Optimising the use of barley straw in tropical ruminant diets

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"Intelligence plus character-that is the goal of true education."

Martin Luther King Jr

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List of acronyms

ADF	Acid Detergent Fibre
ADG	Average Daily Gain
ANOVA	Analysis of Variance
BW	Body Weight
CSA	Central Statistical Agency
DCP	Digestible Crude Protein
DM	Dry Matter
DMI	Dry Matter Intake
DMd	Dry Matter Digestibility
DOM	Digestible Organic Matter
CF	Crude Fibre
CP	Crude Protein
EBW	Empty Body Weight
EE	Ether Extract
EEA	Ethiopian Economic Association
EEPRI	Ethiopian Economic Policy Research Institute
FAO	Food and Agriculture Organisation of the United Nations
FCE	Feed Conversion Efficiency
FCR	Food Conversion Ratio
FV	Future Value
GDP	Gross Domestic Product
GLM	General Linear Model
GY	Grain Yield
HCW	Hot Carcass Weight
HI	Harvest Index
ILRI	International Livestock Research Institute
IVDMD	In vitro Dry Matter Digestibility
IVOMD	In vitro Organic Matter Digestibility
LSD	Least Significant Difference
m.a.s.l.	Meter Above Sea Level
ME	Metabolisable Energy
MT	Metric tons

NDF	Neutral Detergent Fibre
NI	Number of Internodes
NIRS	Near-Infrared Spectroscopy
NPH	Natural Pasture Hay
NRC	National Research Council
NSP	Number of Spike Per Plant
OM	Organic Matter
PH	Plant Hight
PL	Plant Length
PUI	Potential Utility Index
PV	Present Value
SEM	Standard Error of Mean
SPL	Spike Length
STL	Stem Length
SY	Straw Yield
TDN	Total Digestible Nitrogen
USEL	Universal Soil Loss

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Chapter 1: General Introduction

1.1. Background

Livestock production systems in the tropics consists of commercial cattle *(Bos Indicus)* rearing, nomadic pastoralism, transhumant agro-pastoralism, and mixed crop-livestock systems (Smith, 1993). In many lower-income countries with tropical and sub-tropical climates, mixed crop-livestock systems account for about 65%, 75%, 55% and 50% of global beef, milk, lamb and cereal production, respectively (Tarawali et al., 2011).

A mixed farming system involves a varying degree of crop and livestock production, and is common in the tropics and many parts of sub-Saharan Africa including Ethiopia. This system of crop production and livestock rearing complement each other, with the crop providing grain (food) and feed in the form of crop residues, and livestock serving as a main source of farm power, manure and cash income for agricultural inputs (Bezabih et al., 2018). Increasing population, climatic, economic, social and institutional changes are transforming systems of producing crop and livestock. Economic and biological interactions between crops and livestock make mixed farming systems attractive to farmers (Williams et al., 1999).

Currently, high population growth resulting in high stocking rate and land degradation are the major challenges in the Ethiopian highlands where mixed-crop livestock production systems accounts for about 40 % of the total cattle and human population. The system is characterised by competition for resources between livestock and human food crop production (Mekuria & Mekonnen, 2018). In high altitude areas (>2400 m.a.s.l) where barley is the dominant crop, the challenges are more pronounced; soil fertility is extremely poor and feed shortages are critical (Getenet, 2003). In contrast, increase in human population and changes in dietary habits associated with urbanisation and higher incomes are also causing increased demands for foods of animal origin (Delgado et al., 2001).

Ethiopia has the largest livestock population in Africa (CSA, 2018). However, the contribution of the Ethiopian livestock resource to human nutrition and export earnings is disproportionately low due to poor productivity of the livestock resource, attributed to (among others) feed shortage (Behnke & Metaferia, 2013). In Ethiopia, grazing lands are continuously converted to crop land. The available grazing lands are poorly managed and exposed to land degradation, highlight the increased role of cereal crop residues as livestock feed resource during dry periods (Zewdie & Yoseph, 2014). However, the crop residues are also poorly managed (e.g. poor storage conditions), which leads to loss of nutrients, for example, exposing straw to high humidity and rain during storage reduces nutrient value, whilst loss of leaves through wind or trampling of cereals crop residues left in the field also cause deterioration (Reed et al., 1988).

Among cereal crops, barley is an important crop cultivated in a wide range of ecological zonations (800 – 3400 m), within different seasons and production systems (Bantayehu, 2013). Barley straw represents one of the major feed sources in mixed crop-livestock farming system in the Ethiopia highlands during the dry period.

1.2. **Origin, global and local production of barley**

Barley (*Hordeum vulgare* L.) is widely grown and is the fourth most popular, cereal grain cultivated at the global level, next to, maize, wheat and rice (Hashash, et al., 2019). Barley originated in the "Fertile Crescent" of the Middle Eastern countries currently known as Turkey, Iran, Iraq, and Lebanon (Harlan, 1979). Barley is a very important food crop in the semi-arid regions of Africa (Morocco, Algeria, Libya, and Tunisia), Middle East (Saudi Arabia, Iran, Iraq, and Syria). Barley is a widely used food grain in the highlands of Nepal, Ethiopia, Tibet and Andean countries of South America (Peru and Chile) and some Asian countries such as China, and North Korea (Taner et al., 2004).

In Ethiopia, barley is one of the strategic crops amongst the oldest cultivated crops and has been grown for at least 5000 years in a wide range of agro-ecologies (Mamo et al., 2014). The grain part of barley is mainly for food in the highlands and for both local drinks and industrial beverages (Dinsa et al., 2021). Total barley grain production in Ethiopia in 2018 was reported to be 2.1 million tons. Ethiopia is the second largest producer of barley in Africa next to Morocco, and accounts for 1.2% of the total global barley production. Currently more than 4.5 million smallholder farmers grow barley on more than 1 million hectares of land (FAO, 2020; Gebru et al., 2018).

There are two types of barley grown by farmers in Ethiopia, namely food and malt barley. Food barley is among the key crop commodities gaining wider attention from the government and farmers (Bediye, et al., 2019). It is also the major ingredient contained in several traditional staple dishes such as *injera* (flat bread), porridge, and bread. Barley is cheaper than other cereal grains (e.g., maize, wheat, and teff) and often used as a substitute for other cereal grains by lower income families. In recent years, malt barley has provided a source of family income in mixed barley-livestock farming system of Ethiopia because of the high demand for malt barley by the malt factories and growing breweries in the country (Addisu, 2018). The required parameters in malting barley are quality traits such as optimal germination, enhanced enzymatic activities, soluble proteins, starch breakdown and proper development of flavour and colour. Most of the barley cultivars used for malting are two-row types (Figure 1a), whereas six-row types (Figure 1b) have generally been considered unfit for malting. Six-row types are considered as food-type barley (Figure 1b) (Dinsa et al., 2021).

Figure 1. (a) Two-row barley and (b) six-row barley (Yirga, 2018).

1.3. Barley cultivars improvement for straw yield and quality

There is cultivar variation in barley straw feed quality traits and improvement could be achieved through chemical pre-treatment, use of different supplements, physical processing, selection, and breeding within cultivars, without affecting grain yield (Blümmel et al., 2007, 2003). Plant breeding helps to achieve food security through selection of cultivars with high yield and quality traits (Hickey et al., 2019). The breeding techniques include independent trait selection and simultaneous selection of multiple traits (Michel et al., 2019).

In the attempts made to select multi-purpose cereal crops with superior straw yield and quality Zerbini & Thomas (2003) emphasise the effects and relative importance of genetic and environmental variation and their interaction on the nutritive value of multi-purpose cereal crops with superior straw yield. For example, Rattunde et al. (2001) reported a significant difference among sorghum genotype in stem and NDF composition, and suggested stem as a better selection criteria than leaves in sorghum, since stem showed more variation in genotypic and environmental interactions.

The use of chemical composition for selection of barley cultivar in improving nutritive value of crop residue is expensive and time consuming in screening a large quantity of cereal genotypes. Therefore, morphological parameters like plant height/stem height, leaf proportion, and number of internodes (Fig. 2) are heritable genotypes that help in plant breeding and selection programmes, especially when the number of genotypes exceeds the capacity of nutritional laboratories to process samples by *in vitro* or chemical means.

