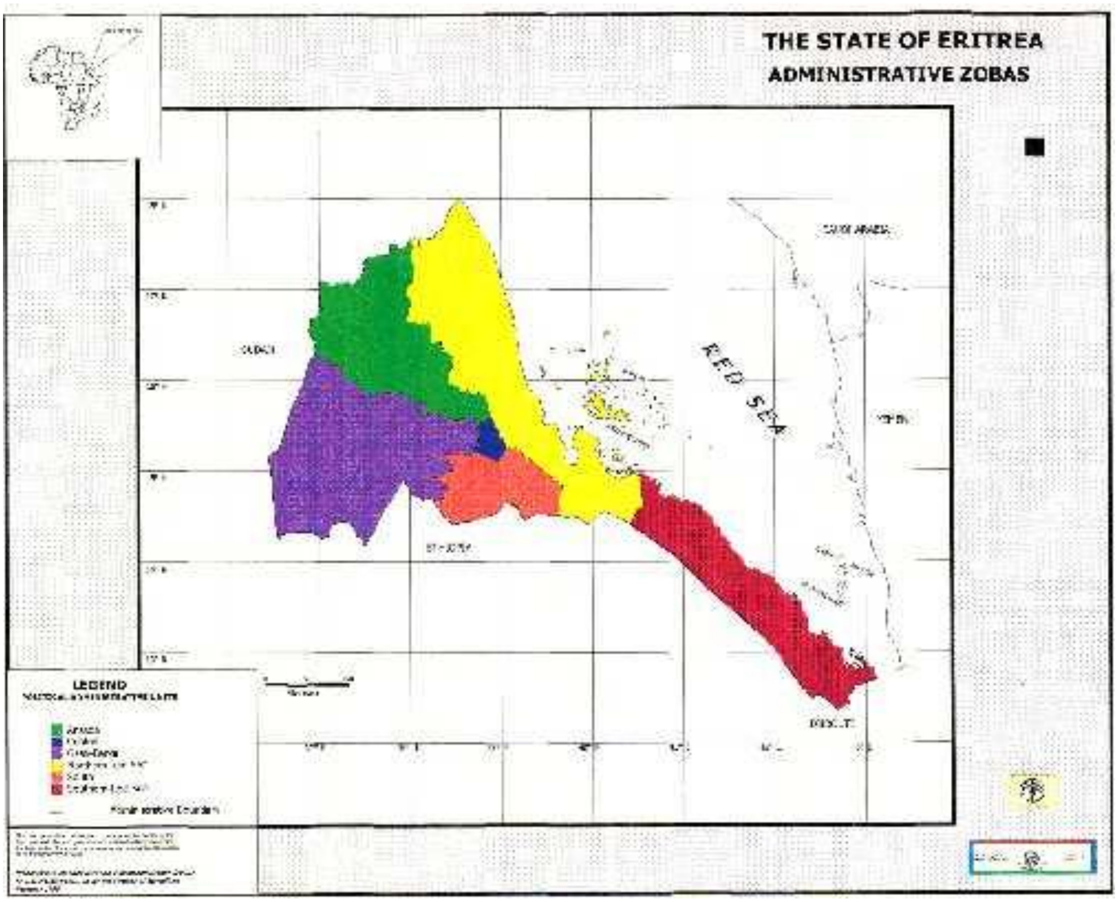


Figure 3.1a: The State of Eritrea Administrative Map

(Source: FAO (2006) Http://Www.Fao.Org)

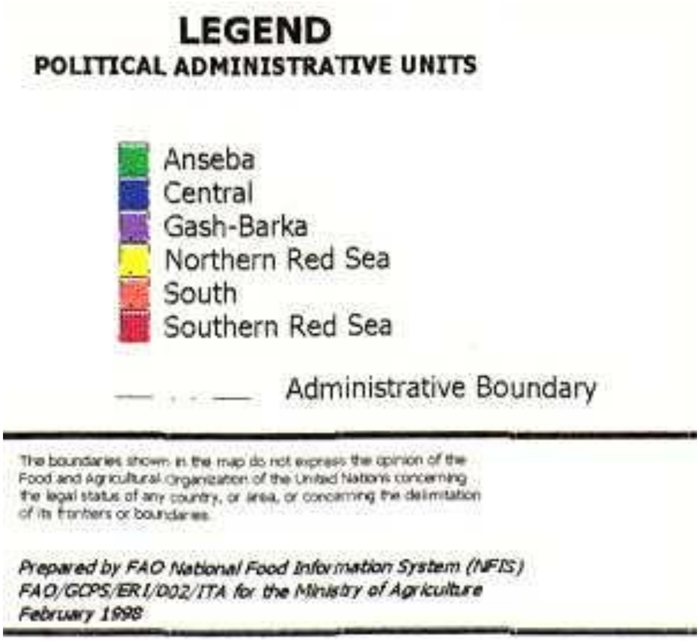


Figure 3.1b: The State of Eritrea Administrative Map

(Source: FAO (2006) Http://Www.Fao.Org)

Agricultural areas in Maekel and Debub are in highland and midland agro-ecological zones and in Anseba, Gash Barka and Northern Red Sea in highland and lowland agro-ecological zones. The highlands, midlands and lowlands altitudes is at over 1500 m with rainfall of 500 mm, betwwen 750 and 1500 m with upto 500 mm rainfall and 600 and 750 m with between 500 and 700 mm rainfall respectivily.

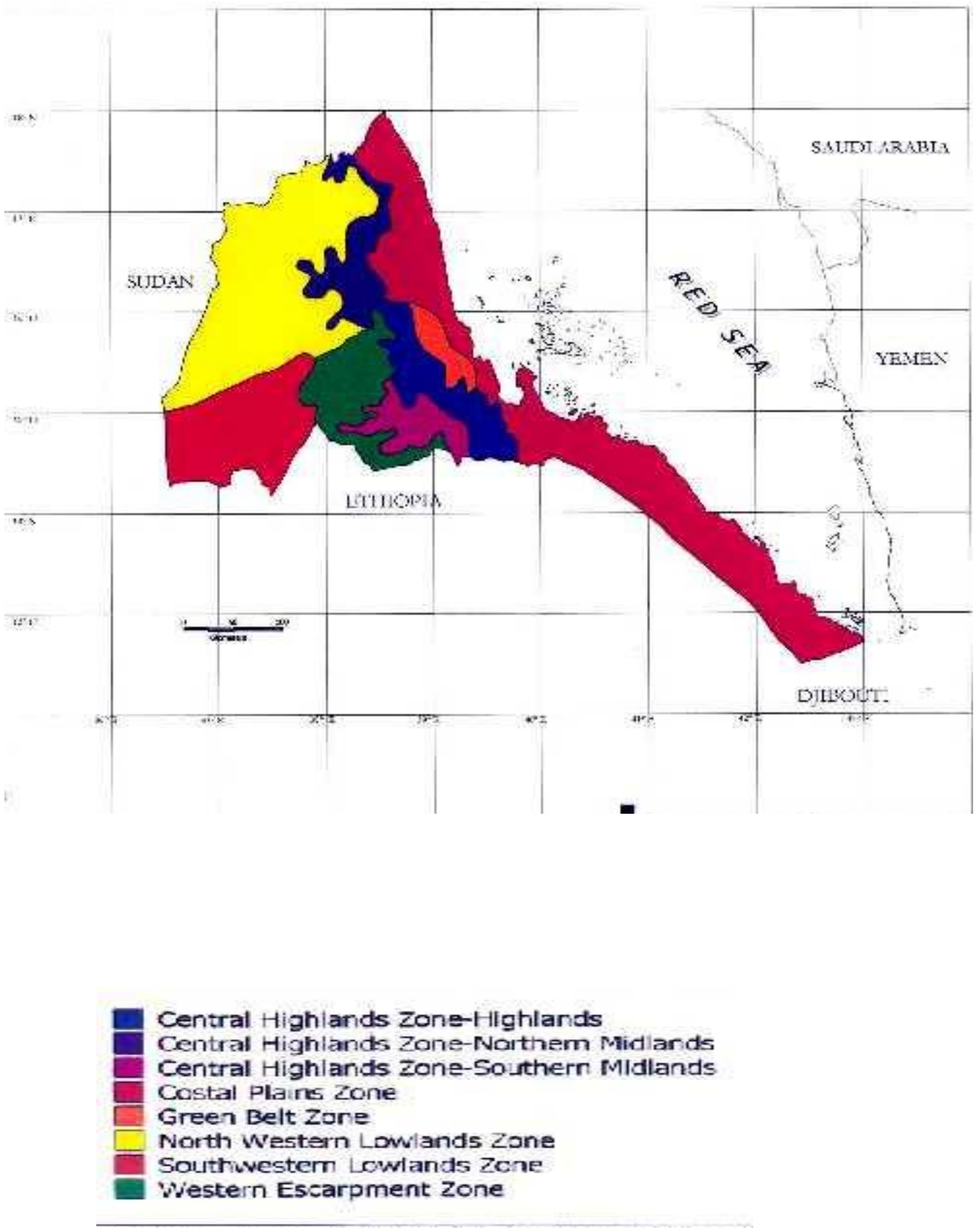


Figure 3.2: The State of Eritrea Agro-ecological zones

Source: FAO (2006) http://www.fao.org

3.3 Chemical Composition

The dry matter (DM) and organic matter (OM) were determined according to the standard methods (AOAC 2005). The DM was determine by drying sample in forced-air oven at 105ºC for 16h. The ash content was determined by ashing samples in a muffle furnace at 550ºC for 6h. The OM was determined as DM minus Ash.

The nitrogen (N) content was determined by Kjeldahl method (AOAC 2005). The N was detrmined by digesting samples for 45 min with sulfuric acid (98%) in digestion tube placed in block digester preheated to 410ºC. The digests was cooled, dilution water and the diluted digest was cooled before soduim hydroxide (45%) was added. The digestion tube was attached to distillaion unit and steam distill. The distillate was collcted in titrating flask containg boric acid trapping solution and titrated with 0.2 N HCL to neutral gray end point. The N% determined was used to calculate the crude protein (CP) as:

$$CP = N * 6.25$$

The crude fibre (CF) and ether extract (EE) were determined by the methods described in the AOAC (1990). In analysing CF, the reagents used were H_2SO_4 (1.25%) and NaOH (1.25%). The EE was analysed by Soxhlet methods using Petroleum Sprite (boiling point of 40-60ºC) as extracting reagent. The nitrogen free extract (NFE) was determined as:

3.4 In situ Degradation Procedures

The nylon bag procedure described by Ørskov *et al* (1980) was used in determining the nutritive value of the crop residues considered in this study. In all, a 5 g of dried sample of the crop residues were milled through a 3 mm screen. The sample was then weighed in nylon bags (16*8 cm, pore size 45 to 60 μm) which were then incubated in the rumen of two steer fitted with rumen cannula. The animals were given a standard diet well balanced in terms of availability of nutrients for efficient rumen function and the animal. The research adhered to the guidelines proposed in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (Federation of Animal Science Societies 1999).

The bags were withdrawn at 4, 8, 16, 24, 48, 72 and 96 h intervals following insertion. They were subsequently rinsed with cold water until it became clear. This was followed by drying of the bags and samples at 60°C for 48 h. The soluble fraction (0h) value was obtained by soaking two bags of the sample in warm water (38ºC) bath for 1 h which was then followed by washing in cold water for 15 min in a washing machine.

The samples were then dried for 48 h at 60ºC. The rumen degradation kinetics of DM, OM and CP were calculated using the exponential equation by Ørskov *et al* (1980) as:

$$P = a + b\left(1 - e^{-ct}\right)$$

where *p* is the percentage degradability for response variable at time *t* which is the time relative to incubation (hours), *a* represents the highly soluble and readily degradable fraction (%), *b* the insoluble and slowly degradable fraction (%), *c* is the rate constant for degradation (h^{-1}) and *e* is the natural logarithm base (2.7182). The effective degradability (ED) of the DM and OM of each sample was determined using the equation proposed by Ørskov *et al* (1987):

$$ED = a + \frac{(b * c)}{(c + k)}$$

where parameters *a*, *b* and *c* are as previously defined while *k* is the rate constant of passage (h^{-1}) which was assumed to be 0.02, 0.05 and 0.08 per hour (Bhargava and Ørskov 1987). The metabolizable Energy (ME) content was estimated using equation described by Bhargava and Ørskov (1987) as:

$$ME\left(MJ/kg\,DM\right) = 2.27563 + 0.1073DMD$$

where, DMD is rumen dry matter degradability at 48 h of incubation.

CHAPTER FOUR

PRODUCTION AND UTILIZATION OF CROP RESIDUES AND AGRO-INDUSTRIAL BY-PRODUCTS IN RUMINANT NUTRITION IN ERITREA

4.1 Introduction

There is potential in use of crop residue and industry by-products in feeding animals, (FAO, 2006). This is more so in the tropics where there is intense competition for grains between humans and animals. In developing countries, grazed systems depend on natural pastures whose supply throughout the year is not guaranteed. Even in systems where the graze is sufficient, quality and quantity varies within and between years (Gicheha *et al*., 2014). The feed deficiency during the dry periods can be catered for using crop residues and/or industrial by-products. Many countries in the tropics practice crop-livestock production systems making the crop residues an important component of the livestock diet (FAO, 2006). Crop residues are the major source of ruminant feed in mixed crop livestock farming systems in Africa and Asia (Timothy *et al*., 1997).

In Eritrea, crop and livestock production are important activities in the smallholder mixed farming systems. Besides providing food for the human, crop production acts as a source of residues and by-products obtained from agro-industries which are source of feed for livestock which are mainly dependent on natural grass/rangelands (FAO, 2006). Seasonal variations causes feed deficits especially dry periods which coincide with crop harvesting times making the crop residue very important in supplementing the poor grazed pastures.

Crop residues are the most abundant and widespread of the non-conventional feed resources and are the most important feed sources for ruminants (Schiere, *et al*., 2004). In the study Schiere *et al* (2004) demonstrated that if a 300 kg animal voluntarily consumes approximately 5 kg of straw DM per day (1.7% of body weight), one hectare of wheat, rice or barley crop, with an approximate grain yield of 3000 kg ha^{-1} would provide enough feed for 800 animal days in one harvest. The importance of crop residues as potential livestock feed varies with the type of crops grown, size of the land under the food crops and proportion of utilisable parts of the crop residue. Generally, the output of crop residues tends to rise with rural population density (Nordblom & Shomo, 1995).

The amount of crop residues produced from a country is approximated from the proportion of land under cultivation (World Bank, 1989; WRI, 1990), the yield estimates of specific crops and the grain residue ratio. The proportion can then be expressed as a percentage of the total animal feed supply given the total amount of natural pastures and/or uncultivated land (Nordblom & Shomo, 1995).

According to FAO (2006), majority of Eritrean smallholder farmers practice some form of crop residue storage for use in feeding livestock during the dry seasons. Most of the residues come from sorghum (*Sorghum bicolor*), millet (*Pennisetum americanum*), taff (*Eragrostic tef*), barley (*Hordeum vulgare*), maize (*Zea mays*) and wheat straw (*Triticum aestivum*), chick pea (*Cicer arietinum*), vetch (*Vicia sativa*), field pea (*Pisum sativum*), horse bean (*Vicia faba*), lentil *(Lens esculanta*), and groundnut (*Arachis hypogaea*). The contribution from sorghum and millet is higher as more land is under the two as they form a major and important staple food in Eritrea. This is evidenced by data obtained from the State of Eritrea Ministry of Agriculture (MoA, 2015) showed that the 91.66% cropland allocated for cereal crops was distributed among sorghum (50.38%), pearl millet (11.82%), barley (8.64%), teff (6.46%), finger millet (5.15%) maize (4.03%) and wheat (3.38%). Similar, pattern would be expected in crop residues production.

In the light of the poor quality and quantity (mainly during the dry seasons) of grazed pastures in Eritrea (FAO, 2006), there is need to optimally use the available crop residue resources for increased livestock productivity and profitability. The first step would be to determine the quality (chemical composition and nutritive value) and quantities of different crop residues. There is also substantial amount of by-products from the agroindustry which can also be integrated in the livestock feeding in the country. Like the crop residues, there is need to determine the amount of by-products and their potential feeding value. This chapter reports the findings of a study that was set to determine the production and utilization of crop residues and agro-industrial by-products in ruminant nutrition in Eritrea.

4.2 Materials and Methods

4.2.1 Describtion of tha main crop production Zones

The climate, agro-ecology and production system of the main crop production zones are described in chapter 3, sections 3.1 and 3.2

4.2.2 Production of Crop Residues

The quantity of crop residues produced annually was estimated based on government crop production statistics. In the current study, an eight years dataset (2007-2015) on the relevant grains and legumes production in Eritrea was obtained from the State of Eritrea Ministry of Agriculture (MoA, 2015). The grain and legume yield data was then used to estimate their equivalent residue yields using the previously established residue to grain ratios which were 1.5, 2.0, 3.0, 3.7, 4.0 and 5.0 for barley, wheat, maize, teff, pules and oil crops, and sorghum/millet residues quantities respectively (Munthali & Dzowela, 1987; Kossila, 1988). Further, a 92%DM content was used in estimating pule and oil crop residues. A value of 3.0 was used in estimating the volumes of the industrial by-products (Tesfaye, 1999).