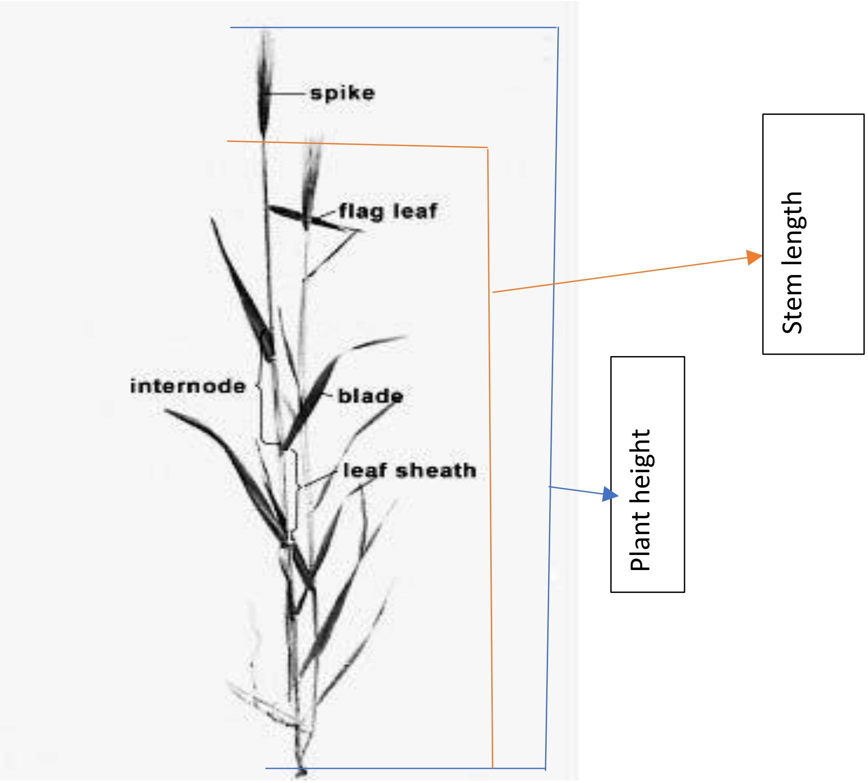

Figure 2. The measured morphological traits of barley

Literature evidence for the influence of morphological fractions on the nutritive value of cereals straws is quite diverse (Capper et al., 1986). The genotype by environment (G*E) interaction is considered an important factor in selection of high yielding and good quality crop residue. In addition to yield potential (grain and straw), quality traits like chemical composition of both grain and straw and yield stability were considered as important selection criteria because stable cultivars tend to perform better under unfavourable conditions (Raggi et al., 2017).

There is no complete list of criteria used in any crop selection for straw traits (for food-feed uses). However, the common issues to be considered in any selection programme include economic, environmental, and social aspects (Cobuloglu & Büyüktahtakin, 2015). Effective selection can improve the yield and nutritive value of barley cultivars (Chen et al., 2021). In Ethiopia, most of the criteria used for the selection of barley focus on grain traits such as raising grain yield, lodging resistance, drought tolerance, maturity, and disease resistance. Lodging resistance is related to lignification because deposition of lignin in the cell wall provides mechanical strength for the plants (Jayumahan & Kumudini, 2011). Lignification is an important part of development and differentiation in plant cells and tissue, as such it depends on many factors (Boerjan, et al., 2003). The amount of lignin, as well as its composition and structure, affects the adaptive value in the process of selection and breeding of different genotypes (Begović et al., 2018). In Ethiopia, straw yield and nutritive value quality have not been considered in barley improvement programmes so far.

1.4. Barley straw utilisation in the tropics

In addition to grain production, barley provides a quantitatively important amount of straw for livestock feeding. For example, 1 ton of barley grain is associated with 1.2 tons of straw (Smil, 1983). Barley straw comprises the residues of the barley plant after the grains are removed during harvesting, it includes chaff, leaf, stem, and leaf sheaths. In Ethiopia, barley straw is commonly used for animal feeding and soil mulching, but also rarely used in house construction particularly in rural areas where it is used as roof thatching and mixed with mud for mud plastering of the house walls. The retention of straw biomass on the crop field as a soil amendment for reducing surface runoff, enhancing soil moisture, improving soil structure, and suppressing weed growth is common (Jaleta et al., 2015).

It was reported that provision of 30% soil cover through straw mulching reduced soil erosion by 80% (Giller et al., 2009). Barley straw is abundant in lignocellulose and contains 37.6, 34.9, and 15.8% of structural cellulose, hemicellulose, and lignin, respectively (Sun & Sun, 2002). In developed countries barley straws are used (in addition to livestock feeding and soil mulching) in a wide range of industrial applications including bio-based building materials (Laborel-Préneron et al., 2018), and the generation of ethanol (García-González et al., 2012; Vargas et al., 2015). Barley straws are also used for extraction of valuable compounds such as cellulose, nanocrystals (Fortunati et al., 2016), and xylitol (Moraes et al., 2020).

The difference in yield and nutritional quality of barley straws can be attributed to a number of factors including climatic factors, agricultural production system, and land availability (Kossila, 1985). Low level straw utilisation is attributed to problems of collection, transportation, storage, processing, alternative uses, seasonal availability, and poor nutritional value.

1.5. Determinants of crop residues utilisation in Ethiopia

In some places, a large quantity of cereal straw (more than 30%) is left on the field for *in-situ* grazing instead of being collected and stored for dry period feeding. Excess amounts of straw left on the field will rapidly deteriorate, become trampled and are wasted (Smith, 1993). The high degree of barley straw utilisation as a source of animal feed, at the expense of mulching, arises because of a shortage of alternative sources of feed.

There are few studies conducted to analyse the determinants of crop residue utilisation in mixed farming system of Ethiopia. The determinants of the utilisation of crop residues in the Ethiopian highlands include biomass production, types of livestock production, farm size, extension services, and agro-ecology. Extension services and training on the use of crop residues as soil mulching materials positively affected the use of maize stover as mulch rather than animal feed, likely influenced by project financing.

The number of livestock held positively affected the use of maize stover as feed rather than using it as soil mulching (Jaleta et al., 2015). The availability of labour required for collection and storing of crop residues also encouraged the use of crop residue as a feed resource. Location and distance of farm plots from family dwellings negatively affected maize stover utilisation as feed and encouraged utilisation as mulching materials (Jaleta et al., 2013). The proportion of cereal residue used for soil mulching is positively affected by the education level of the farmer, level of awareness about soil mulch, the slope of cultivated land, and participation in farmer-to-farmer extension programmes (Alkhtib et al., 2017).

1.6. Nutritive value of barley straw

Cereal straws are poor in nutritive value, particularly in digestible energy, crude protein and mineral contents (Klopfenstein, 1988). In general, most crop residues are deficient in proteins and essential minerals like sodium, phosphorus, and calcium, and high (40-45%) in crude fibre (Klopfenstein, 1988)). Cereal straws induce low feed intake, digestibility and animal performance. The low nutritive value of cereal straws is attributed to their high content of structural carbohydrates and high level of lignification (Smith, 1993). Physical, chemical and biological treatment could disrupt the indigestible bonds formed between lignin, cellulose, and hemicellulose, causing partial solubilisation of the lignin and hemicellulose fractions, resulting in a subsequent rise in digestibility and feed intake (Kitaw et al., 2012).

Efforts have been made to improve the nutritive value of cereal straws by chemical or biological means (Chaudhry, 1998). Treatment with alkalis alter the characteristics of straw, rendering the cell wall constituents more vulnerable to microbial attack and improving intake by the animal. However, there has been little adoption of these techniques or resources by poor, small farmers in lower-income countries, including Ethiopia (Singh, et al., 1997). Alternative practical strategies could involve increasing the nutritive value of crop residues through genetic enhancement. However, in the past, research on cereal crop breeding in lower-income countries has focused mainly on food grain yields and quality (Kush, et al., 1988; Zerbini & Thomas, 2003).

Compared to wheat and teff, barley straws are higher in crude protein and *in-vitro* dry matter digestibility. The dry matter components of barley straw contain about 40-45, 30-50, and 6-12% of cellulose, hemicellulose, and lignin, respectively (Bediye, 1989). The feeding value of barley straw is influenced by genetic makeup, environment, and their interaction. Among the botanical fractions, the leaf components have better nutritional value than the stem (Singh & Delhi, 1995). The chemical composition of barley straw can be affected by location, cultivars, agronomic practices, post-harvest management, and storage condition (Kehaliew, et al., 2006).

1.7. **Effect of varietal difference on yield and straw quality**

The combined genetic and environmental effects on straw digestibility varies with plant species, indicating that it may be possible to select or breed cultivars with a combination of good grain yield and better feed quality straw (Singh & Delhi, 1995). Some of the differences in straw cultivar feed quality can be attributed to plant parts, i.e., leaf, leaf sheath, and stem. Leaf and leaf sheaths are more digestible than stems for most straw types (Singh & Delhi, 1995).

As presented in Table 1.1, cultivar differences affect grain and straw yields, as well as straw feed quality traits of cereal and legume straw. Addisu (2018), reported differences in straw yield and feed quality traits of wheat developed for the highlands of Ethiopia; these difference can be exploited to optimise food-feed traits of barley cultivars used in a mixed crop-livestock system. Zaidi et al. (2013) reported significant variation in livestock feed stover quantity and quality traits among maize genotypes. Sing and Shukl (2010) reported that sorghum genotypes affected DMI, milk yield and quality from buffaloes fed on sorghum-based rations. Bidinger et al. (2010) also reported that genotypes affected DMI and organic matter digestibility intake of pearl millet straw by sheep (*Ovis aries*).

Table 1.1: Genetic variation in grain and straw traits in some cereal and legumes crops

Reference	Crop	Traits	Phenotypic Range	Number of Genotypes
(Subudhi et al., 2020)	Rice	Grain yield	2.34 - 7.85	132
		Straw yield	2.51 - 17.74	
		N%	0.65 - 1.26	
		NDF%	62.1 - 70.9	
		ADF%	48 - 54.2	
		ADL%	3.3 - 5.3	
		IVOMD	38.2 - 45.6	
(Bezabih et al., 2018)	Wheat	Grain yield	1.26 - 8.91	25
		Straw yield	4.85 - 13.3	
		N%	0.49 - 1.07	
		NDF%	70.6 - 82.5	
		ADF%	45.4 - 54.5	
		ADL%	5.16 - 7.25	
		IVOMD	44.5 - 48.3	
		ME	6.5 - 6.66	
(Zaidi et al., 2013)	Maize	Grain yield	1.44 - 5.83	60
		Straw yield	1.49 - 7.27	
		N%	0.79 - 1.64	
		NDF%	65.3 - 80.3	
		ADF%	31.3 - 39.2	
		ADL%	2.9 - 5.3	
		IVOMD	52.3 - 58.2	
		ME	5.82 - 7.91	
(Singh, & Shukla, 2010)	Sorghum	CP	6.12 - 17.1	23
		ME	4.4 – 7.0	

(Bidinger et al., 2010)	Pear millet	Grain yield	2.7 - 4.2	256
		Straw yield	2.8 - 5.5	
		CP	4.3 - 8.6	
		IVOMD	40.7 - 46.1	
(Alkhtib et al., 2017a)	Lentil	Grain yield	2.2 - 3.7	25
		Straw yield	3.7 - 9.3	
		CP	13.7 - 66.1	
		ME	3.5 - 7.7	
(Wamatu et al., 2017)	Chickpea	Grain yield	1.0 - 4.7	79
		Straw yield	2.7 - 8.4	
		CP	33.2 - 67.5	
		IVOMD	44.8 - 48.7	
ADF, acid detergent fibre; ADL, acid detergent lignin; fibre; CP, crude protein; IVOMD, *in vitro* organic matter digestibility; ME, metabolizable energy; N, nitrogen; NDF, neutral detergent				

1.8. Food-feed crops

Food-feed crops are the most important feed resource for ruminants in small scale, mixed crop-livestock systems (Thomas et al., 2002). In sub-Saharan Africa and India, an estimated 140 and 370 million poor livestock keepers, respectively, could be benefited from improved utilisation of food-feed crops within these systems (Lenné et al., 2003).

Barley is one of the important crops having food-feed purpose in some countries like USA, West Asia, North Africa, Mediterranean countries, Australia, and New Zealand. In these cases, grazing barley occurs once or twice during tillering and then a grain crop is produced as food-feed (Hadjichristodoulou, 1983).

Increasing the feed value of crop residues by genetic enhancement depends on nutritionally-significant, cultivar-dependent variation in crop residue quality, as well as sufficient independence between crop residue fodder traits and primary traits, such as grain yield (Blummel et al., 2009). Including straw yield and straw quality traits as selection, breeding and cultivar-release criteria is a first step in the development of food-feed type cultivars (Blummel et al., 2009). The economic value of straws (Capper, 1988) and rejection of cultivars must be taken into account.

Recently, attention has been given to developing food-feed cultivars of cereal and legumes in Ethiopia by including straw traits in the evaluation of pulse and cereal crops. Accordingly, the possibility of improving grain yield along with straw traits have been reported for lentil (Alkhtib et al., 2017a), chickpea (Wamatu et al., 2017), maize (Ertiro et al., 2013), and pear millet (Bidinger et al., 2010). Advances in the analysis of feed quality by using NIRS for rapid screening of barley cultivars are offering opportunities to consider multi-purpose traits in varietal development in the early stages of breeding programmes.

1.9. **Morphological difference in yield and straw quality traits**

Various morphological, chemical and environmental factors affect the nutritional value of cereal straws (Tan et al., 1995). Morphological fractions and the leaf and stem proportion of straw were reported to have been related to genetic variation in terms of feeding value of cereal straw (Capper, 1988). A study conducted by Tolera et al. (1999) determined morphological-based variation in the crop residue quality traits of maize stover. Tolera et al. (1999) indicated that the leaf of maize has better CP and digestible compound content, compared with other botanic fractions.

The intake of sorghum digestible organic matter can be predicted using plant height and stem diameter (r: -0.71 and r: -0.67, respectively). Also, plant height and stem diameter were consistently and inversely related to *in vivo* measurements, with plant height showing slightly stronger correlations than that of stem diameter. Plant height and stem diameter could easily be measured in the field and are a useful means of preliminarily screening straw feed quality (Kelley et al., 1996).

1.10. **Nutrient requirements, dry matter intake, and the impact of cereal straw on growth performance of sheep**

Poor quality roughages like cereal straw are the major ruminant animal feed resource in lower-income countries. Sheep have greater capacity to utilise pasture than goats (*Capra hircus*) and cattle, but sheep also have higher capability in utilising other rangeland feed resources and agro-industrial by-products (Pond et al., 1995; Van Soest, 1994). In common with other ruminant animals, the nutrient requirements of sheep include energy, proteins, minerals, vitamins, and water (Neary, 2008).

The nutrient requirements of sheep depend on age, body weight, and stage or status of production. For example, the daily dry matter intake of local sheep fed finger millet straw alone or supplemented with a mixture of "atella" and NSC at different proportions was reported to be between 2.6 - 3.6 %BW (Almaz, 2008). Solomon Gizaw (1991) reported 95 - 137g gain per day in grazing Horro sheep supplemented with graded levels (200-500 g per day) of concentrate mixture of noug seed cake and maize.

High protein supplementation of sheep optimised rumen fermentation. Therefore, provision of supplements of by-pass protein sources should be given to maximise intake and animal performance (Ngwa and Tawah, 2002).

The voluntary feed intake of sheep varies according to the type of feed and physiological condition of sheep. Energy density of the diet affects the level of feed intake. Diets high in fat are consumed in lower amounts; in such cases, the levels of other nutrients, such as protein, must be increased to ensure adequate nutrient and DM intake. The DM intake of sheep placed on barley and alfalfa straws were estimated to be 44g DM/kg $W^{0.75}$ and 75g DM/kg $W^{0.75}$, respectively (Ranjhan, 1997). Under intensive rearing conditions, nutrient requirements of 20 - 30 kg sheep comprises 0.65 - 0.85 kg DM, 52 - 65g DCP, and 5.9 - 8.4ME MJ (Ranjhan, , 1993). The daily DMI of growing lambs with a mean live weight of 15 - 35kg was estimated as 73.1g/$W^{0.75}$ (Ranjhan, 1997). The recommended total DM intake of roughage as a percent of body weight for a 30 kg sheep is 2.6% of live body weight, or 780g DM intake /day (ARC, 1980).

Palatability is a phenomenon determined by animal, plant, and environmental variables, The palatability of forage is determined by its ability to provide stimuli to the oropharyngeal senses of the animal, i.e., taste, odour and texture (Kaitho et al., 1997). Phenolics, alkaloids, tannins and aromatic compounds are some of the chemical compounds known to alter palatability and intake (Ngwa et al., 2003). Animal factors such as the sensory system, species, previous experience, and physiological conditions influence palatability (Marten, 1970). For poor quality roughages like barley straw, adequate supplementation of concentrate is required to increase rumen fermentation and thereby increase intake and digestion.

Feed intake depends on the structural volume and cell wall content, whereas digestibility depends on both cell wall content and its ability to resist digestion as determined by lignification and other factors (Van Soest, 1982).

In general, in the case of roughages with low CP content (< 6%) such as barley straw, supplementation with high protein concentrates increases intake and digestibility (Lambourne et al., 1986). Feed intake is typically considered to be proportional to the metabolic body weight ($W^{0.75}$) of the animals. Bonsi et al. (1986) reported that the DM intake of Ethiopian sheep fed a roughage-based basal diet was 58.6 - 82.2g DM/Kg $W^{0.75}$.

Sheep (Ovis aries) are commonly reared on poor quality roughage in lower-income countries like Ethiopia. Growth performance in lambs depends on nutritional levels; the minimum energy and protein levels at which growing lambs do not lose weight are, on average, 9 MJ ME/kgDM, and 8%CP (or about 80g/kg DM), respectively (Gatenby, 2002). High levels of NDF (cellulose, hemicellulose, and lignin) plus low levels of CP result in restricted digestibility, poor intakes, and depressed microbial production when cereal crop residues are offered alone (Koralagama et al., 2008).

The consumption of low quality roughages such as straw can be increased markedly by the addition of protein supplements (Pond, *et al*., 1995). Significant differences were reported in growth performance of sheep fed different cereal crop residues supplemented with high CP content in different part of Ethiopia. For example, a significant difference in weight gain of Ethiopian sheep fed maize stover supplemented with a commercial concentrate was reported (Koralagama et al., 2008). It is also reported that significant differences in the digestibility of DM and OM in sheep fed wheat straw supplemented with atela (a local brewery by-product) were observed, compared with sheep fed hay supplemented with a commercial concentrate, however no significant weight changes were noted between them (Nurfeta, 2010).

Growth rates of 26, 78, and 54 g/h/d were reported from sheep supplemented with groundnut cake, sunflower cake, and sesame cake, respectively (Gizaw, 1991). It is also reported that sheep supplemented with cotton seed cake gained more weight than sheep fed rice straw without supplementation (Ngwa and Tawah, 2002).