4.2.3 Availability of crop residues to utilisation by livestock

Besides the production data, this study related the crop residues availability to utilisation by livestock. The livestock population per Zobas used was obtained from MoA (2015). With a mature cattle weighing approximately 250 kg being considered as a single Tropical Livestock Unit (TLU) data on livestock population was converted into Herd Size and expressed in term of TLU using the respective TLUs for a goat or sheep, horse, mule, donkey and camel equalled 0.1, 0.8, 0.7, 0.5 and 1.0 (IFPRI, 2011). Based on estimation of the crop residues production and herd size data in this study the availability of crop residues to livestock was defined in terms of annually crop residues production (Ton) per TLU per year.

4.3 Results and Discussion

4.3.1 Crop Production and Land Allocation

The allocation of cultivable land to the major crops by zones in Eritrea is presented in Table 4-1. Crop production mainly occurs in Maekel, Debub, Anseba, Gash Barka and Northern Red Sea. The allocation varied amongst zones and between land allocated to cereals and that put into legumes. The importance (based on land size) differed between zones. For example, in Gash Barka and Northern Red Sea zones, the respectively highest percentage of crop land from annually cultivated was allocated to sorghum (77.97%) and (50.86%), followed by pearl millet (10.92%) and (24.71%). Conversely, in Anseba pearl millet recorded the highest allocation at 43.86% followed by sorghum at 42.00%. In Maekel, more land was allocated to Barley at 49.51% followed by wheat at 28.62%. Overall, sorghum accounted for 50.38% of the land under cultivation. Second in allocation was millet at 16.97%. These two crops are considered important in Eritrea as they form the main staple food, *Injera* (flatbread made from sorghum, teff, and millet or wheat grain flour).

Table 4.1: Allocation of Crop Land to the Major Crops by Zones in Eritrea (average of the year 2007-2015)

Crops	Zones[1]					
	Debub	Maekel	Gash Barka	Anseba	North Red Sea	Total
	% crop land					
Cereal						
Sorghum	20.54	2.55	77.97	42.00	50.86	50.38
Pearl millet	-	-	10.92	43.86	24.71	11.82
Maize	8.00	3.21	0.71	1.76	14.60	4.03
Millet	13.35	1.18	1.98	0.98	0.01	5.15
Barley	15.53	49.51	0.89	6.27	4.71	8.64
Wheat	7.14	28.62	0.13	1.02	3.64	3.96
Teff	20.42	1.12	0.14	0.00	0.06	6.36
Oat	3.10	6.27	0.00	0.00	0.00	1.31
Sub-Total	**88.08**	**92.46**	**92.73**	**95.89**	**98.59**	**91.66**
Legumes						
Field pea	1.20	0.42	0.04	0.09	0.00	0.43
Chick pea	4.60	3.2	0.15	0.19	0.00	1.71
Vetch	2.28	1.19	0.00	0.00	0.00	0.78
Horse-bean	1.67	1.07	0.01	0.14	0.17	0.54
Haricot-bean	0.05	0.00	0.00	0.01	0.013	0.01
Faba bean	0.66	0.14	0.01	0.02	0.43	0.23
Lentils	0.49	0.33	0.00	0.03	0.00	0.18
Sub-Total	**10.80**	**6.36**	**0.20**	**0.48**	**0.62**	**3.88**
Oil Crops						
Linseed	0.57	0.65	0.00	0.09	0.00	0.23
Sesame	0.00	0.00	6.86	0.00	0.00	3.36
Nueg	0.06	0.00	0.00	0.02	0.00	0.02
Fenugreek	0.05	0.56	0.00	0.00	0.00	0.04
Cotton	0.00	0.00	0.13	0.00	1.24	0.27
Groundnut	0.37	0.00	0.07	3.50	0.00	0.55
Sub-Total	**0.53**	**1.21**	**7.07**	**3.61**	**1.24**	**4.46**

The total land allocated to cereal crops production was 91.67%, legumes 3.88% and oil crops 4.46%. Land allocated to legumes in Debub and Maekel were 10.80% and 6.36% respectively.). Oil crops are mainly grown in Gash Barka and Anseba zones accounting for 7.07% and 3.61% land allocation respectively.

Table 4.2: Annual crop residues production (tons) by zones in Eritrea (average of the year 2007-2015)

	Zones					
	DBU	**MKL**	**GB**	**ASB**	**NRS**	**Total**
Crop Type						
Cereals						
Sorghum	144062	3864	470565	37953	95183	751627
P. millet	-	-	55252	39989	13000	108242
Maize	34294	5751	1987	1043	10673	53749
F. millet	75284	1021	9462	892	5	86664
Barley	35802	22793	1644	3178	1037	64455
Wheat	19629	17049	322	538	894	38432
Teff	73400	411	127	-	23	73961
Oat	7587	3469	-	-	-	11057
Sub-Total	**390058**	**54359**	**539359**	**83594**	**120815**	**1188186**
Legume						
Field pea	4415	218	74	54	0.69	4762
Chick pea	19893	2066	352	44	-	22355
Vetch	10221	822	4	-	-	11047
Horse-bean	3681	740	35	126	46.62	4629
Haricot-bean	39	-	-	21	46.25	105
Fababean	4185	93	15	277	1290.19	5860
Lentils	1168	145	5	40	-	1359
Sub-Total	**43602**	**4084**	**486**	**562**	**1384**	**50117**
Cash crops						
Cotton	-	-	1855	-	211	2066
Groundnut	2408	-	286	6178	-	8872
Sub-Total	**2408**	**-**	**2141**	**6178**	**211**	**10938**
Grand-Total	**436068**	**58443**	**541986**	**90334**	**122410**	**1249241**

As showed in table 4.2 and illustrated on Figure 4-1, the production data on per zone basis, it is evident that different crop residues production varied amongst zones and within zones as did the land allocation. In Gash Barka sorghum and pearl millet residues production followed the land allocation pattern presented in Table 4-1.

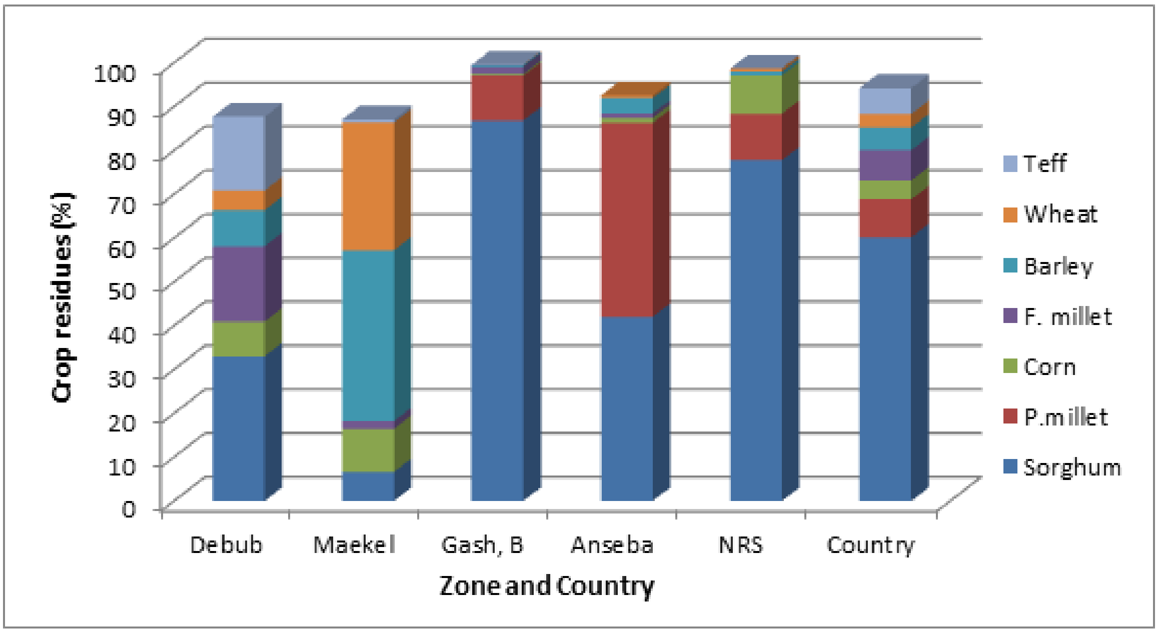
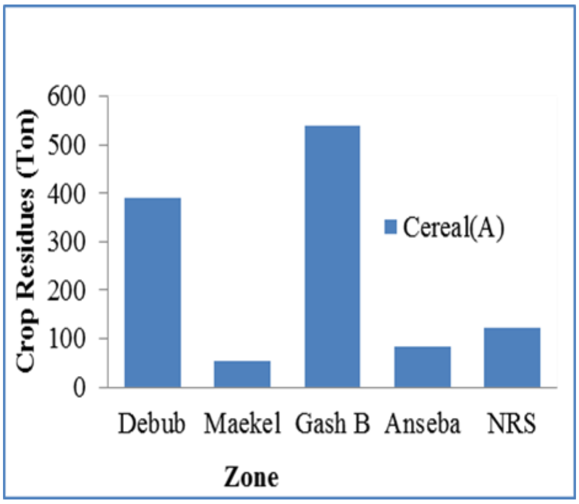


Figure 4.1: Contribution of different cereal crop residues to the annual residues production by zones and country

Figure 4-2 shows the production distribution of the cereal (A) and legume (B) residues in different Zones. The average annual crop residues for the period totalled to approximately 1,249,241 tonnes. Gash Barka zone had the highest cereal crop residue but lagged behind Debub, Maekel and Anseba zones in production of legume residues. Debub had the highest legume residues production and second to Gash Barka in cereal crop residues production. Maekel zone had the lowest quantities of cereal crop residues. Different cereal and legume crops produced different amounts of the corresponding residue with sorghum accounting for the biggest bulk of the residues. This is expected as sorghum is the main grain used in making *Injera* which is an important staple food in Eritrea.



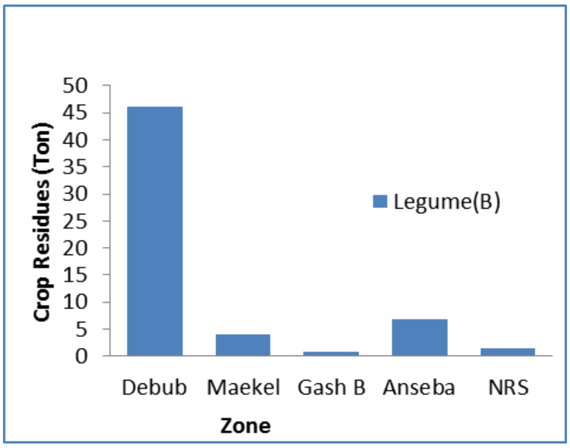


Figure 4.2: Cereal (A) and legume (B) crop residues produced in different zones in Eritrea (Ton × 10^3)

4.3.2 Availability of crop residues to utilization by livestock

It was observed by the researchers thatt he crop residues were mostly used for livestock feeding in all zones. In Zone Gash Barka ,mainly sorghum crop residues and Anseba, mainly millet crop residues were observed to be sold, commonly traded to nearby urban area.

This study further attempted to relate the availability of the crop residues and livestock production in different zones in Eritrea as the ultimate target would be to use the crop residues in supplementing the grazing livestock which are exposed to periods of low feed supply within and between years. Table 4-3 show the herd size in

Tropical Livestock Unit (TLU) and crop residues production in different zones of Eritrea.

Table 4.3: Herd size (TLU), crop residue production per TLU in the five zones of Eritrea

Zones	Herd Size(TLU)	Crop Residues Production	
		Tonnes per year	**Tonnes per TLU per year**
Debub	820,469	436,068	0.53
Maekel	64,213	58,443	0.91
Gash Barka	1,346,959	541986	0.40
Anseba	374,104	90,334	0.24
Northern Red Sea	499,977	122,410	0.24

Gash Barka which had the highest cereal crop residues production had correspondingly largest livestock number at 1,346,959 head with Debub zone ranking second in terms of livestock numbers. A similar ranking was observed in production of cereal crop residues compared to first rank in legume crop residues. This implies that cereal crop residues are utilised more in livestock feeding than the legume crop residues. Maekel which has 64,213 TLU had the highest tonnage per TLU per year at 0.91 and Anseba and Northern Red Sea the lowest at 0.24. This means there is potential underutilisation of the crop residues in this zone and/or there are other factors that affect livestock production more than the feed related constraints.

According to Kayouli (1996) the edible proportion of crop residues is about 70%. This implies that if the annual crop residue production per TLU that was in the range of 0.24-0.91 was converted to daily production; the lowest amount of residue dry matter per TLU would be 0.42 kg dry matter per day and the highest 1.60 assuming a 91.52% DM content. According to Kearl (1982) this would account for 9.63% - 36.31%) of the 4.4 kg maintenance DM required per TLU per day.

Besides the crop residues, this study obtained the quantities of agro-industry by products with an aim of evaluating their potential use in supplementing livestock. The main by-products identified to be in quantities that can be utilised in ruminant feeding were the brewers’ waste, brans mainly wheat and oil cakes especially the sesame cake. The annual brewers’ waste production in Eritrea was estimated at 3,031.51 tonnes of dry waste and 8,431.45 of wet waste. This was sold to smallholder farmers near the brewery.

The main grains by-products are mostly derived from wheat and these are the bran, middling and shorts all of which can be used in supplementing grazing stock especially during dry periods of the year. The respective annual production for the three by-products was 8,579.25, 1,190.68 and 4,514.37 tonnes. The wheat bran was sold to small-scale commercial livestock producers, mainly keeping dairy animal with exotic and/or cross dairy breed, while wheat shorts and middling were mainly used in feeding poultry kept in small-scale commercial farms. Sesame cake is the only oil seed by-product that could be considered to be in volumes that could be sustainably utilised in supplementing livestock in Eritrea with an annual production capacity of 2,299.50 tonnes. The sesame cake was included in poultry rations as a source of protein. The researchers observed that there was little effort applied by the famers in improving the nutrients availability in the crop residues and in efficient use of by-products.

4.4 Conclusion

Findings from this study have shown that there are substantial amounts of cereal and legume crops residues that could be used in feeding livestock in Eritrea. Different cereal and legume crops produced different amounts of the corresponding residue with sorghum followed by millet accounting for the biggest bulk of the residues in the country. Also, it can be indicated that the sorghum and millet residues dietary resources deserve better attention in the development of livestock feeding systems in Eritrea based on the locally available crop residues. The legume crop residues could be used in supplementing diets based on cereals crop residues.

It is notable that the cereal crop residues production corresponds with the livestock numbers in different zones. It could be indicuted that crop residues could daily contribute between 9.57 to 36.30% of the total maintenance feed requirements of animals in Zones. There is also need to determine the reasons why Maekel zone which has the highest tonnage per TLU per year lags behind in livestock keeping. It was observed that there is little effort applied by the famers in improving the nutrients availability in the crop residues and in efficient use of by-products. Hence, it is important to evaluate the chemical and nutritive value of the crop residues and by-products so as to better advise the farmers on the most appropriate utilisation approaches.

CHABTER FIVE

DETERMINATION OF THE CHEMICAL COMPOSITION AND IN SITU DEGRADABILITY OF CEREAL CROP RESIDUES AND LENTILS (*LENS ESCULANTA*) STRAW FOR RUMINANTS

5.1 Introduction

Grazed livestock production systems in many developing countries are constrained by the quality and quantity of feed resources available at any given time of the year (Kosgey *et al*., 2003), especially in dry land systems where feed demand and supply fluctuates within and between years as a result of climatic variability (Gicheha *et al*., 2014). In the extensive grazed livestock production systems of Eritrea, animals are grazed on poor quality unimproved pastures which results in poor animal productivity (FAO 2006). However, studies (Sultan *et al*., 2011; Lopez *et al*., 2005; Abbator *et al*., 2002; Savadogo *et al*., 2002) have shown that crop residues and agro-industrial by-products can be used to supplement the grazing animals and that the nutritional value of the feedstuffs can be enhanced using tested treatment procedures (Li *et al*., 2014; Shawrang *et al*., 2013; Hamed *et al*., 2008; Silva *et al*., 2008; Elseed *et al*., 2007).