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2

Chapter 2: Scientific Aims and Objectives

The world's rapidly growing human population along with urbanisation, changes in lifestyle and eating habits, have increased the demand for animal-origin food. The increased population puts pressure on the availability of land, water and energy needed for animals and crop agriculture. Crop land area per capita decreased globally from 2000 to 2018 due to the growing population, with the largest decrease in Africa (-23%) (FAO, 2020).

The inability of farmers to feed animals adequately throughout the year continues to be the major constraint in meeting future demands, especially in lower-income countries. In Ethiopia, available feed resources include pasture, crop residues, improved forages, fodder trees and shrubs, aftermath grazing and agro-industrial by-products (Alemayehu et al., 2017). Forage development has failed to be widely adopted by farmers in the country as is common for tropical lower-income countries because of shortages in land and resources, inadequate technical support and lack of appropriate and sufficient input supply, particularly forage seed (Reddy et al., 2003).

The contribution of pastureland as a source of feed is decreasing since pastureland is being converted to crop land to fulfil human food demands. The availability (amount and accessibility/distribution) of agro-industrial by-products for animal feed in the country is also very limited, so that efficient utilisation of crop residues for animal feed decreases the competition between humans and animals and maximises land use efficiency.

In intensively cultivated areas, crop residues and aftermath grazing accounts for about 60-70% of the basal livestock diet in Ethiopia (Alemayehu et al., 2017). Yet the yield of crop residues varies greatly in chemical composition and digestibility depending on varietal difference and agronomic practices (Reed, 1986)

To solve the problem of feed shortage under current and future scenarios, optimising both food (grain) for human consumption and feed (straw) for livestock feeding appears to be a more promising option (Lenné et al., 2003). Yet crop improvement programmes that have been practiced in Ethiopia mainly focused on grain production without due consideration of straw yield and quality as livestock feed, so strategies for crop-livestock synergies and interactions are needed to be developed and promoted.

Barley is one of the most popular food-feed crops, with its grain used for human consumption and its straw used for animal feed. In Ethiopia, barley production in terms of area coverage and production is currently increasing due to increasing demand for malt barley by the brewery industries. Additionally, many cultivars were released and studied to optimise the productivity of grain by the Ethiopia Agricultural Research Institute (Regional and Federal Agricultural Research Institutes), higher education institutions and NGOs, but this did not consider the optimisation of straw yield and quality traits.

Many studies have shown the possibility of improving crop residues traits by exploiting the genetic variability in several crops including pearl millet (Bidinger et al., 2010), maize (Alkhtib et al., 2016; Ertiro et al., 2013), sorghum (Sharma et al., 2010), faba bean (Alkhtib et al., 2016) and lentil (Limeneh et al., 2021). As the food-feed traits of barley in Ethiopia have not been exhaustively studied, assessing barley straw utilisation, identifying cultivars that combine high straw (feed) yield and quality with desirable primary food traits of the crop would be a positive step towards addressing food and feed gaps in the mixed crop-livestock systems of Ethiopia.

Therefore, the general aim of this PhD dissertation is to determine the existing gap for total barley biomass utilisation as food-feed use, in order to develop a breeding and utilisation programme that combines both grain and straw optimisation in mixed livestock-barley production in the Ethiopian highlands.

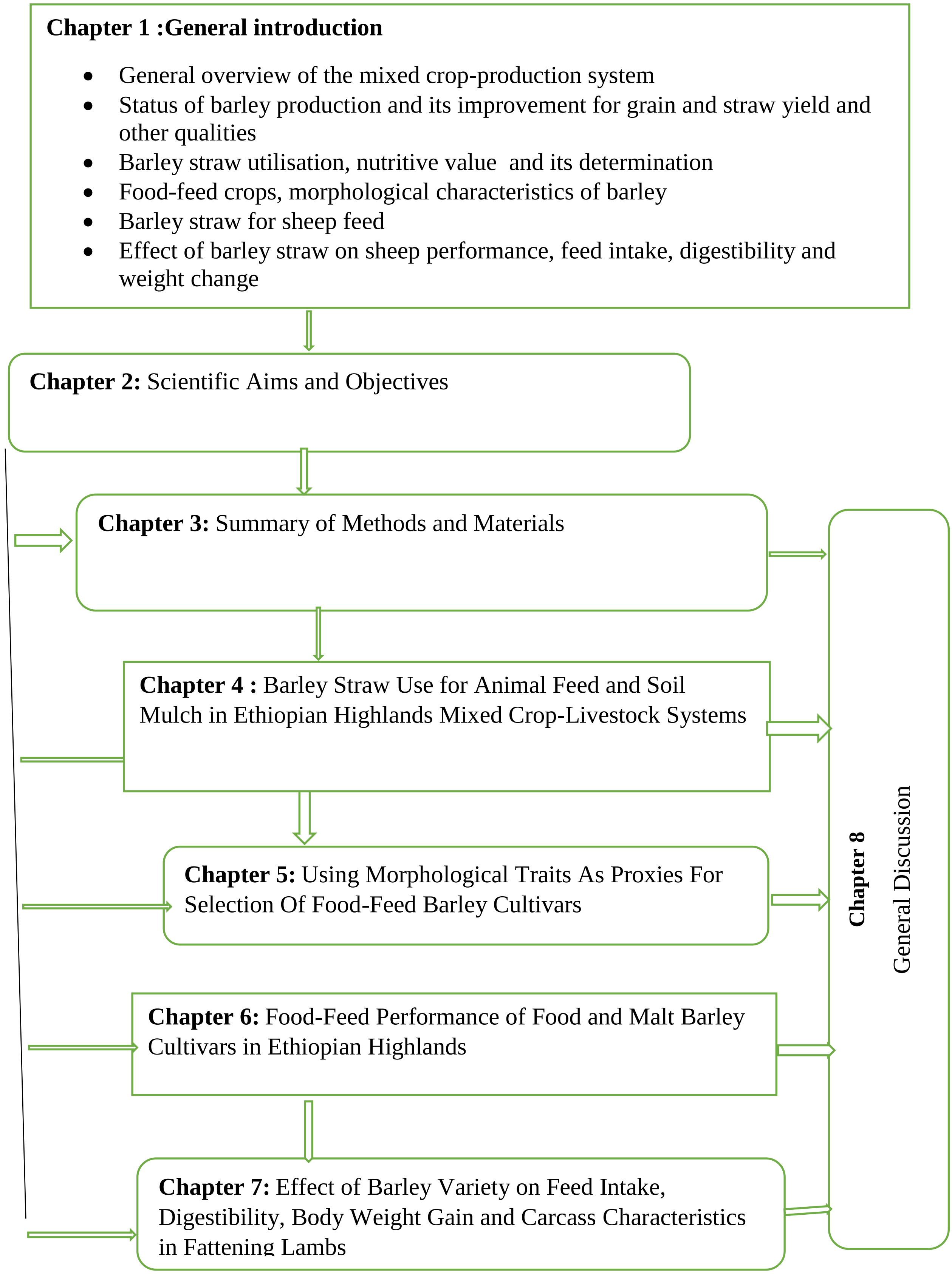
The first objective was to collect information about barley straw utilisation and its determinants, including socio-economic and logistic factors, to identify the determinants of the utilisation of barley straw for mulch and feed.

The second objective was to evaluate the potential of morphological traits for use in screening barley genotypes for yield and nutritive value of barley grain and straw, using forty barley cultivars of food and malt barley types in two locations (Bekoji and Kofele) hosting the Ethiopian Institute of Agricultural Research (EIAR), Kolomsa Agricultural Research Centre.

The third objective was to identify a higher grain yielding, straw yielding and food-feed cultivar, using forty cultivars of food and malt barley types across two locations (Bekoji and Kofele) in Ethiopia.

The fourth objective was to document the genotypic difference in barley straw quality, information on digestibility and palatability (voluntary feed intake), with the associated effect on animal growth, in order identify the best cultivars performance from the three most promising genotypes from objective 3. This should facilitate the generation of a recommendation for the best barley cultivar for use in the Ethiopian highlands and tropical regions in general.

The schematic presentation (helicopter view) of the thesis



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3

Chapter 3: Summary of Materials and Methods

This section aims to summarise the materials and methods used in this PhD work. The current study analysed three datasets. The first dataset involves barley straw utilisation for soil mulch and livestock feed in a mixed farming system of Ethiopia (Chapter 4). The second dataset refers to the relationship between morphological characters of food and malt barley with straw yield and nutritive value (Chapter 5), and cultivar variability of food and malt barley in terms of yield and nutritive value (Chapter 6). The third dataset relates to the effect of cultivar difference on digestibility, feed intake, and animal performance (Chapter 7). However, further details are presented in the materials and methods section of each chapter.

3.1. Barley straw use for animal feed and soil mulch in Ethiopian highland mixed crop-livestock systems

A survey was conducted in six districts (Kofele, Sululta, Degem, Tiyo, Lemu Bilbilo, and Degaluna Tijo) of the Ethiopian highlands. Data included the use of barley straw, amount of straw, household and farm characteristics, and monetary value of the straw. The information was collected from 236 selected households. This survey aimed to identify the determinants of the utilisation of barley straw for mulch and feed.

Data on the value (cost) of one metric ton of straw for feeding and straw yield per ha were collected using questionnaires, and the straw value per ha in USD/ha/yr (Etb/ha/yr) was estimated by multiplying the straw yield by the mean value (cost) per metric ton. The difference in total cost per ha for farmers not using *versus* using barley mulch was considered the present value of straw for mulching.

The future value of straw for mulch was estimated from the present value by considering a 10% discount rate and summing the entire stream of values from all the years in a future time horizon of 10 years. The annual cost of erosion was estimated by multiplying the amount of such soil loss measured in metric ton (t) per hectare (ha) by the value of crop losses attributed to such soil loss.

The theoretical framework adopted for this study is based on the random utility model. The model is described as follows:

$$\boldsymbol{U = X\beta + \varepsilon}$$

where U is a farmer's decision on barley straw utilisation, X is the explanatory variable, β is the parameter to be estimated and ε is the error term associated with the estimation.

Depending on the distribution of the random disturbance term, the linear probability, logit or probit are suitable qualitative choice models for such a scenario. Provided that the identified options are more than two, the multinomial logit and multinomial probit models are the most applicable econometric models. The multinomial logit model is widely used in determining the influence of explanatory variables on a dependent variable with multiple but unordered categories of options (Getibouo, 2009).

The use of barley straw for mulching as a function of household characteristics was analysed by multinominal logit regression using R software (R core Team 2017).

3.2. Using morphological traits as proxies for selection of food-feed barley cultivars and food-feed performance evaluation of food and malt barley cultivars

Twenty cultivars of malt barley and twenty cultivars of food barley were triplicated separately in two locations (Bekoji and Kofole) in randomised complete block trials with plot sizes of 1.2m*2.5m each. All above ground biomass of each plot was harvested at physiological maturity, air-dried for two weeks to a constant moisture, then threshed. Straw yield of each plot was calculated by subtracting grain yield from total biomass yield. Straw harvested from each plot was fractionated to determine the proportion of leaf and stem.

Grain and straw samples were analysed for crude protein (CP), neutral detergent fibre (NDF), metabolisable energy (ME), acid detergent lignin (ADL), and *in vitro* organic matter digestibility (IOMD) using a combination of wet chemistry analyses and near-infrared reflectance spectroscopy (NIRS).

Average space between internodes was calculated by dividing plant height by the number of internodes. Stem length was calculated by subtracting spike length from plant height. The potential of morphological traits as proxies for grain and straw yield and quality traits were analysed with the general linear model procedure in SPSS (IBM Corp., 2020).

Variation in morphological traits of studied barley cultivars was analysed according to the following model:

$$Y_{ijk} = M + G_i + Lo_j + B_k(L_i) + (G \times Lo)_{ij} + E_{ijk}$$

Where Y_{ijk} is the response variable, M is the mean, G_i is the effect of barley genotype I, L_j is the effect of the location j, $B_k(L_i)$ is the effect of the block k within k location I, $(G \times L)_{ij}$ is the interaction between the genotype and the location, and E_{ijk} is the random error.

Data of nutritive value of straw fractions were analysed according to the following model:

$$Y_{ijkl} = M + G_i + Lo_j + F_k + B_l(L_i) + (G\times L)_{ij} + (G\times F)ik + (Lo\times F)jk + (G\times Lo\times F)ijk + E_{ijkl}$$

Where Y_{ijkl} is the response variable, M is the overall mean, + G_i the effect of genotype, Lo_j is the effect of location, F_k is the effect of fraction, $B_l(Lo_i)$ is the effect of block within location, $(G\times L)_{ij}$ is the interaction between genotype and location, $(G\times F)_{ik}$ is the effect of the interaction between genotype and fraction, $(Lo\times F)_{jk}$ is the effect of the interaction between location and fraction, $(G\times Lo\times F)_{ijk}$ is the effect of genotype-location-fraction interaction, and E_{ijkl} is the residual. Least significant difference at $P\leq 0.05$ was used for the multiple comparisons.

For food-feed performance evaluation of food and malt barley, analyses were as follows:

A general linear model was used to test the effect of cultivar on grain yield, straw yield and potential utility index (PUI). PUI, which estimates the proportion of the utilisable portion of total barley biomass for food and feed, was calculated according to the following equations:

$$PUI = \frac{GY + 0.01 \times IVOMD \times SY}{GY + SY}$$

Where PUI is the potential utility index (W/W), GY is the grain yield (t/ha), SY is the straw yield (t/ha), and IVOMD is the *in vitro* organic matter digestibility (analysed by NIRS and expressed as %).

HI, which estimates the proportion of grain yield (GY) to total barley biomass (GY+SY), was calculated as follows:

$$\mathrm{HI} = \frac{\mathrm{GY}}{\mathrm{GY} + \mathrm{SY}}$$

Where HI is the harvest index (W/W), GY is the grain yield (t/ha), and SY is the straw Yield (t/ha).

Data were subjected to the analysis of variance according to the following model:

$$Y_{ijk} = M + G_i + Lo_j + B_k(L_i) + (G\times Lo)_{ij} + E_{ijk}$$

Where Y_{ijk} is the response variable, M is the mean, G_i is the effect of barley cultivar i, L_j is the effect of the location j, $B_k(L_i)$ is the effect of the block k within k location i, $(G\times L)_{ij}$ is the interaction between the cultivar and the location, and E_{ijk} is the random error.

3.3. Effect of barley variety on feed intake, digestibility, body weight gain and carcass characteristics in fattening lambs

The feeding trial experiment was conducted at Jimma University College of Agriculture and Veterinary Medicine. The three selected improved varieties were IBON174/03 (a high grain yielder), Traveller (a high straw yielder), and HB1963 food-feed (high in grain yield as well as straw yield), based on the results of Chapter 5 and one local (control). These were then planted at the Kolumsa Agriculture Research Centre's Kofele site in Ethiopia.

The above-ground biomass of each plot was manually harvested at physiological maturity, air-dried for two weeks to a constant moisture, then threshed and transported to Jimma University College of Agricultural and Veterinary Medicine. Twenty Horro yearling lambs with an initial body weight of 18.0 ± 0.2 kg were obtained from a local market.

The following four treatments were tested: (1) a local straw barley (as control), (2) HB1963 (high grain and straw yield), (3) Traveller (a high straw yielder), and (4) IBON174/03 (a high grain yielder). A concentrate (50:50 wheat bran and noug seed cake) was offered at a fixed amount (300 g DM/d), whereas the straw was offered *ad libitum*. Lambs were fed twice a day (0800 h and 1600 h) in equal proportions. Lambs had free access to a salt lick and clean drinking water.

The apparent digestibility of dry matter (DM) and other nutrients were determined as a percentage of the nutrient intake not recovered in the faeces. The daily feed offered and refusals were weighed and recorded per sheep. Daily feed and nutrient intakes were calculated as the difference between the offered feed and the refusals on a DM basis. Average daily gain (ADG) was calculated as the difference between the final and initial weights, divided by the number of feeding days. The feed-to-gain ratio (FGR) was calculated as the total DMI to the ADG.

At the end of the experiment, all lambs were slaughtered after 24 h of fasting to determine the treatment's effects on carcass characteristics. Lambs were individually weighed before slaughter. Carcass variables were registered individually.

Empty body weight (EBW) was calculated as the slaughtered body weight, minus gastro-intestinal tract contents. Hot carcass weight (HCW) was determined as the body after removing the skin, head, forefeet, hind feet, all the viscera, and fat deposits.

The dressing percentage on a slaughter body weight basis and an empty body weight basis was calculated as the percentage of hot carcass weight to slaughter body weight and empty body weight.

All feed and faecal samples were analysed for dry matter (DM), ash, and nitrogen (determined according to AOAC (1990), neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL) were analysed using the procedure of Van Soest, Robertson, and Lewis (1991), and crude protein content was calculated as N × 6.25.

The experimental lambs were blocked according to live weight. Data from the current study were analysed according to the following model:

$$Y_{ij} = \mu + T_i + Bj + E_{ij}$$

where Y_{ij} is the response variable, μ is the overall mean, T_i is the effect of treatment, B_i is the effect of block, and E_{ij} is the residual. Treatment means were separated using the Tukey test at $p < 0.05$. The statistical analyses were performed using SPSS (IBM Corp., 2020).

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4

Chapter 4: Barley Straw Use for Animal Feed and Soil Mulch in Ethiopian Highland Mixed Crop-Livestock Systems

Adapted from

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Abstract

Barley straw serves as livestock feed and mulch for soil and water conservation in the mixed barley-livestock systems of the Ethiopian highlands. High demand for barley straw biomass in the system creates competition between the two uses. This study aimed to identify the determinants of the utilisation of barley straw for mulch and feed. Data on the production and use of barley straw were collected from 236 households using a structured questionnaire. Use of the straw for the purposes of soil mulch at three levels, 0–15% (marginal mulching), 15–35% (optimal mulching), 35–100% (over-mulching), was analysed using a multinomial logit model. The optimal proportion of barley straw used as soil mulch was positively affected by family size, distance between cropping land and homestead, number of equines in the household, and amount of straw production. Female-headed households were more likely to mulch less than the optimal amount of barley straw. In general, the more the farmer's exposure to formal extension, the less the proportion of barley straw used for soil mulching. This study provides guidance for the proportional utilisation of barley straw. This will contribute to the design of appropriate biomass utilisation strategies in barley-livestock farming systems.