A survey carried out in Eritrea indicated (chapter 4 of this study) that the country produces up to 1.2 million tons of crop residues each year (Eyob *et al*., 2016) which justifies a study of their potential use in livestock production. Understanding the chemical and nutritive characteristics of the crop residues would aid in designing optimal utilization strategies at farm and/or national levels. Furthermore, these characteristics indicate the feeding value of the feedstuffs. In Eritrea, the information on the chemical composition and nutritive value of available crop residues is scanty. Therefore, this study was undertaken to determine the chemical composition and ruminal degradation kinetics of seven different cereal crop residues and a legume straw. Since the cell-wall carbohydrates are the most important components of the straws, an efficient microbial digestion in the rumen is crucial for their utilization in ruminant feeding. In recent years, a number of studies have suggested that degradation characteristics of these types of feeds in the rumen will provide a useful basis for the evaluation of their nutritive value (Ørskov *et al*., 1988; Shem *et al*., 1995; Preston 2007).

5.2 Material and methods

5.2.1 Sample Collection

A total of eight major crop residues found in different agricultural zones, including Maekel, Debub, Anseba, Gash Barka and Northern Red Sea in Eritrea were collected for analysis. They included the sorghum stovers (SS) and its threshed head residues (STH), millet stovers (MS) and its threshed head residues (MTH), corn stover (CS), barley (BS) and wheat (WS) straws and Lentil (*Lens esculanta)*, straw (LS). The LS was included for the purposes of comparing the chemical and nutritional characteristics of legumes with that of the cereal crop residues.

The description of zones and sampling procedures are described in chapter 3, section 3.1 and 3.2 respectively. The Chemical Analysis and *in situ* degradation procedures are described in chapter 3, section 3.3 and 3.4 respectively.

5.3 Statistical Analysis

Data were subjected to analysis of variance using SPSS 21 version while the least significant differences (LSD) test was used in all cases to compare the samples means. Differences were accepted when $p \leq 0.05$

5.4 Results And Discussion

5.4.1 Chemical composition

Results for the chemical composition analysis of the crop residues are presented in Table 5-1. The DM content of the residue ranged between 90.6%-91.9% in CS and SS respectively. A similar trend was observed in the OM content with the highest value of 94.9% being recorded for MTH and the lowest being 86.0% for BS. There were minor differences in chemical and nutritional characteristics of samples from different zones and therefore the results presented were obtained by averaging the data across zones for the same crop residue.

Table 5.1: Chemical composition of crop residues (% DM)

	Crop Residues[1]								SEM
Nutrients[2]	**SS**	**STH**	**MS**	**MTH**	**CS**	**WS**	**BS**	**LS**	
DM (%)	91.9^{a}	91.4^{bd}	91.5^{b}	91.3^{b}	90.6^{c}	91.3^{b}	91.01^{d}	91.5^{b}	1.00
Chemical composition (%)									
Ash	8.6^{c}	8.7^{c}	12.2^{d}	5.11^{e}	7.59^{b}	9.70^{a}	13.02^{f}	9.99^{a}	0.61
OM	91.4^{a}	91.2^{a}	87.8^{c}	94.9^{b}	92.4^{d}	90.3^{e}	86.0^{f}	90.01^{e}	0.61
CP	3.6^{b}	6.73^{d}	3.81^{b}	10.7^{c}	7.68^{e}	7.45^{e}	6.71^{d}	9.40^{f}	0.59
EE	1.10^{ab}	1.48^{b}	5.40^{c}	2.47^{d}	0.82^{a}	1.10^{ab}	1.43^{b}	3.82^{e}	0.39
NFE	51.3^{a}	56.01^{b}	32.2^{c}	66.4^{d}	45.6^{e}	41.7^{f}	37.1^{g}	40.5^{f}	2.69
CF	35.4^{c}	27.0^{b}	46.5^{a}	15.3^{d}	38.3^{e}	40.05^{f}	41.7^{g}	36.3^{c}	2.36
NDF	74.1^{a}	76.8^{b}	79.3^{c}	62.5^{d}	66.4^{e}	71.9^{f}	73.8^{a}	52.0^{h}	2.16
ADF	46.6^{d}	31.5^{c}	53.2^{a}	20.6^{b}	37.0^{e}	43.9^{f}	46.7^{g}	32.5^{c}	2.56
ADL	6^{ab}	5.48^{a}	10.4^{c}	7.60^{d}	18.3^{e}	6.08^{ab}	6.78^{bd}	19.1^{e}	1.36
ME (MJ/kg DM)	7.05^{c}	7.83^{b}	6.64^{e}	8.51^{d}	7.14^{c}	6.80^{ce}	6.32^{e}	8.39^{d}	0.2

Means within the same row with different superscript are significantly different (P≤0.05).

[1]See text for the description of the crop residues

[2]See text for the description of the nutrients; the values for the Ash, OM, CP, EE, NFE, CF, NDF, ADL are presented as percent of the DM content

The ash content varied from a low of 5.11% from MTH to a high of 13.02% in BS. The CS had significantly higher (P<0.05) CP, ADL and lower (P<0.05) NDF and ADF than the SS and MS. The WS had higher (P<0.05) CP than BS. The STH and MTH had higher (P<0.05) CP, ME and lower (P<0.05) CF and ADF content than SS and MS. The legume straw had higher (P<0.05) CP, ADL, ME but lower NDF and ADF than the cereal straws/stover. The EE was highest (P<0.05) in MS and lowest in CS while NFE was highest (P<0.05) in MTH and lowest in MS.

The variations in the chemical composition of different crop residues realized in this study can be explained by the differences in proportion of botanical fractions. In the stovers and straws, the leaves are higher in CP than the stems (Savadogo *et al.,* 2002) fiber are lower in stems than in leaves (khatir *et al.,* 2013). The higher CP and lower NDF and ADF in CS than in SS and MS could be the differences in leaf to stem ratios within and among the stovers. The ears and some broken grain constituted in STH and MTH could be the possible reasons for higher CP and ME but lower CF and ADF than SS and MS. The legume straw had higher ($P<0.05$) CP, ADL, ME but lower ($P<0.05$) NDF and ADF than the cereal straws/stovers.

The variations in the chemical composition observed between legume and cereal straws/stovers could possibly be the differences in proportion of botanical fractions between the crop residues. Savadogo *et al* (2002) recorded variations in the chemical composition in relation to the differences in proportion of botanical fractions within and between crop residues. In their study Savadogo *et al* (2002) pointed out that Sorghum stover consisted of 70.6% stems and 29.4% leaves, while these proportions respectively were 64.2% and 35.8% for cowpea and 50.1 and 49.9%. Furthermore, they indicated that the CP was higher in the leaves than the stem and the concentration in cowpea and groundnut haulms was much higher than in the leaves of sorghum stover.

The chemical composition results of cereal and legume straw obtained in this study are in agreement with those presented in Sultan *et al* (2011) and Lopez *et al* (2005) whose studies found higher levels of CP and lignin and low NDF and ADF in legumes than in cereal crop residues. The results for the EE and OM obtained in this study match those reported in Sultan *et al* (2011) and Lopez *et al* (2005) studies for the WS and BS. The CP, EE OM, NDF and ADF values obtained from SS and CS in the current study agree with those reported by Sultan *et al* (2011). Results for the CP, CF, NDF, ADF, ADL and ash content of LS reported in this study are similar to those reported by Abreu *et al* (1998). The SS residue OM value presented in Savadogo *et al* (2000) is higher than that obtained in the current study but the CP content is in agreement. Generally, chemical composition values reported for cereal and legume crop residues (Theander *et al*., 1984; Sultan *et al*., 2011) are consistent and within the ranges of those obtained in this study.

The small variations that exist in the chemical composition of different crop residues realized in this study and those presented in other studies can be explained by the differences in varieties, proportion of botanical fractions, growing conditions (geographic, seasonal variations, climatic conditions and soil characteristics), extent of foreign materials and impurities such as soil contamination, different measuring methods and laboratories procedures (Elseed *et al*., 2007; Maheri-Sis *et al*., 2007; Bampidis & Christodoulou 2011; Kafilzadeh & Maleki 2011; Maheri-Sis *et al*., 2011; Aghajanzadeh *et al*., 2012).

5.4.2 *In situ* Degradability

5.4.2.1 Dry Matter Degradability (DMD)

Dry matter degradability (DMD) of crop residues is presented in Table 5-2. The SS, CS and WS had higher (P<0.05) degradability than MS and BS in all the incubation times.

Table 5.2: *In situ* dry matter degradability of crop residues (% DMD)

	Time of Incubation in the Rumen (Hrs.)								**SEM**
Crop residues[1]	**0**	**4**	**8**	**16**	**24**	**48**	**72**	**96**	
SS	20.4^{h}	24.6^{ab}	28.2^{i}	33.9^{ce}	38.4^{dj}	44.5^{g}	46.6^{gk}	46.6^{gk}	0.33
STH	14.8^{g}	18.7^{cg}	21.9^{ch}	35.3^{be}	41.5^{dfi}	51.8^{a}	56.1^{a}	56.1^{a}	0.73
MS	16.6^{fg}	22.06^{bh}	26.2^{ci}	30.8^{ed}	34.1^{j}	40.7^{k}	43.1^{kl}	43.1^{kl}	0.35
MTH	17.8^{ef}	18.8^{eg}	20.7^{eh}	30.5^{bcd}	47.6^{i}	58.1^{j}	62.2^{jm}	62.2^{ajm}	0.70
CS	21.03^{h}	24.9^{a}	27.9^{i}	34.3^{bcd}	39.1^{fj}	44.9^{g}	47.4^{k}	47.9^{k}	0.102
WS	19.07^{eh}	22.2^{bh}	24.6^{chi}	29.9^{bcd}	34.9^{fj}	42.2^{gk}	42.3^{kl}	42.4^{k}	0.61
BS	16.76^{fg}	22.1^{bf}	24.4^{bci}	28.6^{bcd}	32.3^{j}	37.7^{k}	39.8^{l}	39.8^{l}	0.69
LS	24.4^{c}	30.6^{d}	34.3^{d}	40^{f}	46.5^{i}	56.9^{jm}	59.8^{am}	59.8^{am}	0.56
SEM	0.76	0.95	1.09	1.001	1.47	1.86	2.12	2.12	

Means within the same row with different superscript are significantly different (P<0.05)
Means within the same column with different superscript are significantly different (P<0.05)
[1]See text for the description of the crop residues

The percentage DMD in STH and MTH was lower (P<0.05) at 4 and 8 h than SS and MS, but the trend reversed after 8 h with the STH and MTH having significantly higher (P<0.05) DMD at 24, 48, 72 and 96. The high initial rate of degradation in SS and MS could be due to small particle size of milled stovers (because of especial physical structure). A decrease in the particle size will increase the surface area per unit weight of substrate and this increase may affect the initial rate of degradation, but not necessarily the final extent of degradation Orskov *et al.*, 1980).The legume straw had higher (P<0.05) DMD at 0, 4, 8, 16, and 24 h than all the cereal crop residues. An increase in the incubation time led to increase in DMD and the DMD amongst different crop residues varied with the incubation time. However, there was no significant difference (P<0.05) in DMD after 48 h amongst all the residues.

5.4.2.2 Organic matter degradability (OMD)

The organic matter degradability (OMD) of crop residues is presented in Table 5-3. It varied amongst residues and incubation times. However, the percentage OMD within the respective crop residues was not significantly different (P<0.05) after 48 h of incubation.

Table 5.3: *In situ* organic matter degradability of cereals crop residues (% OMD)

	Time of Incubation in the Rumen (Hrs.)								SEM
Crop residue[1]	0	4	8	16	24	48	72	96	
SS	19.4[h]	23.7[i]	27.6[a]	32.9[e]	37.8[g]	44.9[l]	46.5[cl]	46.9[cl]	0.27
STH	13.7[g]	17.8[f]	20.7[i]	34.1[h]	40.8[c]	50.9[a]	55.8[d]	55.8[d]	0.19
MS	8.1[f]	11.1[h]	17.2[j]	22.6[k]	26.1[d]	32.9[e]	37.4[b]	37.4[b]	0.22
MTH	15.8[g]	16.7[e]	18.7[k]	29.5[f]	47.5[i]	58.1[h]	62.1[a]	62.1[a]	0.05
CS	15.5[g]	18.9[d]	21.7[e]	29.8[f]	35.6[h]	41.6[m]	45.0[ln]	45.1[ln]	0.07
WS	14.7[g]	16.03[e]	19.4[d]	25.5[d]	30.5[a]	39.6[i]	42.4[h]	42.5[h]	0.06
BS	9.6[f]	16.3[e]	19.9[d]	27.2[g]	30.3[a]	36.1[j]	38.5[bj]	38.5[b]	0.05
LS	21.1[h]	27.6[c]	30.9[c]	36.6[c]	43.3[f]	54.2[k]	58.8[k]	58.8[k]	0.07
SEM	1.07	1.22	1.14	1.33	1.76	2.16	2.28	2.279	

The SS had higher (P<0.05) OMD than all the cereal stovers/straw at all the incubation intervals except for CS after 48 h. The STH had lower (P<0.05) OMD at 0, 4 and 8 h than the SS, but, the trend reversed after 8 h with the SS having significantly higher (P<0.05) OMD at 16, 24, 48, 72 and 96. The legume straw had higher (P<0.05) OMD at all incubation intervals than all the cereal stovers/straws.

5.4.3 Degradability Characteristics

The results for the rapidly soluble fraction (*a*), potentially degradable fraction (*b*), rate of degradation of *b* fraction (*c*) and effective degradability (ED) are presented in Table 4 together with ED of DM and OM at 0.02, 0.05 and 0.08 per hour rates of passage.

Table 5.4: The DM and OMD characteristics and effective degradability values of crop residues

	Crop Residues[1]								SEM	Sig
	SS	STH	MS	MTH	CS	WS	BS	LS		
DM										
a (%)	15.78^{a}	13.4^{b}	11.4^{c}	16^{ad}	16^{ad}	17.6^{d}	15.1^{ab}	23.6^{e}	0.87	*
b (%)	32.2^{b}	43^{a}	33.1^{b}	46.6^{c}	33.4^{b}	25.2^{d}	25.3^{d}	36.5^{e}	1.84	*
(*a* + *b*) %	48^{a}	56.4^{b}	44.5^{c}	62.6^{d}	49.4^{e}	42.8^{f}	40.4^{g}	60.1^{h}	2.00	
c per h	0.03^{c}	0.04^{d}	0.03^{c}	0.04^{d}	0.03^{c}	0.04^{bd}	0.04^{b}	0.05^{a}	0.00	**
ED (%)										
0.02	35.6^{a}	42.5^{b}	31.4^{c}	47.3^{d}	36.5^{a}	34.5^{e}	31.7^{c}	49.5^{f}	1.68	***
0.05	29.7^{a}	33.3^{b}	25.5^{c}	37.4^{d}	30.5^{a}	29.3^{a}	26.5^{c}	41.8^{e}	1.34	**
0.08	27.2^{a}	28.7^{a}	22.9^{b}	32.5^{d}	27.9^{a}	24.8^{ac}	24.0^{bc}	37.8^{e}	1.15	***
OM										
a (%)	14.9^{a}	12.3^{b}	2.8^{c}	14.04^{a}	10.4^{d}	12.4^{b}	7.2^{e}	20.4^{f}	1.27	*
b (%)	32.9^{b}	43.8^{c}	35.6^{a}	48.4^{d}	36^{a}	30.7^{e}	31.8^{be}	38.7^{f}	1.49	**
(*a* + *b*)	47.8^{a}	56.04^{b}	38.4^{c}	62.5^{d}	46.4^{e}	43.04^{f}	39.0^{g}	59.02^{h}	2.22	
c per h	0.03^{a}	0.04^{b}	0.02^{c}	0.04^{b}	0.03^{a}	0.03^{d}	0.03^{d}	0.05^{e}	0.00	**
ED (%)										
0.02	35.2^{a}	41.9^{b}	23.6^{c}	46.6^{d}	32.1^{e}	32.1^{e}	27.3^{f}	47.7^{d}	2.13	***
0.05	29.1^{a}	32.6^{b}	17.2^{c}	36.2^{d}	25.6^{e}	25.8^{e}	20.7^{f}	39.6^{g}	1.83	**
0.08	26.4^{a}	27.8^{a}	14.6^{b}	31.1^{d}	22.7^{c}	22.8^{c}	17.7^{f}	35.2^{e}	1.64	***

[1]See text for the description of the crop residues
Means within the same row with different superscript are significantly different (P<*0.05, **0.01 or ***.001); SEM = Standard Error Mean, Sig. = significance level (*0.05, **0.01 and ***0.001)

The respective DM and OM *a* fraction for MS were the lowest (P<0.05) at 11.40% and 2.80% amongst all the crop residues. The DM and OM *a* fraction was higher (p<0.05) in legume residue than in the cereal crop residues. The DM and OM *b* fraction was higher (P<0.01) in MTH and STH than in the SS and MS. The WS and BS had higher (P<0.01) *c* fraction for the DM and OM than the other cereal residues but lower than the legume straw. Similarly, higher DM and OM *c* fraction were obtained in MTH and STH than in SS and MS.