Keywords: barley; barley-livestock farming system; livestock; straw

4.1. Introduction

Mixed crop-livestock farming systems are the backbone of farmers' livelihoods in lower-income countries (Herrero et al., 2010; Ryschawy et al., 2012). In these systems, the use of crop residues is important for various uses that include soil mulching and livestock feeding (Alkemade et al., 2013). In cereal-based crop-livestock systems, residues include stover and straw from cereal crops after harvesting the grain. The retention of such residual biomass in crop fields has the potential to improve soil quality by reducing surface runoff, enhancing soil moisture, improving soil structure and potentially suppressing weed growth (Jaleta et al., 2013).

However, mixed crop-livestock farming systems typically use crop residues for livestock feed. This often becomes increasingly important due to the expansion of cropland, low productivity of natural pasture, and prevailing livestock feed scarcity (Sileshi et al., 2001). In the Ethiopian highlands where crop-livestock systems are prevalent, the contribution of straw to the total dry matter fed to livestock ranges from 10% to 70% (Sileshi et al., 2001).

The efficient utilisation of straw resources will decrease soil erosion, enhance soil fertility, improve livestock feed supply, decrease pollution, produce biofuels, and create jobs in rural societies. In Ethiopia, the barley-livestock farming system is predominantly found in the Central Highlands (Amede et al., 2017).

Barley is a major food crop in the highland areas of Ethiopia. The annual main season for barley crops involves 0.92 million ha of land, making up 13% of the total area in the country (Agegnehu et al., 2006). This system includes tree crop production with the emergence of apples and small backyard garden patches. Sheep are the dominant livestock type, with one or two cattle for milk production, and equines for the transportation of goods. Livestock is fed mainly on rangeland and barley straw. Agricultural activities and petty trade are important sources of income. Poverty is severe in these systems with deteriorating food security (Amede et al., 2017).

The pressure on the barley-livestock farming system is increasing due to an increase in human and livestock populations, income and rate of urbanisation (Herrero et al., 2010). These challenges tend to intensify land use, which results in the continuous cultivation of cropping lands without fallowing (Collier & Dercon, 2014; Drechsel et al., 2001). Without suitable investments in agricultural land management, this may contribute to land degradation and the deterioration of productivity (Lal, 2009). It has been reported that leaving 30% of the straw on crop farm plots decreases soil erosion by up to 80% (Rockström et al., 2009). Barley straw is a key resource in mixed crop-livestock systems in the country; production of 1 metric ton of barley grain is accompanied by 1.2 metric tons of straw.

Barley straw has a better nutritive value compared to wheat straw with an average of 90.9% dry matter, 3.8% crude protein and 6 MJ metabolizable energy per kg of dry matter (Heuzé et al., 2016). However, it is rich in lignocellulose and poor in calcium and phosphorus. Ruminant animals have the ability to utilise barley straw since the ruminal microbes are able to ferment cell walls. Caecal microbes in equines also have the ability to digest fibre (Heuzé et al., 2016; McDonald et al., 1964).

Maize crop residue (i.e., stover) is also used for soil mulching and livestock feeding in Ethiopia. Extension outreach has been shown to encourage farmers to leave more maize stover on crop plots. Farmer households who kept more livestock were more likely to use more maize stover for feed and less for soil amendment. Cropping pattern, farm size, agro-ecology and crop residue production affect maize stover use in the mixed farming systems of Ethiopia (Jaleta et al., 2015). The use of cereal and pulse straw by smallholder farmers in mixed farming systems in Ethiopia has also been studied (Alkhtib et al., 2017). The use of cereal and pulse straw for soil amendment was positively influenced by the education level of the farmer, the distance between the homestead and the cropping plot, extension service, awareness about soil amendment, the cropping plot slope, farmer-to-farmer extension, and the stock of crop residue (Alkhtib et al., 2017).

Farming at higher slopes without leaving crop residues as mulch can accelerate soil erosion (Bai et al., 2008). One of the impacts of soil erosion is the loss of soil productivity over time. Therefore, the cost of soil erosion can be conceptualised as the monetary value of reduced crop yield(s) resulting from lost soil productivity. In Ethiopia, the estimated average cost of soil erosion, assuming a soil loss rate of about 20 metric tons per hectare per year, is 0.4% annual decline in value for all cereals (Bojo & Cassells, 1995). The impacts of soil erosion are not just incurred for one year, but can continue over multiple years, until erosion is reduced through soil conservation measures such as mulching of crop residues (Berresaw, 2016).

While prior research has identified factors that encourage or discourage Ethiopian farmers from using crop residues for soil conservation, the focus so far has been on pulses, corn grain and other cereals. No studies have evaluated straw use exclusively for barley-livestock systems in Ethiopia. Therefore, this study aims to fill this knowledge gap around the challenges to using the optimal proportion of barley straw as mulch and as livestock feed/bedding by Ethiopian highland farmers. The objectives of our research are to (1) determine the use of barley straw as mulch for reduced erosion, relative to its use as livestock feed/bedding, and (2) identify the characteristics of farmers more or less likely to use barley straw as mulch for soil conservation, and as feed for livestock feeding. This can help agricultural extension and other stakeholders design more targeted approaches to encouraging farmers to use the optimal proportion of barley straw as mulch and as livestock feed.

4.2. Materials and methods

4.2.1. Study area and data

The study was conducted in cereal-based farming systems of six districts of Oromia Regional State, Ethiopia. These sites represent highland regions of the country that have the potential for barley production. The average minimum temperature ranges between 6–17 °C and the average maximum temperature between 20–36 °C. The mean annual rainfall varies between 900 and 3800 mm (Table 4.1). Barley is grown between June and December. The dominant soil type of the locations is loam soil, sandy soil, black vertisols, red nitisols and camisols. The sources and provision mechanisms of agricultural extension services are similar across the districts, but the skills of the extension workers vary.

A total of 236 households randomly selected from 12 farmer associations within six districts were interviewed (Table 4.1, Figure 3). Households within each farmer association were selected using a proportionate-to-size sampling method. Data from farmers, including household characteristics and barley straw allocations, were collected using a structured questionnaire. Barley straw was calculated by a straw-to-grain ratio of 1.2 (Smil, 1983).

Table 4. 1: Description of sites and distribution of households surveyed.

Zone	District	Village	N	Altitude (m)	Temp (°C)	Rainfall (mm)
West Arsi	Kofele	Germama	21	2700	19.5	1800
		Guchi	21			
Oromia	Sululta	Nono Sayo	8	2450	16.5	1060
		Waresa Malema	9			
North	Degem	Ano Kore	26	2878	18.5	1118
Shewa		Ano Degam	12			
Arsi	Tiyo	Dosha	19	2200	19.5	1118
		Hora Bulbula	22			
	Lemu Bilbilo	Lemu	26	2567	16	1100
		Chiba Mikael	29			
	Degaluna Tijo	Digalu Kidame	27	2700	17.5	2750
		Digalu Bora	12			

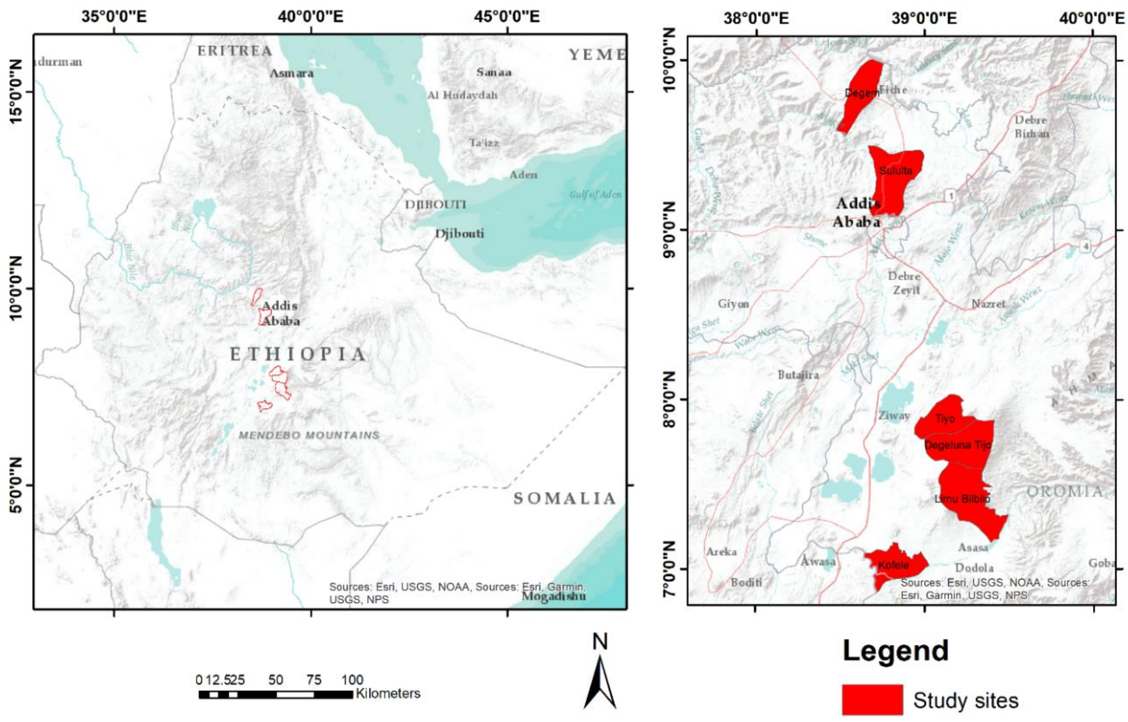

Figure 3: Ethiopian municipalities used for farmer surveys

4.2.1.1. Erosion cost and mulch value calculations

Straw value as feed and mulching

It has been reported that leaving 30% of crop residue in the cropping plot after harvest would decrease soil erosion by 80%. Using less than 15% of barley straw for soil mulching would lead to soil deterioration while using more than 35% would be more than optimum. This upper threshold is predicted on the basis that, under the given circumstances where there is high demand for animal feed, barley straw may be better used as feed, but using high amounts of mulch might contribute further to increasing soil organic matter content. Thus, the allocation of barley straw to soil mulch was recoded into an ordinal variable as follows: 1 if it was between 0% and 15%, 2 if it was between 15% and 35%, and 3 if it was higher than 35%.