The respective ED of DM and OM was higher (P<0.001) at 0.02 and (P<0.01) at 0.05 rates of passage for STH and MTH than SS and MS. The BS and MS had the lowest ED of DM at 0.02 (P <0.001) and 0.05 (P<0.01), while LS had the highest.

There was variation in *in situ* degradability characteristics among the crop residues. The DMD (which is an indicator of the level of cell walls in a feedstuff) varied between the feedstuff. This implies that the values of DM and OM *a*, *b* and (*a* + *b*) would be dependent on the content and the composition of the cell walls of particular feedstuff. The possible reason for higher DMD observed in this study for SS, CS and WS than MS and BS could be the content and composition of cell walls in the residues. Also it could be the reason for low value of DM and OM *a* fraction and (*a* + *b)* in MS.

Bruno-Soareset *et al* (2000) reported that there are strong correlations among the *b* fraction and the NDF, ADF and ADL contents of test feedstuff. The study further demonstrated that the content and the composition of the cell walls are the best variables to describe the variation of DM (*a* + *b*) of the feedstuff. It is Woods *et al* (2003) who determined the relationship between the degradability parameters *a, b* and *c* and the chemical composition of 60 test feeds and noted that the slowly fermentable structural carbohydrates in feedstuff are the determinant of the degradation characteristics in the rumen.

The values of DM *a* fraction and *c* parameter for the SS obtained in the present study correspond to those reported in Abbator *et al* (2002) and Elseed *et al* (2007). However, in the work by Elseed *et al* (2007) for the SS, the *b* fraction and ED were higher than those obtained in the present study. Hamed *et al* (2008) and Hamed *et al*

(2009) reported lower values of DM and OM *a*, *c* fraction and higher *b* fraction for SS than those obtained in this study. However, the value of the degradable fraction (*a* + *b*) for DM for the SS was similar to that determined in the Hamed *et al* studies. It is Elseed *et al* (2007) who observed that the nutritional characteristics of SS varied widely and could be explained by differences in the proportion and chemical composition of the botanical fractions.

The values obtained for the DM *b* fraction and *c* for CS in this study are similar to those reported in Silva *et al* (2008) but results from the two studies differ in that the *a* fraction is lower in the current study than in Silva *et al* study. Further, Silva *et al* (2008) pointed out that the high value for *a* fraction of CS in their study could be explained by the lower NDF content across four stage of maturity tested.

The DM disappearance at 0h incubation time for CS reported by Li *et al* (2014) is lower than the value determined in this study which could be due to higher NDF content of the whole CS evaluated in the Li *et al* study. The degradation parameters *a, b,* and *c* fraction and the ED at all passage rates of DM for WS are in agreement with those presented in Shawrang *et al* (2013). Besides, the potentially degradable (*a* + *b*), and *c* fraction as well as the ED at 0.02 and 0.05 passage rates of DM for WS were identical to those reported in Nasehi *et al* (2014). However, the value of *a* fraction of DM for WS is lower and that of *b* higher in the studies of Kamalak *et al* (2005) and Nasehi *et al* (2014) than in the current study. The OM *a* fraction for WS is similar to that reported by Nasehi *et al* (2014) while *b*, *c* fraction and ED are lower in the present study. The DM *a*, *b* fractions for LS are similar to those obtained by Bruno-Soares *et al* (2000) with the exception of the (*a* + *b*) which was higher.

The DM *c* fraction and ED values for BS obtained in the current study are similar to those reported by Trujillo *et al* (2010), however the *a* fraction is higher while *b* is lower. The values of *b* fraction and ED of DM for BS are different from those reported by Kamalak *et al* (2005) and Nasehi *et al* (2014). The OM *a*, *b* fractions and ED for BS are lower than those reported by Nasehi *et al* (2014). The differences in the values presented in the other studies and those obtained in the current study could be explained by probable use of different crop varieties evaluated in the studies.

Varieties with higher grain yield were observed to have higher digestible crop residue yields suggesting the possibility of selecting maize varieties that combine grain yield with desirable residue quality attributes (Geleti *et al*., 2011). The potential differences as a result of use of different varieties in degradability tests was confirmed by the study carried out by Anjum *et al* (2014) who detected differences in *in situ* DM degradability in WS of different varieties. Ørskov *et al* (1990) have also detected differences in *in situ* degradability parameters between straw varieties. The differences could also be attributed to differences in the proportion of leaf and stem, animal and diet effects, particle size, incubation characteristics, rumen conditions and microbial contamination (Huntingdon & Givens 1995; Ramanzin *et al*., 1997).

Other factors that could account for the differences between published values for different crop residues and those obtained in the current study would include different chemical composition, leaves to stems proportion, method of feedstuff evaluation (*in vivo, in vitro and in situ*), straw varieties, maturity and impurity as well as technical variation such bag pore size, sample size, washing procedures, grinding size, diet of experimental animal, species of animal, sample preparation, incubation time and washing method (Chumpawadee, 2009; Bampidis & Christodoulou, 2011; Kafilzadeh & Maleki 2011; Maheri-Sis *et al*., 2011; Aghajanzadeh-Golshani *et al*., 2012; Anjum *et al*., 2014).

5.5 Conclusion

There are differences in chemical and nutritive characteristics amongst cereals and between cereal and legume crop residues found in Eritrea as hypothesized in this study. The results of chemical composition, degradation level and degradability kinetic of the crop residues tested in this study suggest that they may be used as component in the diet of ruminants. Nitritive value of legumes was better than the creal straws/stovers. However, the cereal straw/stover can be efficiently utilized in diet of ruminant after improving their nutritive value by chemical treatment and/or supplementation.

CHAPTER SIX

CHEMICAL COMPOSITION AND *IN SITU* DEGRADATION KINETICS OF LEGUME AND TEFF (*ERAGROSTIC TEF*) CROP RESIDUES

6.1 Introduction

In dry land grazing systems, where feed demand and supply fluctuates within and between years as a result of climatic variability (Gicheha *et al*., 2014), livestock production is constrained by the quality and quantity of feed resources available at any given time of the year (Kosgey *et al*., 2003). Use of feed resources such as crop residues, which are easily available at low cost that have been identified as a key source of nutrients in tropical ruminant nutrition (Mugerwa *et al*, 2012), to fill the feed deficit gaps would offer an opportunity to improve animal production. Use of cereal crop straws and stover is common in ruminant diets in Eritrean extensive livestock production systems. According to FAO (2006) there is substantial amount of feed resources from crop residues in Eritrea that has the potential to support animal production considering that 90% of the livestock in the country is grazed on unimproved pastures.

The estimation of crop residues production based on a 10 year period (2004-2014) data from Eritrea indicated that the country produces up to 1.25 million tons of crop residues each year (Eyob *et al*, 2016). The bulk of the crop residues are mainly from cereal crops, however, the legume residues although quantitatively less important, represent a valuable animal feed resource during dry season for the grazing ruminants. In order to use the crop residues optimally, there is need to determine their chemical composition and nutritive value.

Evidence is available to show that crop residues available in Africa and Asia satisfy nutritional requirement of ruminant livestock (Chimwano, 1990; Aregheore, 2000; Abrar *et al.*, 2004; Afshar and Naser, 2008; Naser *et al.*, 2011; Mugerwa *et al.*, 2012). Various studies (Ørskov *et al*., 1988; Shem *et al*., 1995; Preston, 2007) have proposed use of the residues degradation characteristics in the rumen as a useful basis for the evaluation of their nutritive value. No research has been done to provide the necessary information on the chemical composition and nutritive value of crop residues produced in Eritrea, making it infeasible to optimally use the resource. Therefore, this study was conducted in order to determine the chemical composition and degradability of six legume and two cereal crop residues produced in Eritrea.

6.2 Material and Methods

6.2.1 Sample Collection

Six different legume residues and two cereal residues from teff were collected from local farms in Debub and Anseba Zones of Eritrea. The legume crops residues collected were the chickpea (CPS), field-pea (FPS), horse-bean (HBS), groundnut (GNS) and vetch straw (VS), and groundnut hull (GNH). Besides the legume crop residues, teff straw (TS) and teff threshed head residue (TTH) were also collected. Several samples for each feedstuff were ground for chemical and *in situ* degradation procedures. The description of zones and sampling procedures are described in chapter 3 sections 3.1 and 3.2 respectively. The chemical analysis and *in situ* degradation procedures are described in chapter 3, section 3.3 and 3.4 respectively.

6.3 Statistical Analysis

Data were subjected to analysis of variance using SPSS 21 version while the least significant differences (LSD) test was used in all cases to compare the samples means. Differences were accepted when $p \leq 0.05$.

6.4 Results and Discussion

6.4.1 Chemical composition of the legume and teff crop residues

The Results analysis of chemical composition of the legume and teff crop residues is presented in Table 6-1. The CPS had the highest ($P<0.05$) CP and lowest ($P<0.05$) NDF and ADF compared to all the straws evaluated. The GNS had higher ($P<0.05$) ME than all the crop residues and lowest ($P<0.05$) ADL amongst the legume straws.

Table 6.1: Chemical composition of legume and teff crop residues

Nutrients[2]	Crop residue[1]								SEM
	GNS	GNH	CPS	VS	HBS	FPS	TS	TTH	
DM (%)	90.12[a]	91.73[b]	91.64[b]	91.34[c]	91.02[d]	90.91[d]	91.28[c]	91.35[c]	0.12
Ash	11.04[b]	8.99[a]	15.25[c]	11.43[b]	12.92[d]	9.83[e]	7.39[f]	13.82[g]	0.63
OM	88.96[a]	91.01[b]	84.75[c]	88.57[a]	87.08[e]	90.17[d]	92.61[g]	86.18[f]	0.63
CP	9.61[c]	11.41[b]	10.67[a]	10.28[d]	9.24[c]	9.55[c]	7.93[e]	8.68[f]	0.27
EE	1.94[a]	1.38[b]	2.72[c]	1.68[ab]	1.10[b]	3.03[c]	1.02[b]	1.44[ab]	0.18
NFE	38.43[b]	10.71[a]	37.16[c]	37.85[bc]	34.79[d]	32.03[e]	43.96[f]	47.75[g]	2.69
CF	38.98[ac]	67.50[b]	34.20[d]	38.76[a]	41.94[e]	45.55[g]	39.69[c]	28.31[f]	2.80
NDF	53.72[a]	79.04[b]	45.63[c]	58.17[d]	59.93[e]	68.36[f]	77.81[g]	64.06[h]	2.78
ADF	41.72[b]	68.08[a]	25.63[c]	36.24[d]	41.77[b]	46.08[e]	41.09[f]	31.04[g]	3.05
ADL	10.38[a]	39.57[b]	12.56[c]	11.20[d]	18.01[e]	11.74[d]	6.01[g]	3.58[f]	2.69
ME[3]	9.10[a]	4.70[c]	7.94[b]	7.79[b]	7.71[b]	7.46[b]	6.52[d]	7.47[b]	0.31

[1]See text for the description of the crop residues

[2]See text for the description of the nutrients

[3]MJ per kg DM

Means within the same row with different superscript are significantly different (P≤0.05)

The ADL was the highest (P <0.05) in HBS in all samples while fibre was highest (P<0.05) in the GNH but with the lowest ME when compared to all the crop residues considered. Between the two cereal residues evaluated, it was found that TTH had lower (P<0.05) CF, NDF, ADF and ADL, and higher (P<0.05) CP and ME than TS. When legume and cereal straws were compared it was shown that there was more (P<0.05) CP, ADL, ME and low (P<0.05) NDF in legume straws than in cereal straw. The variations in the chemical composition of different crop residues realized in this study could possibly be due to the differences in proportion of botanical fractions as explained in section 5.4.1.

The DM, CP, EE, NDF and ADL values reported by Abbator et al. (2002), and the OM and CP reported by Savadogo *et al* (2002) for the GNS compare well with finding of this study. Similarly, the values of DM and CF reported by Aghajanzadeh-Golshani *et al* (2012), and ADL by Abreu *et al* (1998) for CPS are similar to those reported in this study. However, the ash content of the CPS reported in the studies by Abreu *et al* (1998) and Maheri-Sis *et al* (2011) is lower than the value determined in this study. Variations in chemical composition of crop residues can be explained by differences in crop varieties, proportion of botanical fractions, growing conditions (geographic, seasonal variations, climatic conditions and soil characteristics), the level of contamination (foreign materials and impurities such as soil), different determination approaches and laboratories procedures (Elseed *et al*., 2007; Maheri-Sis *et al*., 2007; Bampidis & Christodoulou, 2011; Kafilzadeh & Maleki, 2011; Maheri-Sis *et al*., 2011; Aghajanzadeh-Golshani *et al*., 2012). Results for the CP, CF, NDF, ADF, ADL and ash content for HBS and VS in the present study are similar to those reported by Abreu *et al* (1998). The chemical composition values for the legume straws in this study are in agreement with and/or within acceptable range with those presented in other studies (Theander *et al*., 1984, Sultan *et al*., 2011).

6.4.2 *In situ* Degradability

6.4.2.1 Dry Matter Degradability

The DMD of various crop residues considered is presented in Table 6-2. The GNS had the highest ($P<0.05$) degradability level than the other legume straws after 16 h of incubation, while GNH had lowest ($P<0.05$) DMD. TTH had higher ($P<0.05$) DMD than TS after 8 h. There was an observable trend where increase in the incubation time resulted in an increase in the DMD. However, increase in DMD decreased with in incubation time. There was minimal change in DMD between 72 and 96 hours in all samples.

Table 6.2: *In situ* dry matter degradability of legume and teff crop residues (% DMD)

			Time of incubation in the rumen (Hrs.)						SEM
Crop residue[1]	0	4	8	16	24	48	72	96	
GNS	25.84^{ad}	29.04^{dg}	34.57^{eg}	44.29^{c}	52.27^{b}	63.60^{h}	65.17^{h}	65.17^{h}	0.76
GNH	12.30^{be}	14.69^{be}	16.15^{bf}	19.04^{df}	21.30^{dg}	22.63^{fg}	23.56^{g}	23.58^{g}	0.44
CPS	26.04^{a}	34.68^{dh}	37.91^{eh}	43.96^{c}	47.05^{f}	52.83^{i}	56.11^{i}	56.82^{i}	0.60
VS	26.43^{a}	32.70^{dj}	35.55^{ej}	41.97^{bc}	47.00^{f}	51.36^{i}	53.16^{i}	54.87^{i}	0.44
HBS	25.95^{a}	28.14^{cd}	30.48^{cg}	37.90^{be}	45.83^{f}	50.65^{i}	54.37^{i}	54.37^{i}	0.44
FPS	21.87^{ck}	23.10^{fk}	25.89^{dk}	32.55^{eg}	40.14^{h}	48.32^{i}	51.90^{i}	51.90^{i}	0.55
TS	14.33^{bi}	17.26^{ei}	20.17^{afi}	26.03^{aj}	31.07^{cj}	39.51^{d}	41.55^{d}	41.55^{d}	0.64
TTH	10.84^{b}	15.70^{bel}	20.11^{fl}	28.56^{ag}	35.90^{ch}	48.37^{i}	51.31^{i}	51.31^{i}	0.73
SEM	1.67	2.00	2.01	2.29	2.50	2.90	3.04	3.06	

[1]See text for the description of the crop residues

Means within the same row with different superscript are significantly different (P<0.05) while those within the same column with different superscript are significantly different (P<0.05)

Although the level of degradability was different at the various incubation times both between and within the feeds, there was no significant difference (P <0.05) within the samples after 48 h. Legume straws had higher (P<0.05) DMD than the cereal crop residues at all incubation times.

6.4.2.2 Organic Matter Degradability (OMD)

The *in situ* organic matter degradability of the other crop residues evaluated is presented in Table 6-3.The OMD increased with the increase in the incubation time and varied between cereal and legume residues as well as amongst all the residues. The differences in OMD for each sample were not significant (P<0.01) between 72-96 h.

Table 6.3: *In situ* organic matter degradability of legume and teff crop residues (% OMD)

	Time of incubation in the rumen (Hrs.)								SEM
Crop residue[1]	**0**	**4**	**8**	**16**	**24**	**48**	**72**	**96**	
GNS	25.67^{af}	26.79^{f}	31.82^{b}	42.86^{g}	51.74^{h}	62.77^{e}	64.60^{d}	64.61^{d}	0.112
GNH	8.70^{bh}	10.38^{ah}	14.16^{c}	16.74^{fi}	17.63^{di}	20.02^{g}	21.04^{g}	21.51^{g}	0.131
CPS	17.60^{cd}	28.09^{f}	32.06^{b}	41.55^{g}	44.88^{e}	52.06^{a}	52.67^{a}	52.94^{a}	0.157
VS	19.55^{c}	26.50^{f}	29.87^{b}	37.24^{e}	42.18^{g}	48.84^{h}	52.71^{a}	52.79^{a}	0.139
HBS	18.79^{cd}	22.01^{b}	24.16^{f}	34.50^{a}	43.50^{eg}	48.86^{h}	50.21^{i}	50.22^{i}	0.052
FPS	16.73^{d}	17.68^{cd}	19.90^{e}	28.94^{b}	34.99^{a}	46.13^{f}	50.43^{i}	50.44^{i}	0.112
TS	10.41^{b}	15.47^{d}	18.35^{d}	24.19^{c}	28.50^{f}	37.99^{i}	40.51^{j}	40.51^{j}	0.123
TTH	4.56^{e}	11.58^{a}	15.90^{c}	26.65^{d}	33.74^{a}	48.03^{b}	51.26^{f}	51.26^{f}	0.142
SEM	1.658	1.705	1.754	2.187	2.600	2.99	3.060	3.031	

[1]See text for the description of the crop residues

Means within the same row with different superscript are significantly different ($P<0.01$) while those within the same column with different superscript are significantly different ($P<0.01$)

The GNS had the highest OMD at all incubation times. Within the legumes residues, the GNH had the least OMD at all incubation times. A different pattern was observed between the cereal crop residues where TS had higher OMD than TTH between 0 to 8 h but lower than TTH between 16-96 h. The OMD in legume straws was higher ($P<0.01$) than in cereal straw.

6.4.2.3 Crude Protein Degradability (CPD)

Crude protein degradability (CPD) of crop residues is presented in Table 6-4.The CPD increased with the increase in the incubation time and varied between cereal and legume residues as well as amongst all the residues.

Table 6.4: *In situ* crude protein degradability of legume and teff crop residues (% CPD)

CR	Time of Incubation in the Rumen (Hrs.)							SEM
	0	4	8	16	24	48	72	
GNS	8.09[a]	29.87[b]	63.19[f]	70.95[g]	73.96[h]	76.48[ci]	76.50[ci]	0.309
GNH	32.65[b]	49.07[a]	64.84[f]	72.22[g]	74.88[h]	77.15[ci]	77.17[ci]	0.208
CPS	18.16[c]	40.16[e]	56.31[ad]	65.86[b]	70.48[f]	72.27[gh]	73.05[gh]	0.154
VS	1.51[d]	38.68[ce]	61.17[af]	69.88[bg]	74.41[h]	76.28[i]	76.36[i]	0.305
HBS	1.08[d]	30.92[b]	42.89[c]	49.80[a]	54.00[e]	58.64[f]	58.74[f]	0.134
FPS	3.91[e]	36.17[c]	51.06[d]	63.06[b]	71.13[f]	73.02[gh]	73.33[gh]	0.107
TS	1.67[d]	19.12[f]	31.32[e]	55.97[c]	65.51[a]	69.10[gh]	69.14[gh]	0.313
TTH	3.14[e]	24.14[g]	38.13[b]	58.50[c]	67.47[a]	70.18[h]	70.19[h]	0.308
SEM[*]	2.076	2.304	3.023	1.937	1.679	1.469	1.466	

Means within the same row with different superscript are significantly different (P<0.001) while those within the same column with different superscript are significantly different (P<0.001)

6.4.3 Degradability Characteristics

The rapidly soluble fraction (*a*), potentially degradable fraction (*b*), rate of degradation of *b* fraction (*c*) and effective degradability (ED) are presented in Tables 5-5. The DM *a* fraction was higher (P<0.05) in GNS, CPS, VS and HBS than FPS and cereals crop residues. GNS had higher (P<0.05) OM *a* fraction than the other legume residues and cereal crop residues. The CPS had higher (P<0.001) CP *a* fraction than the other legume straws and cereal crop residues.

Table 6.5: The DM, OM and CP degradability parameters and ED values of legume and teff crop residues

	Crop residues[1]								SEM	Sig.
	GNS	**GNH**	**CPS**	**VS**	**HBS**	**FPS**	**TS**	**TTH**		
DM										
(a) %	24.66^{a}	3.68^{b}	24.84^{a}	25.32^{a}	24.69^{a}	20.82^{c}	12.87^{d}	8.70^{e}	2.08	*
(b) %	40.85^{b}	22.85^{a}	32.36^{d}	29.91^{de}	30.09^{de}	31.38^{de}	29.05^{e}	42.78^{b}	1.58	*
(a + b)%	65.51^{c}	26.53^{d}	57.20^{e}	55.23^{b}	54.78^{c}	52.21^{a}	41.92^{f}	51.49^{g}	2.83	
c per h	0.045^{d}	0.015^{f}	0.044^{de}	0.045^{d}	0.043^{de}	0.044^{d}	0.038^{c}	0.042^{e}	0.003	*
ED (%)										
0.02	53.15^{c}	17.11^{d}	47.21^{a}	46.08^{ab}	45.38 ^{b}	42.57^{e}	32.16^{f}	38.24^{g}	2.72	***
0.05	44.57^{e}	14.88^{f}	40.46^{d}	39.86^{d}	39.13^{d}	35.99^{a}	26.08^{b}	29.31^{c}	2.36	**
0.08	40.10^{a}	14.07^{b}	36.98^{c}	36.63^{c}	35.93^{c}	32.58^{d}	23.97^{e}	24.76^{e}	2.17	*
OM										
(a) %	24.48^{c}	1.23^{d}	16.36^{a}	18.21^{b}	17.46^{ab}	15.50^{a}	7.12^{e}	3.51^{f}	1.96	*
(b) %	40.47^{a}	22.46^{d}	36.89^{b}	34.94^{bc}	33.12^{c}	35.24^{bc}	34.07^{c}	47.84^{e}	1.73	**
(a + b)%	64.95^{d}	23.69^{a}	53.25^{c}	53.15^{c}	50.58^{b}	50.75^{b}	41.19^{e}	51.35^{b}	2.89	**
c per h	0.045^{c}	0.015^{b}	0.042^{d}	0.042^{d}	0.041^{d}	0.042^{d}	0.037^{a}	0.041^{d}	0.002	*
ED (%)										
0.02	52.65^{e}	14.14^{f}	41.56^{a}	41.99^{a}	39.95^{b}	39.52^{b}	29.97^{c}	36.05^{d}	2.90	***
0.05	44.13^{a}	11.63^{e}	33.76^{c}	34.64^{c}	32.99^{cd}	32.06^{d}	23.23^{b}	25.71^{b}	2.26	**
0.08	39.71^{d}	10.70^{e}	29.79^{bc}	30.92^{b}	29.47^{c}	28.28^{c}	19.95^{a}	20.48^{a}	2.13	**
CP										
(a) %	8.09^{a}	32.63^{b}	18.11^{c}	1.48^{d}	1.00^{d}	3.90^{e}	1.62^{d}	3.13^{e}	2.71	***
(b) %	68.41^{b}	44.55^{a}	54.95^{c}	74.88^{d}	57.74^{c}	69.43^{b}	67.52^{b}	67.06^{b}	2.34	**
(a + b)%	76.50^{a}	77.18^{a}	73.06^{b}	76.36^{a}	58.74^{d}	73.33^{b}	69.14^{c}	70.19^{c}	1.47	***
c per h	0.106^{b}	0.093^{b}	0.079^{a}	0.088^{a}	0.069^{c}	0.085^{a}	0.077^{c}	0.091^{b}	0.003	***
ED *(%)*										
0.02	65.64^{a}	69.26^{b}	61.93^{c}	62.27^{c}	45.79^{d}	60.09^{c}	55.15^{e}	58.00^{ce}	1.73	***
0.05	54.57^{b}	61.56^{a}	51.75^{bd}	48.97^{bd}	34.54^{c}	47.60^{de}	42.49^{f}	46.28^{e}	1.96	***
0.08	47.07^{a}	56.54^{b}	45.41^{a}	40.48^{c}	27.81^{d}	39.66^{c}	34.69^{e}	38.69^{ce}	2.10	***

[1]See text for the description of the crop residues

Means within the same row with different superscript are significantly different (p<*0.05, **0.01 or ***0.001)

The DM and OM *b* fraction for GNS CP *b* fraction for CPS) respectively was higher (P<0.05) and (P<0.001) than all the straws considered in this study. It was further observed that legumes straw had higher (P<0.05) DM and OM *c* fraction, higher (P<0.001) CP *c* fraction except HBS than the cereal straw (TS). The value for DM and OM degradability parameters was significantly lower (P<0.05) in GNH than in the other legume crops residues considered.

The DM and OM effective degradability at 0.02, 0.05 and 0.08 per hour rate of passage are presented in Table 5-4. It was observed that ED of DM, OM and CP respectively was higher ($P < 0.001$) at 0.02. At 0.05 rate of passage, ED of DM and OM and CP was higher ($P < 0.01$) and ($P < 0.001$) respectively for GNS than all the crop residues. The ED was better in legume straws than cereals residues (TS and TTH). The ED of DM and OM at all the rates of passage were the lowest in GNH than in all the crop residues tested in this study.

There was variation in *in situ* degradability parameters among the crop residues. The DMD (which is an indicator of the level of cell walls in a feedstuff) varied between the feedstuff. This implies that the values of DM, OM and CP *a*, *b* and (*a* + *b*) would be dependent on the content and the composition of the cell walls of particular feedstuff. The higher values of degradability parameters in GNS than the other crop residues could be the content and the composition of the cell walls of GNS.

The value of the DM *a* fraction was similar to that reported by Abbator *et al* (2002) for GNS, however the *c* value was higher in the same residue than that reported by Abbator *et al* study. The *in situ* non-soluble but potentially degradable fraction *b*, degradation rate *c* and ED (at 0.02 and 0.05 passage rates) of DM and OM for CPS in current study were lower than those reported by Maheri-Sis *et al* (2011) and Aghajanzadeh-Golshani *et al* (2012), however the DM potential degradability (*a* + *b*) are similar to those determined by Maheri-Sis *et al* (2011). The values of *a*, *b* fractions of DM for CPS were higher in this study than those reported in Bruno-Soares *et al* (2000). The *b* fraction and ED of DM for VS reported by Hadjipanayiotou (2000) were similar to those obtained in the current study, however, the values of the *a* fraction was higher while that of *c* was lower than presented in this study. The DM *a* fraction for HBS is higher while *b* is lower in this study than in the study by Bruno-Soares *et al* (2000). The degradation parameter *a*, *b* and *c* of OM for the VS were higher in the study by Abreu *et al* (1998) than those determined in this study. The OM *a* fraction and (*a* + *b*) values for HBS are similar to those of Abreu *et al* (1998), and *b* and *c* fraction higher than in the current study. The degradation parameters, *a b* fraction of DM for FPS are lower than those reported by Bruno-Soares *et al* (2000). Differences in *in situ* degradability parameters between straw varieties and studies have been reported by Ørskov *et al* (1990) and are attributable to the differences in the proportion of leaf and stem, animal and diet effects, particle size, incubation characteristics, rumen conditions and microbial contamination (Huntingdon and Givens, 1995; Ramanzin *et al* 1997).

Wide range of DM degradability in various studies can be due to different chemical composition, leaves to stems proportion, method of feedstuff evaluation (*in vivo*, *in vitro and in situ*), straw varieties, maturity and impurity as well as technical variation such as bag pore size, sample size, washing procedures, grinding size, diet of experimental animal, species of animal, sample preparation, incubation time and washing method (Chumpawadee 2009; Bampidis & Christodoulou 2011; Kafilzadeh and Maleki, 2011; Maheri-Sis *et al*., 2011; Aghajanzadeh-Golshani *et al*., 2012; Anjum *et al*., 2014).

6.5 Conclusions

There are differences in chemical and nutritive characteristics amongst legumes and between cereal and legume crop residues found in Eritrea as hypothesized in this study. The results of chemical composition, degradation level and degradability kinetic of the legume straws and cereal crop residues tested in this study suggest that they may be used as component in the diet of ruminants. The legume straws could be used as a valuable feedstuff in supplimenting cereal crop residues based diets for ruminant. Based on degradation level and degradability kinetic of GNH it could be used in diet of ruminant only after improving its nutritive value by chemical treatment.

Further, the results showed that the chemical composition and degradability characteristics of the legume and cereal crop residues tested are within those reported in other areas with similar farming conditions as Eritrea. This implies that Eritrea can learn from regions that have optimised on the use of the crop residues which was evident from literature.

CHAPTER SEVEN

CHEMICAL COMPOSITION AND NUTRITIVE VALUE OF AGRO-INDUSTRIAL BY-PRODUCTS IN RUMINANT NUTRITION

7.1 Introduction

There is potential for increased livestock production in Eritrea through use of agro-industrial by-products as a supplement in ruminant diets. The bulk of livestock feed (estimated to be about 90%) comes from grazing on pastures and stubble. According to FAO (2006), grazed pastures in Eritrea are declining partly as a result of overstocking aimed at producing more protein to satisfy the increasing demand resulting from an increase in human population. This coupled with climate change and increased climatic variability has resulted in reduction in nutrients available for grazing stock thus compromising productivity. Besides the increase in the protein demand, competition for cereal grains between animal and human has been on the rise leaving very little for use in animal feeding. This implies that there need to search for alternative source of animal feed and/or sustainable supplementation.

Cereal and legume crop residues and agro-industrial by-products have played a major role in supplying supplemental nutrients to the grazed stock in Eritrea (FAO, 2006). Studies by Eyob *et al* (2016) evaluated the chemical characteristics and nutritive value of the cereal and legume residues respectively reported that they contained nutrients that can supply 9.63 to 36.31% of the total annual maintenance feed requirement of ruminants. Furthermore, chemical composition and nutritive value data available for most of crop residues and agro-industrial by-products available in the tropics indicate that they can satisfy significant proportion of the nutritional requirement of ruminant animals (Chimwano, 1990; Aregheore 2000; Abrar *et al*., 2004; Afashar *et al*., 2008; Naser *et al*., 2011; Mugerwa *et al*., 2012). However, basic chemical composition and nutritive value data are not available for the crop residues and agro-industrial by-products produced in Eritrea.

Despite their potential in supplementing ruminant nutrition, crop residues have been shown to have high fibre content besides being low in metabolized energy (ME) and crude protein (Devandra 1991; Preston 1995; Tingshuang *et al*., 2002) that result in low degradability in the rumen. Various approaches that have potential to increase digestibility and intake have been proposed. Besides the crop residues, Eritrea produce substantial amounts of agro-industries by-products (Eyob *et al*., 2016) with potential to be used in supplementing the grazing animals thus further availing the much needed nutrients to increase livestock production. However, the chemical composition and nutritive value data for the by-products are scanty. This implies that there is need to determine the chemical and nutritional characteristics of the by-products so as to optimally integrate them in the animal feeding strategies utilised in Eritrea. The aim of this study was to determine the chemical composition and nutritive value of agro-industrial by-products in ruminant nutrition in Eritrea.

7.2 Material and Methods

7.2.1 Sample Collection and Chemical Analysis

A total of 8 different samples including wheat bran (WB), short (WS) and middling (WM); brewers' dry grain (BDG), hops (BDH) and yeast (BDY); and sesame cakes (SCM and SCT) were collected from milling, beer and oil industries respectively. Dry samples were collected from milling and oil industries while those from the beer industries were wet. The wet samples were sun dried before grinding. Samples for each feedstuff were pooled and milled for the chemical and *in situ* (nylon bag technique) analysis. The chemical analysis and *in situ* degradation procedures are described in chapter 3, section 3.3 and 3.4 respectively.

7.3 Statistical Analysis

Data were subjected to analysis of variance using SPSS 21 version while the least significant differences (LSD) test was used in all cases to compare the samples means. Differences were accepted when $p \leq 0.05$.

7.4 Results and Discussion

7.4.1 Chemical composition of agro-industrial by-products

The chemical composition of the agro-industrial by-products are presented in Table 7-1. The DM varied between 88.39% for WB to 92.39% for the SCT. The WM recorded the highest OM content of 97.52% while the lowest recorded was from SCT at 89.07%. The SCT recorded the highest ash content at 10.93% followed by BDY at 10.16% with the least being obtained from WM at 2.48%. The CP was highest in SCT at 40.41% and lowest in WM at 10.11%. The SCM and SCT contained the highest ME of 11.17 and 11.18 MJ per kg DM respectively. The EE and ADL contents were generally low in all cases for all the by-products.

The CP content of the agro-industrial by-products ranged from 10.11% to 48.20%. The lowest ($P<0.05$) was recorded in WM while the highest ($P<0.05$) was obtained from the BDY. The WS had higher ($P<0.05$) CP amongst all the milling by-products with the BDG recording lower ($P<0.05$) CP when compared to the other brewers' by-products. The CF content for different by-products ranged from 1.14% in BDY to 22.58% in BDG. The NDF, ADF, and ADL ranged between 3.30% in BDY to 74.43 in BDG, 1.55% in BDY to 21.18% in BDG and 0.9% in BDY to 5.23% in BDH respectively.