Data on the value (cost) of one metric ton of straw for feeding and straw yield per ha were collected using questionnaires and the straw value per ha in USD/ha/yr (Etb/ha/yr) was estimated by multiplying the straw yield by the mean value (cost) per metric ton. The difference in total cost per ha for farmers not using versus using barley mulch was considered the present value of straw for mulching.

The future value of straw for mulch was estimated from the present value by considering a 10% discount rate and summing the entire stream of values from all the years in a future time horizon of 10 years. An infinite time horizon was assumed for the computation of gross discount future value: some researchers used 100 years (Bojo & Cassells, 1995), 25 years, or 10 years as the time horizon (Sutcliffe, 1993). There was no specific or standard time horizon; therefore, 10 years was used for this study as a time horizon.

Straw value and erosion cost calculations

The study area required quantifying soil loss. Soil loss was estimated using the universal soil loss equation (USLE) (Wischmeier & Smith, 1978), adapted to Ethiopia (Hurni, 1985), as follows:

$$A = R*K*L*S*C*P \quad (1)$$

where A is the estimated soil loss (metric tons/ha/year), R is the rainfall erosivity factor, K is the soil erodibility factor, L is the slope length factor, S is the slope gradient factor; C is the land cover factor, and P is the management practice factor. The erosivity factor (R) was calculated based on tabular values (Wischmeier & Smith, 1978) used specifically for Ethiopia (Hurni, 1985) based on long-term annual rainfall (P), and defined as:

$$R = -8.12* + (0.562*P). \quad (2)$$

The rainfall data in Table 4.1 were used as long-term annual rainfall (P) for this calculation. The tabular values for the soil erodibility factor (K), slope length factor (L), slope gradient factor (S), land cover factor (C), and management practice factor (P) were also determined using values adapted for Ethiopia (Hurni, 1985). A summary of the range of values used for this calculation is presented in Table 4.2.

Table 4.2. Summary of the range of values used for calculating erosion.

Factors	Range of Values Used
Rainfall erosivity factor (R)	586–1532
Soil erodibility factor (K)	0.15–0.25
Slope length factor (L)	0.5–3.8
Slope gradient factor (S)	0.4–4.3
Land cover factor (C)	0.001–0.4
Management practice factor (P)	0.5–1

Higher soil erosion for farmers not using barley mulch *versus* those using it can result in 0.4% lower crop yields for un-mulched systems (Bai et al., 2008). The annual cost of erosion was estimated by multiplying the amount of such soil loss, measured in metric tons (t) per hectare (ha), by the value of crop losses attributed to such soil loss. The total monetary value of both grain and straw yield reduction from soil erosion was estimated to be USD 5.20 for an assumed soil loss of 20 t/ha (Bai et al., 2008). Thus, the value of reduced barley grain and straw yield of USD 5.20 was divided by 20 t/ha to determine USD 0.26/t (Etb 10.65/t) of eroded soil as the estimated present monetary cost per one metric ton of soil loss. The difference in monetary value (USD 12.69 − 8.14 = 4.55, or 524 − 336 Etb = 188 Etb) per ha for farmers not using *versus* using barley is conceptually the present value of using straw mulch for preventing yield loss.

The future monetary costs of not using straw mulch are the successive losses in crop yield and the values expected in future years discounted to the present day. We used the standard formula for discounting future values to present value (PV):

$$PV = FV \times (1/(1 + r)^n) \quad (3)$$

where FV is a future value of the cost of erosion, r is the assumed discount rate of 10% and n is the time period into the future whose FV is being discounted to the present day.

4.2.1.2. Empirical analyses

The theoretical framework adopted for this study is based on the random utility model. The model is described as follows:

$$U = X\beta + \varepsilon \qquad (4)$$

where U is a farmer's decision on barley straw utilisation, X is the explanatory variable, β is the parameter to be estimated, and ε is the error term associated with the estimation. Assuming Y_{ia} and Y_{ib} are the farmer ($_i$) selections on the three levels of barely straw mulching, which are based on the utilities obtained from them, they can be presented as U_{ia} and U_{bi}. The option picked by the farmer ($_i$) between the three uses reveals which one has a higher utility; however, the farmer's utility is latent. Thus, the observed indicator is equal to 1 if $U_{ai} > U_{bi}$ and 0 if $U_{ai} \leq U_{bi}$. This is specified as:

$$U_i^a = X_i\beta_{ia} + \ell_{ia} \qquad (5)$$

$$U_i^b = X_i\beta_{ib} + \ell_{ib} \qquad (6)$$

Given the proposition that a farmer prefers the option with the highest net benefit, the observable discrete choice option is related to the latent continuous dependent variable as specified in the equation:

$$Y_{ia}\begin{cases} 1\ if\ U_i^a > U_i^b \\ 0\ if\ otherwise \end{cases} \qquad (7)$$

Thus, Y_{ia} is a binary dependent variable and takes the value 1 if farmer ($_i$) adopts option ($_a$) over others; and 0 if otherwise (Greene, 2003). The probability that farmer ($_i$) will choose option ($_a$) over other options is given as follows:

$$P(Y_{ia} = 1|X) = P(U_i^a > U_i^b \qquad (8)$$

Integrating Equations (5) and (6) into Equation (8) results in the following equation:

$$\begin{aligned} P(Y_{ia} = 1|X) &= P(X\beta_{ia} + \ell_{ia} - X_i\beta_{ib} - \ell_{ib} > 0|X) \\ &= P[(\beta_{ia} - \beta_{ib})X_i + \ell_{ia} - \ell_{ib} > 0|X] \\ &= P(\beta^* X_i + \ell^* > 0|X = F(\beta^* X_i) \end{aligned} \qquad (9)$$

where β^* is a vector of the parameters to be estimated, ℓ^* is a disturbance term, and $F(\beta^* X_i)$ is a cumulative distribution of the disturbance term evaluated at $\beta^* X_i$. Depending on the distribution of the random disturbance term, the linear probability, Logit or Probit are suitable qualitative choice models for such a scenario. Provided that the identified options are more than two, the multinomial logit and multinomial Probit models are the most applicable econometric models. The multinomial Logit model is widely used in determining the influence of explanatory variables on a dependent variable with multiple but unordered categories of options (Getibouo, 2009). The explanatory variables of the regression model are presented in Table 4.3. The use of barley straw for mulching as a function of household characteristics was analysed by multinominal logit regression using R software (R core Team 2017).

4.3. Results

4.3.1. Descriptive analyses

Table 4.3 summarises the socio-economic and biophysical characters of the households included in the current study. The households produced ~8 metric tons of barley straw, on average. Of the households, 50% reported leaving some of their straw on the plots as soil mulch, while only 14.4% of the households reported that they allocated more than 30% of the barley straw biomass for soil mulching. About 95% of the households reported using barley straw for livestock feeding. The correlation between the allocation of barley straw to soil mulch and livestock feeding was strong and negative ($r = -0.9$, $p < 0.001$). In total, 77% of the households used less than 15% of their barley straw for soil mulching, 11.5% of the households mulched 15–35% of the barley straw, while 11.5% of them mulched more than 35% of the barley straw.

Table 4. 3: Explanatory variables used in the empirical models

Variable	Unit	Mean	Std. Dev.
Household head			
Age	Years	41	12
Gender (Female)	%	14	
Education	Years of formal schooling	6	3
Family size	Persons	7	4
Cultivated land			
Land area	Ha	2.7	1.7
Distance to homestead	Minutes of walking	16	12
Slope	(1 to 3)	1.8	0.8
Livestock (heads)			
Small ruminant	Head	5	5
Cattle	Head	6	3
Equine	Head	1	1
Aggregated livestock units	Tropical livestock units (Bai et al., 2008)	5	3
Extension			
Number of friends and relatives	Persons	16	9
Official extension	%	55	
Straw			
Straw production	T	7.89	4.07
Straw price	Etb/kg	1.7	

Etb, Ethiopian birr; 1 USD = 36 Etb (2018) exchange rate at the year of the study.