Table 7.1: Chemical composition of agro-industrial by-products

	Agro-Industrial By-Products[1]							
Nutrients[2]	WB	WS	WM	BDG	BDH	BDY	SCM	SCT
DM	88.39^{a}	90.42^{b}	88.9^{a}	90.17^{b}	91.35^{b}	88.46^{a}	92.00^{c}	92.39^{c}
Ash	5.32^{b}	4.45^{c}	2.48^{a}	5.32^{b}	2.53^{a}	10.16^{d}	9.82^{d}	10.93^{f}
OM	94.68^{c}	95.55^{a}	97.52^{b}	94.68^{c}	97.47^{b}	89.84^{e}	90.18^{e}	89.07^{d}
CP	11.05^{h}	12.27^{g}	10.11^{f}	19.96^{e}	21.63^{d}	48.20^{c}	37.45^{b}	40.41^{a}
EE	2.98^{ab}	4.03^{b}	2.25^{a}	5.92^{d}	2.52^{ab}	0.47^{e}	16.84^{c}	15.43^{c}
NFE	67.96^{d}	66.46^{d}	79.2^{f}	46.22^{e}	60.12^{c}	40.02^{b}	27.86^{a}	26.17^{a}
CF	12.7^{e}	12.79^{e}	5.96^{a}	22.58^{b}	13.2^{e}	1.14^{c}	8.04^{d}	7.05^{d}
NDF	61.95^{c}	46.91^{d}	20.93^{b}	74.43^{e}	22.63^{b}	3.3^{f}	18.54^{a}	18.98^{a}
ADF	19.73^{c}	13.78^{a}	5.88^{d}	21.18^{f}	13.51^{a}	1.55^{e}	9.18^{b}	9.02^{b}
ADL	3.96^{ac}	3.66^{ac}	2.51^{ac}	4.07^{ac}	5.23^{a}	0.9^{c}	1.5^{c}	1.29^{c}
ME(MJ/ kg DM)	10.32^{b}	10.52^{b}	9.89^{a}	8.85^{c}	8.72^{c}	ND	11.17^{d}	11.18^{d}

Means within the same row with different superscript are significantly different (P≤0.05).

[1]See text for the description of the Agro-Industrial By-Products

[2]See text for the description of the nutrients; the values for the Ash, OM, CP, EE, NFE, CF, NDF, ADL are presented as per cent of the DM content

ND=Not Determined

Generally, the BDY had lower (P<0.05) CF, NDF and ADF content. Conversely, the BDG recorded higher values (P<0.05) for the parameters when compared to all other agro-industrial by-products. The WM resulted in lower (P<0.05) CF, NDF and ADF than the other milling by-products. The ME value of the agro-industrial by-products ranged from 8.72 to 11.18 MJ per kg DM with the BDH recording the lowest value (P<0.05) of 8.72 MJ per kg DM. The sesame cakes (SCM and SCT) recorded higher values (P<0.05) of 11.17 and 11.18 MJ per kg DM respectively.

There was variation in chemical composition between by-products and within by-products from a common crop. Getachew *et al* (2004) while studying the chemical composition, DM and *in vitro* gas production of different ruminant feedstuff noted that the difference in chemical composition as well as the feeding quality between alternative feedstuffs could be explained by the variation in the composition of the original material, the method used in processing (physical or chemical) and type of components extracted.

The values for chemical composition of the by-products obtained in this study were compared to findings from other studies with care being taken to consider those obtained from study areas and production systems similar to the conditions found in Eritrea to avoid bias. It was found that the CP and EE for WB reported by Paya *et al* (2008) were higher than those obtained in the present study while the NDF and ADF were lower. Similarly, Batajoo & Shaver (1998) reported higher values for the CP, EE and NDF in WM than those obtained from this study. However, the CP for BDG in the present study was similar to that reported by Paya *et al* (2012) as did the CP content in SCM which matched that reported by Mahala and Assad (2007) and Marghazani *et al* (2013).

7.4.2 *In situ* Degradability

The *in situ* DMD, OMD and crude protein (CP) degradability of agro-industrial by-products are presented in Table 7-2. The CPD data is presented for the 72 hours beyond which the entire sample had been degraded in most of the by-products.

7.4.2.1 Dry Matter Degradability

The sesame cakes (SCM and SCT) had the highest ($P<0.05$) DMD at all incubation times while the brewer's by-products had the least (BDG and BDH). The WM had lower values ($P<0.05$) compared to the other milling industry by-products except at 0h where WB recorded the lowest value of 32.57%.

Table 7.2: *In situ* DM, OM and CP degradability of agro-industrial by-products (% DMD, OMD and CPD)

AIBP[1]	Time of Incubation in the Rumen (Hrs.)								SEM
	0	4	8	16	24	48	72	96	
DMD									
WB	32.57^{ab}	48.33^{c}	53.72^{d}	61.57^{e}	66.93^{f}	74.98^{g}	77.56^{gi}	77.67^{gi}	0.169
WS	36.63^{a}	47.72^{c}	53.23^{d}	60.62^{e}	66.16^{f}	76.84^{g}	79.03^{gi}	79.03^{gi}	0.140
WM	34.34^{ab}	42.21^{d}	46.15^{c}	50.91^{f}	57.91^{e}	70.95^{k}	73.97^{ik}	73.98^{ik}	0.208
BDG	21.77^{c}	34.62^{e}	39.11^{f}	44.77^{d}	49.27^{g}	61.31^{h}	64.47^{h}	65.05^{h}	0.293
BDH	29.17^{b}	32.87^{a}	37.43^{f}	43.14^{d}	47.72^{g}	60.04^{h}	61.56^{h}	61.68^{h}	0.057
SCM	63.88^{d}	65.35^{b}	67.45^{a}	71.15^{c}	74.90^{h}	82.87^{j}	85.30^{j}	85.34^{j}	0.178
SCT	62.01^{d}	64.39^{e}	67.50^{a}	71.53^{c}	74.91^{h}	82.98^{j}	85.36^{j}	85.36^{j}	0.081
SEM	4.200	3.334	3.140	3.001	2.882	2.403	2.421	2.378	
OMD									
WB	32.59^{a}	47.10^{e}	52.40^{b}	59.75^{d}	65.19^{c}	73.01^{f}	76.27^{k}	76.27^{k}	0.085
WS	33.94^{a}	45.56^{e}	52.46^{b}	60.47^{d}	65.44^{c}	75.78^{g}	78.15^{j}	78.15^{j}	0.040
WM	33.87^{a}	40.57^{d}	45.57^{c}	49.40^{b}	56.23^{e}	69.67^{h}	73.11^{i}	73.12^{i}	0.023
BDG	19.23^{b}	33.68^{c}	38.00^{d}	44.22^{a}	48.78^{f}	60.38^{e}	63.38^{h}	63.98^{h}	0.091
BDH	27.63^{c}	31.43^{b}	36.18^{a}	42.06^{e}	45.84^{d}	58.87^{i}	60.72^{g}	60.89^{g}	0.036
SCM	64.03^{d}	65.71^{a}	67.88^{e}	71.53^{c}	75.44^{b}	83.18^{j}	85.78^{f}	85.78^{f}	0.016
SCT	63.51^{d}	65.89^{a}	68.43^{e}	71.34^{c}	75.10^{b}	83.37^{j}	85.86^{f}	85.86^{f}	0.089
SEM	4.498	3.586	3.330	3.112	3.044	2.530	2.542	2.502	
CPD									
WB	28.22^{e}	50.26^{b}	67.36^{fj}	74.14^{dgj}	77.58^{g}	79.79^{ghi}	79.96^{gh}	-	0.348
WS	35.22^{c}	54.98^{a}	69.82^{f}	76.70^{d}	78.50^{g}	80.96^{hi}	81.08^{hi}	-	0.216
WM	22.05^{d}	45.62^{c}	56.11^{e}	66.97^{b}	73.03^{g}	77.10^{h}	77.58^{h}	-	0.179
BDG	27.19^{e}	36.64^{d}	48.39^{c}	67.68^{f}	77.52^{g}	83.78^{i}	84.18^{i}	-	0.114
BDH	30.13^{a}	45.03^{c}	56.02^{e}	69.63^{f}	77.53^{g}	83.76^{i}	84.15^{i}	-	0.188
SCM	77.80^{b}	82.57^{e}	90.75^{ad}	91.81^{ac}	92.78^{cf}	93.82^{f}	93.82^{f}	-	0.142
SCT	78.40^{b}	82.34^{e}	90.52^{ad}	91.87^{ac}	92.82^{cf}	94.28^{f}	94.61^{f}	-	0.088
SEM	6.287	4.727	4.321	2.968	2.067	1.737	1.719	-	

Means within the same row with different superscript are significantly different ($P \leq 0.05$) while those within the same column with different superscript are significantly different ($P<0.05$)

[1]See text for the description of the crop residues

7.4.2.2 Organic Matter Degradability

The *in situ* OMD differed amongst and within the sesame cakes, milling and brewery by-products. However, a pattern similar to the one in the DMD was obtained with the cakes having the highest OMD followed by the milling by-products with least content being obtained from the brewery by-products.

7.4.2.3 Crude Protein Degradability

The CPD pattern differed from that of the DMD and OMD except for the sesame cakes which remained higher ($P<0.05$) than the brewery and milling by-products. The highest CPD was obtained from SCT at 94.61% in the 72th hour of incubation while the lowest was from WM at 22.05% before start of the incubation in the rumen. Generally, an increase in the incubation time led to increase in the CPD for all by-products**.**

The DM, OM and CP disappearance from the nylon bags incubated in the rumen increased with increase in time. The rate of increase however reduced with increase in the incubation time. In all cases, there was minimal change in DMD, OMD and CPD between hours 72 and 96. Although, the level of degradability was different at the various incubation times both between and within the feedstuff, it was revealed that there was no significant difference ($P<0.05$) within the feedstuff and between the by-products from milling, or brewers' industry after 48 h.

7.4.3 Degradability Characteristics

The percentage DM, OM and CP rapidly soluble fraction (*a*), potentially degradable fraction (*b*), rate of degradation of *b* fraction (*c*) and the effective degradability (ED) of different by-products are presented in Table 6-3.

Table 7.3: The percentage DM, OM and CP degradability characteristics and the effective degradability values of different agro-industrial by-products

	Agro-industrial by-products[1]							SEM
	WB	WS	WM	BDG	BDH	SCM	SCT	
DM								
a	30.61[ab]	34.86[a]	31.89[ab]	20.97[c]	28.12[b]	63.71[d]	61.85[d]	4.342
b	47.64[c]	44.73[cd]	42.86[d]	44.28[cd]	33.89[a]	21.70[b]	23.58[b]	2.746
(*a* + *b*)	78.25[f]	79.59[e]	74.75[d]	65.25[b]	62.01[c]	85.41[a]	85.43[a]	2.363
c per h	0.042[a]	0.044[ab]	0.040[a]	0.049[b]	0.047[b]	0.071[c]	0.071[c]	0.004
ED (%)								
0.02	63.13[b]	65.69[b]	60.65[b]	52.48[c]	51.90[c]	80.61[a]	80.22[a]	3.218
0.05	53.16[a]	56.37[a]	51.83[a]	43.16[b]	44.84[b]	76.45[c]	75.70[c]	3.603
0.08	48.10[c]	51.58[c]	47.44[c]	38.18[a]	41.12[a]	73.95[b]	72.98[b]	3.785
OM								
a	30.41[a]	32.07[a]	31.51[a]	18.26[b]	26.50[c]	63.86[d]	63.34[d]	4.651
b	46.51[b]	46.65[b]	42.36[c]	45.94[b]	34.75[d]	21.99[a]	22.60[a]	2.832
(*a* + *b*)	76.92[a]	78.72[b]	73.87[c]	64.20[d]	61.25[e]	85.85[f]	85.94[f]	2.484
c per h	0.041[c]	0.043[cd]	0.040[c]	0.046[b]	0.045[bd]	0.071[a]	0.071[a]	0.004
ED (%)								
0.02	61.90[c]	64.03[d]	59.97[e]	50.50[a]	50.71[a]	80.98[b]	80.93[b]	3.238
0.05	52.21[c]	54.28[a]	51.24[b]	40.77[d]	43.45[e]	76.76[f]	76.60[f]	3.755
0.08	47.34[b]	49.30[c]	46.89[b]	35.65[a]	39.67[d]	74.23[e]	73.99[e]	3.993
CP								
a	28.22[a]	35.22[b]	22.05[c]	27.12[a]	30.09[d]	77.80[e]	78.40[e]	6.289
b	51.74[b]	45.85[a]	55.53[c]	57.08[d]	54.07[e]	16.03[f]	16.22[f]	4.693
(*a* + *b*)	79.96	81.08	77.58	84.20	84.16	93.82	94.61	1.714
c per h	0.175[a]	0.176[a]	0.119[b]	0.077[c]	0.082[c]	0.186[d]	0.186[d]	0.013
ED (%)								
0.02	74.65[a]	76.39[b]	69.58[c]	72.49[d]	73.51[e]	92.27[f]	93.04[g]	2.481
0.05	68.46[g]	70.91[f]	61.13[e]	61.82[d]	63.62[c]	90.43[b]	91.18[a]	3.334
0.08	63.72[a]	66.72[b]	55.23[c]	55.23[c]	57.40[d]	89.01[e]	89.74[f]	3.884

Means within the same row with different superscript are significantly different (<0.05)
[1]See text for the description of the agro-industrial by-products
[2] Not significant

The respective values of the DM, OM and CP *a*, *b*, *c*, (*a* + *b*) and ED parameters varied amongst by-products. The highest values of DM, OM and CP *a* fraction were obtained from SCT at 61.85%, SCM at 63.86% and 78.40% from SCT respectively. The respective *b* values were 44.73% in WB, 46.65% in WS and 57.08% in BDG. The DM (*a* + *b*) varied between 62.01% in BDH and 85.43% in SCT. Respective values for the OM (*a* + *b*) were 61.25% in BDH and 85.94% in SCT while they were between 77.58% in WM and 94.61% in SCT for the CP. The rate of the degradation of *c* fraction varied minimally between the DM whose range was between 0.040 in

WM and 0.071 in SCM and SCT as the two by-products resulted in a similar value. The rate in OM was similar to that in DM. The CP *c* values were higher than the corresponding DM and OM *c* values and ranged between 0.077 for BDG and 0.186 for SCM and SCT which had a common value. In general, the value of *c* was highest in SCM and SCT in all cases. The SEM was generally high for the percentage DM, OM and CP degradability characteristics and the effective degradability values of different agro-industrial by-products. This could result from variation in the processing procedure rather than the differences in the by-products.

The values for DM ED at 0.02, 0.05 and 0.08 hourly rate of passage ranged between 51.90% to 80.61%, 43.16% to 76.45% and 38.18% to 73.95% respectively. Similarly, respective rates in the OM were 50.50% to 80.98%, 40.77% to 76.76% and 35.65% to 74.23% while in the CP the rates ranged between 69.58% to 93.04%, 61.13% to 91.18% and 55.23% to 89.74% respectively. The sesame cakes (SCT and SCM) had higher ($P<0.05$) DM, OM and CP ED than all the by-products at all the passage rates.

The DM, OM and CP ED varied among by-products and passage rates. However, there was no significant difference for the DM ED amongst the milling (WB, WS and WM), the brewery (BDG and BDH) and sesame cakes (SCM and SCT) by-products. The OM ED for the WS within the milling by-products was always higher ($P<0.05$) as did the BDH and SCM between the brewery and sesame cake by-products respectively.

The results of this study have provided vital information on the chemical composition as well as the nutritive value of different agro-industrial by-products produced in Eritrea. As expected, the nutritional values varied within (by-products from a common crop) and between by-products. This implies that they would supply different quantity and quality nutrients when used in livestock feeding. Getachew *et al.* (2004) noted that the difference in feeding quality between alternative feedstuffs could be explained by the variation in the composition of the original material, the method used in processing (physical or chemical) and type of components extracted.

The DMD, which is an indicator of the level of cell walls in a feedstuff, varied within and between by-products. This implies that the values of DM, OM and CP *a*, *b* and (*a* + *b*) would be dependent on the content and the composition of the cell walls of particular feedstuff.

Bruno-Soareset *et al.* (2000) reported that there are strong correlations among the *b* fraction and the NDF, ADF and ADL contents of test feedstuff. The study further demonstrated that the content and the composition of the cell walls are the best variables to describe the variation of DM (*a* + *b*) of the feedstuff. It is Woods *et al* (2003) who determined the relationship between the degradability parameters *a*, *b* and *c* and the chemical composition of 60 test feeds and noted that the slowly fermentable structural carbohydrates in feedstuff are the determinant of the degradation characteristics in the rumen. The limiting factor of fiber digestibility in ruminant is presence of lignin, which make cellulose and hemicellulose unavailable by combining with them (Srivastava *et al*., 2012). Generally, SCM and SCT had high levels of DMD, OMD and CPD at all incubation times. This can be attributed to the low lignin content and availability of rumen degradable nitrogen thus optimizing on the microbial activity which would then enhance the sesame cake by-products to be degraded to their potential. Despite high NDF in WB, its corresponding DMD and CPD were higher than in the WM which can be explained by high levels of soluble containing fraction of DM and CP as well as the high hemicellulose in NDF content that tend to have high degradability. The values for different parameters used in evaluating the ruminant feedstuffs obtained in this study were compared to findings from other studies with care being taken to consider those obtained from study areas and production systems similar to the conditions found in Eritrea to avoid bias.

The values for the degradability parameters *a*, *b* and *c* obtained from this study match most of those reported in other studies. For instance, the values of the DM *a* and *c* fractions for WB were similar to those obtained by Paya *et al.* (2012) while the DM *c* fraction in BDG reported by Batajoo and Shaver (1998) is similar to that of the present study. Marghazani *et al.* (2013) also presented CP *c* fraction similar to the one obtained in this study. This is possible since the industrial processing would be expected to follow the same principles and probably use similar machinery in the extraction resulting in by-products that only differ as a result of other factors, such as the composition of the original material, rather than the extraction procedures. Besides, it is common to find commonality in different crop production conditions from different countries implying that the differences might not be such huge. It is however possible to find small differences in similar by-products in different studies such as the one by Paya *et al* (2012) who reported a slightly higher DM *c* fraction in BDG this would be explained by the use of test feed that was low in NDF. Similarly, Mahala *et al* (2007) reported slightly lower DM *a c* and higher *b* fractions in SCT and SCM than those obtained in the current study. The small differences were expected and could be explained by factors such as variation in laboratory equipment and techniques as well as differences in the milling screen sizes among others.

7.5 Conclusion

This study has shown that different agro-industrial by-products differ in terms of chemical composition as well as in nutritional value. By determining the chemical composition and the nutritional value of different by-product, the findings have demonstrated the opportunity available in utilizing them in ruminants feeding. Based on the results of the chemical composition and degradability characteristics of the agro-industrial by-products tested in this study it can be indicated that they could be used as valuable feedstuff in supplementing cereal crop residues based diet for ruminants. Generally, the wide variation in chemical composition, DMD, OMD, CPD, and ME offer farmers huge flexibility in formulating rations according to the productive performance of target animals. It is evident that legume by-products are superior in terms of nutritional value when compared to the cereal based ones. However, it is important to evaluate the availability of the nutrients to the target animal by carrying out feeding trials and determining the performance (such as growth rate) of animals fed on diet incorporating different by-products.

CHAPTER EIGHT

GROWTH RATE IN LAMBS FED ON UREA TREATED SORGHUM AND MILLET STOVER

8.1 Introduction

Livestock production plays important social and economic roles in rural households in the developing countries (Kosgey *et al*., 2003). The animals reared satisfy tangible and intangible roles (Upton, 1985). The former includes provision of milk and meat, cash income from sale of live animals and/or their products, manure for fertilising crop lands and skin and hides used in leather industry or as a source of foreign exchange when sold to other countries (Kosgey *et al*., 2003). According to Jaitner *et al* (2001) livestock production especially so in the tropics play intangible roles such as acting as a cushion against emergencies and informal insurance against unpredicted occurrences, a means of risk-aversion especially in crop-livestock smallholder systems, an indicator of social status and use in important cultural and ceremonial functions. Baker & Rege (1994) observed that livestock such as the goats are very useful in utilising natural pasturelands where crop production is not feasible.

Despite the socio-economic roles played by livestock production in different regions in the tropics, there are identifiable constraints that have hampered increased productivity and profitability and more so in grazed systems. The main ones which have been identified in Africa include shrinking grazed lands, disorganised and/or lack of reliable market channels for animal products, lack of clear and defined (developed) value chains for animal products, high infections with parasites and high incidences of diseases, poor or unavailable veterinary services and products, low literacy level amongst the smallholder producers (Gatenby, 1986).The key limiting factor in many grazed systems (which characteristically tend to be dry) is the fluctuation in livestock feed demand and supply within and between seasons (Gicheha *et al*., 2014). In the tropics this is at times so severe that producers have lost entire flocks mainly when the dry spell prolong for longer than normal (Kosgey *et* *al*., 2003). Attempts by governments to intervene during such periods have proved complex both financially and logistically (Kosgey 2004).

In mixed crop-livestock production systems, crop residues have been used in plugging the feed deficit and/or in supplementing the low nutrients grazed pastures. Different countries through their Nation Research Systems (NRS) have estimated the amounts of crop residues available to the livestock, their chemical composition and nutritional value and responses from various species fed on treated or untreated residues (FAO 2006). This has however not happened in Eritrea which according to FAO (2006) has substantial amount of feed resources from crop residues with potential to harness animal production considering that 90% of the livestock in the country is grazed on unimproved pastures. The main crop residues produced in Eritrea are mainly the sorghum (*Sorghum bicolor*), millet (*Pennisetumamericanum*), teff (*Eragrostictef*), barley(*Hordeumvulgare*), maize (*Zea mays*) and wheat straw(*Triticumaestivum*), straw of leguminous crops such as chick pea (*Cicer arietinum*), vetch (*Viciasativa*), field pea (*Pisumsativum*), horse been (*Viciafaba*), lentil *(Lens esculanta*), and groundnut (*Arachishypogaea*).

The amount of crop residues produced in Eritrea have been estimated (Eyob *et al*., 2016) while the chemical composition and nutritive value of cereal (Chapter 5) and legume (Eyob *et al.,* 2017) crop residues have been determined. Based on the findings from the study by Eyob *et al* (2016) that sorghum and millet stover contributed more than 60% of the crop residue, there was need to evaluate the effects of treating the stover using urea on chemical composition, nutritive value and the impact of feeding growing lambs on the treated stover. This information would be very helpful in formulating policies on the utilisation of the crop residues in Eritrea.

In chemical treatment the most commonly used alkaline agents are sodium hydroxide (NaOH), ammonia (NH_3) and urea. Chemical treatments appear to be the most practical for use on-farm, as no expensive machinery is required, the chemicals are relatively cheap and the procedures to use them are relatively simple. However, the chemicals themselves are not harmless and safety precautions are needed for their use (Srivastava *et al.,* 2012). Therefore, the strategy for improving production should be to optimize the efficiency of utilization of the available feed resources, and thereby attempt to maximize animal production. Urea treatment of cereal straws is one of the technologies that has been strongly recommended for field application and tried extensively. Urea treatment is reported to improve the nutritive value of cereal straws by increasing digestibility, palatability and crude protein content (Hossain 1981: Sharma *et al*., 1995; Chenost & Sansoucy 1991; Badve 1991; Ranjhan 1999; Israel and Pearson 2000: Hameed *et al*., 2012: Mohammed *et al*., 2016). The objective of this study was to assess the rumen degradability and kinetic properties of sorghum and millet stover subjected to urea treatment and determined the growth rate of growing lambs when fed the treated stovers.

8.2 Material and Methods

The feeding trials were conducted at Hamelmalo Agricultural College (HAC) located at sub-zone Hamelmalo of Anseba zone in Eritrea. The descriptions of Zoba Anseba are described in chapter 3, sections 3.1. Two trials were carried out and differed on which stover (sorghum or millet) was being tested.

8.2.1 Sample Collection

Sorghum and millet stover were collected from HAC farm as well as from farmers around the college. The sesame seed cake used in fortifying the stover was purchased from oil cottage industries at Gash Barka region. The stover samples collected were chopped using a hand-operated chaff cutter into smaller pieces measuring approximately 1 to 2 cm in length. Each batch of 10 Kg chopped sorghum and millet stover was sprinkled with a 5% w/v of urea solution (Hossain 1981: Sharma *et al*., 1995; Chenost & Sansoucy 1991; Badve 1991; Ranjhan 1999; Israel and Pearson 2000: Hameed *et al*., 2012: Mohammed *et al*., 2016). The treated stover were immediately put in polyethylene bags (500 gauges) measuring 70 cm x 120 cm and ensiled for two weeks. A small sample from the urea treated stover were pooled, dried and ground for chemical and *in situ* procedure. The remainder was used in the feeding trials. The sampling, chemical analysis and *in situ* degradation procedures are described in chapter 3, sections 3.1, 3.3 and 3.4 respectively.

8.2.2 Feeding trials

8.2.2.1 Sorghum and millet diets formulation

A total of six rations each for the sorghum and millet were formulated as presented in Table 8-1. Besides being either treated or untreated with urea, the rations were fortified with groundnut haulms and/or sesame cake meal. The diets were formulated to be iso-caloric.

Table 8.1: Experimental diets based on urea treated or untreated sorghum and millet

Diet	Sorghum	Millet
1	Sorghum stover (50%) and threshed heads of sorghum (50%); USS	Millet stover (50%) and threshed heads of millet (50%); UMS
2	Urea-treated sorghum stover (50%) and threshed heads of sorghum (50%); TSS	Urea treated millet stover (50%) and threshed heads of millet (50%); UMS
3	Sorghum stover (35%) and threshed heads of sorghum (35%) plus groundnut haulms (30%)	Millet stover (35%) and threshed head of millet (35%) plus groundnut haulms (30%)
4	Urea treated sorghum stover (35%) and threshed heads of sorghum (35%) plus groundnut haulms (30%)	Urea treated millet stover (35%) and threshed head of millet (35%) plus groundnut haulms (30%)
5	Sorghum stover (35%) and threshed heads of sorghum (35%) plus sesame seed cake (30%)	Millet stover (35%) and threshed head of millet (35%) plus sesame seed cake (30%)
6	Urea treated sorghum stover (35%) and threshed heads of sorghum (35%) plus sesame seed cake (30%)	Urea treated millet stover (35%) and threshed head of millet (35%) plus sesame seed cake (30%)

8.2.2.2 Animals feeding and general management

This study evaluated the effect of the experimental diets based on urea treated or untreated sorghum and millet on intake, digestibility and growth of Eritrean Barka sheep. A total of thirty six Barka yearling ram lambs weighing approximately 22 Kg live weight were used. They were randomly allotted, in complete randomized design, to six feeding treatment groups of three animals each for the sorghum and millet based diets. The animals were kept in a roofed half-walled shed with concrete floor. The animals were offered poly-vitamins dissolved in water. The animals were treated against ecto- and endo-parasites. The experimental diets were first fed to the animals for a 15 days period without collecting data for acclimatization.

8.2.2.3 Intake, growth and digestibility

The diets were provided at 08.00 hours in the morning. Data on feed offered and refusals were recorded to determine the daily feed intake. The water was availed at all times in the sheds. The experiment was run for a total of 84 days with the animals being weighed every two weeks during the time. Feces were collected for seven days to determine digestibility. Sample taken from the daily collected feces per ram was sun dried and stored until used for chemical analysis. Chemical analysis *in situ* degradation procedures are described in chapter 3, section 3.3 and 3.4 respectively.

8.3 Statistical Analysis

Data were subjected to analysis of variance using SPSS 21 version while the least significant differences (LSD) test was used in all cases to compare the samples means. Differences were accepted when $p \leq 0.05$.

8.4 Results and discussions

8.4.1 Chemical composition of urea treated and untreated stover

The chemical composition of the urea treated and untreated sorghum and the millet stover are presented in Table 7-2. The crude CP content of the sorghum stover increased ($P<0.05$) with urea treatment from 3.59% in the untreated sorghum stover (USS) to 8.93% and in millet stover from 3.81% in the untreated millet stover to 11.93%.

Table 8.2: Chemical composition of urea treated and untreated sorghum and millet stoves

Nutrients[2]	Crop residues[1]				SEM
	USS	TSS	UMS	TMS	
DM (%)	91.97[b]	56.99[a]	91.49[b]	43.47[c]	8.051
Ash	8.56[a]	11.53[bc]	12.18[dc]	11.93[ec]	0.552
OM	91.44[c]	88.47[de]	87.82[ae]	88.08[be]	0.552
CP	3.59[b]	8.93[c]	3.81[b]	11.93[a]	1.335
EE	1.10[a]	0.83[a]	5.40[c]	9.14[b]	1.297
NFE	51.30[d]	34.06[c]	32.17[bc]	32.33[ac]	3.040
CF	35.44[a]	44.65[b]	46.45[bc]	46[db]	1.771
NDF	74.13[d]	70.64[c]	79.26[b]	72.96[d]	1.194
ADF	46.61[ab]	45.16[a]	53.15[b]	47.91[a]	1.156
ME(MJ/kg DM)	7.05[a]	8.25[b]	6.64[a]	7.53[c]	0.230

Means within the same row with different superscript are significantly different ($P \leq 0.05$).
[1]See text for the description of the crop residues
[2]See text for the description of the nutrients
The values for the Ash, OM, CP, EE, NFE, CF, NDF, and ADF are presented as percent of the DM content

Conversely, the NDF and ADF content reduced with urea treatment. Besides, there was a decrease ($P<0.05$) in the content of NDF from 74.13% to 70.64% in the sorghum stover. A reduction from 79.26% to 72.96% was also obtained from treating the millet stover with urea. The ME increased from 7.05 to 8.25 MJ per kg DM in sorghum and from 6.64 to 7.53 MJ per kg DM in millet stover following the treatment with urea. In the current study it was found that the chemical composition (potential nutritive value) of sorghum and millet was improved with urea treatment by increasing the CP and ME while at the same reducing the values of the NDF and ADF.

The reduction in fiber fraction and increase in CP and ME due to ensilage of urea treated stover could be explained by the breakdown of the glucosidic linkage in the stover by the ammonia gas released from the hydrolysis of urea as proposed by Srivastava *et al* (2012). According to Srivastava *et al* (2012), the presence of lignin in stover makes cellulose and hemicellulose unavailable by combining with them. The lignification of Cellulose and hemicellulose, the polysaccharides carbohydrate components of cell wall, by lignin is high in crop residues and could be broken down by alkali or urea treatment (Srivastava *et al.*, 2012). It has been reported (Chenost & Kayouli 1997; Lam *et al*., 2001) that alkali agents such as the urea are absorbed into the cell wall and chemically break down the ester bonds between lignin and hemicellulose and cellulose.

The finding in this study is in agreement with Mohammed, *et al* (2016) who reported an increase in CP and a decrease in NDF when millet stover was treated with urea. Similar observation was made by Yadete (2014) while studying the effects of urea treatment on wheat straw. Hameed *et al* (2012) went further to determine the effects of different urea treatment levels (2%, 4%, or 6%) on ensiled groundnut hull. They observed that the CP contents increased while cells wall diminished significantly in all the treatments irrespective of the inclusion level. Studies by Ranjhan (1999) and Israel and Pearson (2000) demonstrated that urea treatment improves the nutritive value of crop residues (cereal straws) by increasing digestibility, palatability and CP.

8.4.2 Dry matter degradability (DMD)

The DMD of urea (un)treated sorghum and millet stover is presented in Table 8-3. The DMD at 0, 4, 8, 16, 24, 48, 72 and 96 varied between treated and untreated stover, amongst incubation time and between sorghum and millet stover. The highest value of 58.41 was obtained from TSS at 96 h while the lowest was 16.58 from TMS at 0 h. The TSS had the highest DMD at all incubation times followed by USS except at 48, 72 and 96 h when TMS recorded higher values when compared to USS.

Table 8.3: *In Situ* dry matter degradability of urea treated and untreated sorghum and millet stover (% DMD)

Crop Residue[1]	Time of Incubation in the Rumen (Hrs)							
	0	4	8	16	24	48	72	96
USS	20.38^{a}	24.64^{bc}	28.15	33.86^{a}	38.38^{b}	44.48^{a}	46.55^{bc}	46.56^{a}
TSS	21.53^{a}	24.79^{c}	28.25	35.50^{a}	41.58^{c}	55.68^{b}	58.40^{a}	58.41^{b}
UMS	16.58^{bc}	22.06^{b}	26.19	30.84^{b}	34.07^{a}	40.70^{ac}	43.03^{b}	43.03^{a}
TMS	16.74^{c}	22.15^{b}	26.94	33.56^{a}	38.86^{b}	48.97^{d}	50.92^{c}	51.51^{d}
SEM	**0.84**	**0.55**	**NS**	**0.82**	**1.06**	**2.27**	**2.21**	**2.22**

Means within the same column with different superscript are significantly different ($P \leq 0.05$).

[1]See text for the description of the crop residues

Generally, the DM degradability of the treated sorghum and millet stover was consistently higher than that of the untreated stover at all the incubation time.

8.4.3 Organic matter degradability (OMD)

The OMD of urea treated and untreated sorghum and millet stover is presented in Table 8- 4. It varied the untreated, stover type and incubation time. The highest value of 58.71 was obtained from TSS at 96 h while the lowest was 16.58 from UMS at 0 h. The TSS had the highest DMD at all incubation times except at 0 h where USS recorded the highest value of 19.36%.

Table 8.4: *In situ* organic matter degradability of urea treated and untreated sorghum and millet stover (% OMD).

CR[1]	Time of Incubation in the Rumen (Hrs.)							
	0	4	8	16	24	48	72	96
USS	19.36[a]	23.73[b]	27.61[c]	32.88[a]	37.84[b]	44.86[a]	46.47[d]	46.48[a]
TSS	19.23[a]	23.87[b]	27.67[c]	34.59[b]	40.10[c]	54.31[b]	57.44[c]	58.71[b]
UMS	8.14[b]	11.13[a]	17.16[b]	22.61[c]	26.14[d]	32.97[c]	37.40[b]	37.40[c]
TMS	10.83[b]	17.42[c]	22.59[a]	29.92[d]	35.00[a]	47.55[d]	50.82[a]	51.11[d]
SEM	1.919	1.987	1.641	1.773	2.005	2.917	2.766	2.931

Means within the same column with different superscript are significantly different (P≤0.05).

[1]See text for the description of the crop residues

8.4.4 Crude protein degradability (CPD)

The CPD of urea treated and untreated sorghum and millet stover is presented in Table 8-5. The highest value of 76.64% was obtained from TSS at 72 h while the lowest was 1.07% from UMS at 0 h. The trend for the CPD was similar to that of the DMD and OMD where the TSS had the high values of CPD at all incubation times except at 0 h where TMS recorded the highest value of 6.48%.

Table 8.5: The *in situ* crude protein degradability of urea treated and untreated sorghum and millet stover

Crop Residue[1]	Time of Incubation in the Rumen (Hrs.)						
	0	4	8	16	24	48	72
USS	1.22[b]	12.09[a]	20.28[b]	33.78[a]	39.82[c]	42.78[a]	42.86[b]
TSS	2.27[a]	50.39[b]	70.67[a]	74.70[b]	75.77[a]	76.51[b]	76.64[c]
UMS	1.07[b]	11.13[a]	19.05[b]	31.63[a]	37.47[c]	40.32[a]	41.23[b]
TMS	6.48[a]	36.23[c]	51.85[c]	69.49[d]	72.43[b]	73.26[c]	73.34[a]
SEM	0.085	6.287	8.255	7.483	6.728	6.325	6.246

[1]See text for the description of the crop residues

Means within the same column with different superscript are significantly different (P≤0.05)

8.4.5 Degradability Characteristics

The DM, OM and CP degradability characteristics and effective degradability (ED) values of urea treated and untreated sorghum and millet stover are presented in Table 8-6. The DM, OM and CP *a, b, c* fraction varied between treated and untreated stover, passage rate and between stover.

Table 8.6: Dry matter, organic matter and crude protein degradability characteristics and effective degradability values of urea treated and Untreated sorghum and millet stover

	Crop residues				**SEM**
	USS	**TSS**	**UMS**	**TMS**	
DM					
a (%)	15.78[a]	20.33[b]	11.40[c]	15.25[b]	1.200
b (%)	32.18[b]	38.40[a]	33.06[b]	36.62[a]	0.965
(a + b) %	47.96[a]	58.73[c]	44.47[d]	51.87[b]	2.003
c per h	0.028[b]	0.044[a]	0.025[b]	0.040[c]	0.003
ED (%)					
0.02	35.63[a]	46.84[b]	31.40[c]	39.89[d]	2.156
0.05	29.76[b]	38.75[a]	25.51[c]	32.16[b]	1.813
0.08	27.15[a]	34.57[c]	22.97[b]	28.30[a]	1.574
OM					
a (%)	14.89[ab]	17.61[a]	2.80[c]	8.99[bc]	2.164
b (%)	32.90[b]	41.50[ac]	35.58[b]	42.44[a]	1.514
(a + b)	47.79[a]	59.11[b]	38.37[c]	51.43[d]	2.819
c per h	0.028[bd]	0.040[c]	0.022[b]	0.037[d]	0.003
ED (%)					
0.02	35.16[b]	45.63[a]	23.63[c]	36.88[b]	2.961
0.05	29.14[a]	36.86[b]	17.22[c]	27.86[a]	2.650
0.08	26.43[ac]	32.47[a]	14.57[b]	23.48[c]	2.449
CP					
a (%)	1.01[a]	2.27[b]	0.83[a]	6.48[b]	0.881
b (%)	41.85[a]	74.37[b]	40.41[a]	66.86[b]	5.669
(a + b)	42.86[b]	76.64[a]	41.24[b]	73.34[a]	6.245
c per h	0.056[a]	0.182[b]	0.054[a]	0.178[b]	0.024
ED (%)					
0.02	31.91[a]	69.27[b]	30.30[c]	66.60[d]	6.002
0.05	23.23[b]	60.60[a]	21.83[b]	58.70[a]	5.997
0.08	18.38[a]	53.91[b]	17.17[a]	52.64[b]	5.672

Means within the same row with different superscript are significantly different (P≤0.05).
[1]See text for the description of the crop residues

Generally, the DM and CP *a, b, c* fraction values and ED (0.02 and 0.05 passage rate) in the urea treated stover were higher ($P<0.05$) than in the untreated stover. The DM degradability characteristics and ED of the treated stover was consistently higher than that of the untreated stover.

The chemical composition of the six experimental diets fed to the Barka sheep are shown in Table 7. Various nutritional components varied between sorghum and millet and amongst diets. However, the diets were formulated to be iso-caloric thus allowing for the comparison of the growth rate of sheep fed on different diets.

Table 8.7: Chemical composition of the sorghum and millet diets fed to Barka sheep

Nutrients[1]	**Diets**[2]					
	DietT1	**DietT2**	**DietT3**	**DietT4**	**DietT5**	**DietT6**
Sorghum						
DM	91.66	74.17	91.15	79.49	91.91	80.25
OM	91.34	90.19	89.59	89.81	89.62	89.89
CP	5.16	7.57	6.50	8.19	15.74	15.79
EE	1.29	1.23	1.49	1.44	5.53	4.78
NFE	53.66	47.67	49.09	44.81	45.41	42.18
CF	31.21	33.72	33.54	35.37	23.96	27.14
NDF	75.47	74.46	68.94	68.21	58.52	60.56
ADF	39.07	36.70	39.86	38.26	30.05	29.85
ME (MJ/kg DM)	7.44	7.99	7.94	8.32	8.56	8.79
Millet						
DM	91.37	67.36	90.99	74.95	91.71	75.71
OM	91.36	92.71	90.64	91.58	90.67	92.17
CP	7.26	11.10	7.97	10.65	17.21	17.05
EE	3.94	4.60	3.34	3.81	7.38	6.82
NFE	49.31	55.52	52.74	50.75	49.06	50.04
CF	30.87	25.11	33.30	29.30	23.72	21.64
NDF	70.86	65.82	65.72	62.20	55.30	56.56
ADF	36.86	29.32	38.32	33.07	28.51	25.40
ME (MJ/kg DM)	7.58	8.20	8.03	8.47	8.66	8.81

[1]See text for the description of the nutrients; the values for the Ash, OM, CP, EE, NFE, CF, NDF, ADL are presented as percent of the DM content
[2]See text for the description of the diets

8.5.6 Feed intake and body weight change in Barka sheep fed on the experimental diets

Dry matter and nutrient intake and body weight change in sheep fed the experimental diets are presented in Table 8-8. The intake varied amongst diets and between sorghum and millet stover. It was higher in urea treated diets when compared with the corresponding untreated diets.

Table 8.8: Dry matter and nutrient intake and body weight changes of Barka sheep

Parameter[1]	**DietT1**	**DietT2**	**DietT3**	**DietT4**	**DietT5**	**DietT6**	**SEM**
Intake(g/animal/day)							
DM	847.21^{a}	936.33^{b}	897.00^{c}	901.00^{c}	1035.85^{d}	1055.63^{e}	18.361
OM	773.84^{b}	844.45^{c}	812.92^{d}	809.17^{d}	939.09^{e}	948.95^{a}	15.836
CP	43.72^{a}	70.84^{b}	58.26^{c}	73.77^{d}	162.99^{e}	166.06^{f}	11.998
NDF	639.34^{b}	697.19^{c}	618.41^{a}	614.60^{a}	606.17^{d}	639.27^{b}	7.297
ADF	330.96^{a}	343.66^{b}	357.56^{c}	344.75^{b}	311.29^{d}	315.11^{e}	4.0193
ME(MJ/animal/day)	6.30^{a}	7.48^{b}	7.12^{d}	7.50^{b}	8.87^{c}	9.28^{e}	0.247
Intake(g/kg$^{0.75}$ /day)							
DM	75.75^{a}	78.80^{b}	78.60^{b}	78.77^{b}	79.50^{c}	79.74^{c}	0.318
OM	69.19^{b}	71.07^{ac}	71.24^{a}	70.74^{c}	72.07^{d}	71.68^{d}	0.193
CP	3.91^{a}	5.96^{b}	5.11^{c}	6.45^{d}	12.51^{e}	12.54^{e}	0.841
NDF	57.17^{b}	58.68^{a}	54.19^{d}	53.73^{c}	46.52^{f}	48.29^{e}	1.065
ADF	29.59^{a}	28.92^{b}	31.33^{c}	30.14^{d}	23.89^{e}	23.80^{e}	0.725
ME(MJ/kg$^{0.75}$ /day	0.56	0.63	0.62	0.66	0.68	0.70	NS
Avrage Daily Gain (g/day/animal)	50.96^{a}	99.89^{b}	69.35^{c}	72.25^{d}	217.09^{e}	225.55^{f}	17.305

Means within the same row with different superscript are significantly different (P≤0.05).
[1]See text for the description of the nutrients

Treating with urea and/or supplementing legumes to the crop residues resulted in an increase in body weight gain (BWG). Similar trend was observed in terms of the intake which increased with urea treatment and/or supplementation. It was observed that higher intakes of millet did not correspond to higher weight gains when compared with corresponding diets in sorghum. Sesame cake meal fortified rations resulted in higher nutrients intake and BWG.

8.4.7 Digestibility coefficients, utilization efficiency and cost of sorghum and millet residues based diets

Table 7-9 presents the digestibility coefficients, utilization efficiency and cost of sorghum and millet residues based diets. Generally, the digestibility increased with urea treatment in both sorghum and millet residues. Inclusion of legume residue (Diets 3 to 6) resulted in an increase in digestibility except in the case of Diet3 for the sorghum and millet. Efficiency of feed utilization which was presented in kg DM intake per kg body weight gain increased with inclusion of the legume residues as well as with urea treatment. There was marginal increase in the cost of daily ration per animal with the inclusion of the legume residues and/or urea treatment.

Table 8.9: Digestibility coefficients, utilization efficiency and cost of diets fed growing Barka sheep

Parameter[1]	Diet1	Diet2	Diet3	Diet4	Diet5	Diet6	SEM
Sorghum							
Digestibility coefficients (%)							
DM	56.57^{a}	78.65^{b}	74.14^{c}	78.50^{b}	81.47^{d}	83.40^{e}	2.16
Efficiency of feed utilization	16.63^{a}	9.37^{b}	12.93^{c}	12.47^{d}	4.77^{e}	4.68^{f}	1.07
Cost of daily ration per animal	0.35	0.40	0.34	0.38	0.77	0.73	
Cost per kg body weight gain per day	5.54^{a}	3.55^{b}	4.25^{c}	4.48^{d}	3.50^{e}	3.28^{f}	0.19
Millet							
Digestibility coefficients (%)							
DM	50.83^{a}	74.95^{b}	69.98^{c}	74.64^{b}	80.64^{d}	82.48^{d}	2.53
Efficiency of feed utilization	20.86^{a}	9.61^{b}	11.84^{c}	11.34^{d}	4.68^{e}	4.36^{f}	1.34
Cost of daily ration/animal	0.37	0.43	0.38	0.37	0.75	0.66	
Cost per kg body weight gain per day	7.65^{a}	4.04^{b}	4.28^{c}	4.04^{d}	3.43^{e}	2.78^{f}	0.38

[1]Costs presented in USD

Means within the same row with different superscript are significantly different ($P \leq 0.05$)

There were differences ($P<0.05$) in the cost per kg body weight gain per day amongst diets, between urea treated and untreated residues, and between diets with or without legume fortification. The cost was lower with urea treated and/or supplemented diet. Generally, the level of DM, OM and CP degradability was found to be higher in urea treated sorghum and millet stover than the untreated stover as reported in Eyob *et al* (2016b). The intake and digestibility of feed was high in diet with urea treated 88sorghum and millet stovers. The improvement in degradability characteristics observed with urea treatment could be the action of the alkali agents such as the urea that are absorbed into the cell wall and chemically break down the ester bonds between lignin and structural carbohydrates (hemicellulose and cellulose), and physically make the structural fibres swollen (Chenost & Kayouli 1997; Lam *et al*., 2001).This process enables the rumen microorganisms to attack the structural carbohydrates more efficiently thus enhancing the degradability and palatability of the residue (Prasad *et al.,* 1998; Shen *et al.,* 1999; Selim *et al.,* 2004). This would result in a higher nutrients intake and digestibility as demonstrated in this study.

Besides, the urea treatment animal performance can be enhanced by including fortifier such as residues with higher CP as is the case with the groundnut haulms and/or sesame cake meals in the current study. This is confirmed by the findings presented by Srivastava *et al* (2012) who demonstrated that supplementation of cereal residue with rich protein, energy and/or minerals led to optimized rumen function thus maximizing utilization of the straw and increasing intake.

8.5 Conclusion

The findings from this study have demonstrated that treating sorghum and millet stovers positively impact on the chemical composition, degradability kinetic and effective degradability in diets formulated for improved ram lamb growth. Incorporating protein rich (legume residue) in diets targeted to growing ram sheep would further enhance animal performance and subsequently the enterprise productivity and profitability. The costs related to urea and/or legume residue supplementation in diets utilising sorghum and/or millet stover is relatively small and justifiable in production systems constrained by feed constraints. Summarily, strategies of urea treatment and/or supplementation could be used as alternative method to improve the nutritional values of poor quality roughages.

CHAPTER NINE

GENERAL CONCLUSIONS AND RECOMMENDATIONS

Results from this study have shown that Eritrea produces substantial amounts of cereal and legume crops residue with potential for use in feeding livestock. The crop residues contribute approximately 9.63% to 36.3% of the total annual maintenance feed requirement of ruminants in the five zones of Eritrea. The contribution is dependent on the zone with those inclined to pastoralism relying less on the residues compared to those where crop production is considered more important than livestock rearing. Based on the results this study it could be indicated that Animal Production Based on Crop Residues in mixed crop/livestock systems of the country could result in significant economic benefits.

The agro-industrial by-products such as milling by-products, oilseed cakes and brewers waste were high value feeds available for feeding ruminants. On the other hands production managers in the respectivey factory pointed out that the factories were not producing to the full capacity of their potential due to shortage of ingredients and/or problem of machinery maintenances. Furthermore, it was observed by the researchers of this study that the by-product feed sources were not efficiently utilized by small-scale commercial livestock producers because they lack technical knowhow on formulating feed ration.

Therefore, a coordinated effort of government and expertise is essential in availing improved technologies and inputs that, firstly boost both grain and residue yields and efficient utilization of residues so that farmers can derive more benefits from their residues, and secondly boost both output (primaries and by-products) of agro-industries and efficient utilization of by-products so that livestock producers can derive more benefits from agro-industrial-by-products.

The findings also indicated differences in the chemical and nutritive characteristics of crop residues and agro-industrial by-products as had been hypothesized in this study. The characteristics compare favourably with those reported from other countries implying that Eritrea can share success lessons learnt in such countries in use of the crop residues. It is recommended that a detailed analysis of use of crop residues in countries in similar production circumstances as Eritrea for success lessons in optimal integration and utilisation of this important feed resource. The variation in chemical composition and nutritive values of feedstuffs offer users flexibility in formulating rations according to the productive performance of target animals.

A recommendation is made that treatment with urea be considered for efficient utilisation of the residues. Despite the fact that there are many residues treatment methods, this study opted to use urea treatment as it would be readily available in Eritrea as urea fertiliser but caution should be taken in use of the chemical as it can be lethal when not properly used. Training farmers on safe use of urea in harnessing the nutrients availability from crop residues is proposed as the benefits have been demonstrated at all levels of evaluation in this study. In order to obtain optimal results especially in feeding growing animals it would be advisable to fortify the cereal crop residues with legume residues as demonstrated in this study. Besides the crop residues, there need to consider integrating various agro-industrial by-products produced in Eritrea in supplementing diets for livestock as their nutritional value has been demonstrated.

This study considered the potential use of the crop residues and related nutrients release technologies and found that the costs related to urea and/or legume residue supplementation in diets utilising sorghum and/or millet stover is relatively small and justifiable in production systems constrained by feed constraints.

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