Table 4.4 shows that the overall soil loss in the study area was 46.7 metric tons (t)/hectare (ha)/year (yr). The mean annual soil loss in metric ton per hectare for those farmers that did not use barley straw for soil mulch in the study area was 49.2 t/ha/yr, while the mean annual soil loss for farmers using barley straw as a mulch was 31.5 t/ha/yr. The result shows that farmers who did not use barley straw for soil mulch had an average cost of USD 12.67 (Etb 524) per hectare of land per year, and those using barley straw for mulching had a cost of USD 8.13 (Etb 336)/ha/year.

Table 4. 4: Soil loss in metric tons (t) per hectare (ha) per year (yr) and erosion costs for Ethiopian barley-livestock systems, with and without barley straw mulch

Mulch	Soil Loss (t/ha/yr)	Annual Cost		Costs Over 10 Years	
		Ethiopia birr/ha/yr	USD/ha/yr	Ethiopian birr/ha/yr	USD/ha/yr
Not used	49.2	524	12.69	8122	196.66
Used	31.5	336	8.14	5208	126.10
Total	46.7	498	12.13	7719	186.90

The cost of straw per metric ton in the study area at the local market was USD 41.16 (Etb 1700) and the yield of straw per ha was 2.9 metric tons. The total cost of straw for feeding per hectare was estimated at USD 119.37 (Etb 4930). The cost of straw per ha used as soil mulch in the first year was estimated at USD 4.55 (Etb 188), but this value increased to USD 70.56 (Etb 2914) in 10 years (Table 4.5).

Table 4. 5: Estimated monetary value of barley straw per ha when used for feed and mulch

Value of Barley Straw	Monetary Value for 1 ha of Crop Land	
	Ethiopian birr/ha	USD/ha
Feed	4930	119.37
Mulch (present value)	188	4.55
Mulch (future values discounted over 10 years)	2914	70.56

4.3.2. Empirical analyses

The effect of the socio-economic and biophysical characteristics of households on the use of barley straw for soil mulching is presented in Table 4.6. The higher the education level of the household head and the larger the size of the household, the higher the probability of using the optimum amount of barley straw for soil mulching. The further the farming plot from the homestead, the higher the probability of optimising barley straw mulching. The more equines kept within the household, the higher the probability of optimising barley straw mulching. More exposure to formal extension was associated with a lower probability of using the optimal amount of straw for soil mulching. The more the straw production, the higher the probability that the farmer would use the optimal amount of barley straw for soil mulching. The wastage of barley straw as soil mulch was negatively associated with household head age, but positively associated with family size. The decrease in the probability of keeping barley straw as soil mulch was associated negatively with exposure to formal agricultural extension. The more the production of barley straw in the household, the higher the probability of over-mulching the barley straw.

Table 4. 6: Multinominal logit regression analysis of the use of barley straw for mulching as a function of household characteristics.

Explanatory Variables	Coefficient (Standard Error)	
Household Head	15–35% of Barley Straw Used for Soil Mulch	35–100% of Barley Straw Used for Soil Mulch
Age	−0.042 (0.03)	−0.157 (0.064) **
Sex (Female)	−5.88 (2.52) **	−3.2 (3.66)
Education	−0.197 (0.1) **	−0.031 (0.125)
Size	0.108 (0.066) *	0.231 (0.112) **
Cultivated land		
Land area	−0.364 (0.251)	−0.079 (0.292)
Distance to homestead	0.175 (0.038) ***	0.289 (0.054) ***
Slope	−0.622 (0.44)	−0.867 (0.582)
Livestock		
Small ruminants	0.036 (0.052)	0.049 (0.084)
Cattle	0.218 (0.122)	0.201 (0.194)
Equine	0.059 (0.225) *	−1.35 (0.486)
Extension		
Number of friends and relatives	−0.001 (0.023)	−0.008 (0.05)
Official extension	−1.06 (0.59) **	−2.33 (0.948) **
Straw		
Straw production	0.026 (0.009) ***	0.039 (0.012) ***
Straw price	0.031 (0.033)	−0.013 (0.056)
Model goodness of fit		
Correctly predicted (%)	88	
Log−likelihood	−79.4	
Chi square test	210 ***	
Pseudo R^2	0.684	

*, **, ***: significant at 0.1, 0.05 and 0.01, respectively.

4.4. Discussion

Soil erosion is a key limitation to soil fertility and thus crop production in lower-income countries. Up to 30% of soil cover by crop residue mulch can reduce soil erosion by 80% (Bai et al., 2008). Half of the households in the study did not leave any barley straw for soil mulch.

Only 14% adhered to the soil mulching recommendations issued by extension services. In line with our results, previous studies reported farmers' low interest in applying crop residue soil amendment (Alkhtib et al., 2017; Jaleta et al., 2015). Thus, soil fertility and biomass productivity of crop plots can be prone to gradual deterioration from soil erosion. To avoid this, farmers should be encouraged to mulch adequate amounts of barley straw to preserve the fertility of their cropping plots.

One tropical livestock unit requires roughly 7.5 kg of dry matter daily (Amsalu et al., 2007). In the current study, the households were calculated to require a total of 13.1 metric tons of dry matter to feed their livestock. However, barley straw production per household was only 7.1 metric tons of dry matter. If barley straw is the main forage available for livestock, the demand for barley straw for both livestock production and soil conservation is far higher than the production, especially in the case of a deterioration in biomass and nutritive value of natural pastures. The strong correlation between the use of barley straw for livestock feeding and soil mulch in the current study confirms this challenge. The high pressure on crop residues for livestock feeding and soil mulching was previously reported for maize-livestock systems in Ethiopia (Jaleta et al., 2013, 2015). Given the limited resources of most farmers in the region, optimisation of the use of barley straw for soil mulch and livestock feeding is warranted.

4.4.1. Soil erosion loss

The overall soil loss in the study area was 46.7 metric tons (t)/hectare (ha)/year (yr), which is a severe soil loss area according to (Gelagay & Minale (2016). Our soil erosion estimates were lower than the range of 84 to 300 t/ha/yr reported by some studies (Berry, 2003; Bewket & Teferi, 2009; Kefeni, 1995; Selassie & Belay, 2013; Zeleke, 2015). They were consistent with soil losses of 42 to 47.3 t/ha/yr reported by others (Ermias, et al., 2009; Gelagay & Minale, 2016; Hurni, 1993; FAO, 1986), yet higher than other measurements of 10 to 31 t/ha/yr (Mengistu & Beweket, 2015; Abera, 2014; Amsalu & Mengaw, 2014; Bojo & Cassells, 1995; Girmay et al., 2020; Haile & Fetene, 2012; Miheretu & Yimer, 2018; Tesfahunegn & Mekonnen, 2009; Tessema et al., 2020). This may be due to the intensification of agricultural production in the study area.

The mean annual soil loss for farmers that did not use barley straw for soil mulching in the study area was 49.2 t/ha/yr, which is higher than the overall soil loss, whereas the mean annual soil loss for farmers using barley straw as mulch was 31.5 t/ha/yr. This means that using barley straw for soil mulch is associated with a reduction in soil loss of 17.7 t/ha/yr, or 36%, compared with not using barley straw for mulching in our study. Factors such as heavy rainfall, steep topography, deforestation, over-grazing, use of marginal land, and agricultural intensification can accelerate soil erosion in mixed crop-livestock farming systems in Ethiopia (Amsalu et al., 2007).

In the first scenario, by considering the short-term impact of soil mulch, most farmers would prefer using barley straw for feeding rather than mulching, which is the case for our study. If the farmers left 30% of straw yield on the plot, they would indirectly lose USD 35.81 (Etb 1479)/ha/yr, or 30%, of the total value of barley straw when it is used for feeding since the estimated value of barley straw when used for feeding is USD 119.37 (Etb 4930). That amount is much higher than the cost reduction of USD 4.55 (Etb 188)/ha/yr from using barley straw for soil mulch. That figure is valid when only the present value is considered but when the future value is considered, the value of using barley straw for mulch would become USD 70.56 (Etb 2914).

In the second scenario, the long-term effect of using barley straw for mulching was not valued by the farmers in the study area. This is likely because the farmers are not fully aware of the long-term cost of soil deterioration on grain yield and straw yield.

4.4.2. Empirical analyses

Female-headed households were more likely to mulch less barley straw in the cropping land than households with male heads. In addition to that, the increasing education of the household head lowered the probability of optimal mulching. This is in agreement with other authors (Alkhtib et al., 2017; Jaleta et al., 2015) who found an effect of household socio-economic characteristics on crop residue use in mixed farming systems.

4.4.2.1. Distance

According to a previous study (Kassie et al., 2013), the ability of farmers to carry materials to and from the cropping land affects the probability of optimal mulching. Farmers economise their labour by using barley straw as feed/bedding only when the fields are close enough. Our results deviate from prior research that has reported that farmers mulched crop fields less when fields were farther from their homesteads (Bai et al., 2008), or showed there was no significant effect of distance on soil mulching (George et al., 2020). Unlike past studies, our results suggest that soil erosion may be more aggravated closer to farm homesteads since soil mulching there is reduced compared with more remote fields. Such an imbalance in the distribution of crop residues highlights the need for more even spreading of barley straw residues in the Ethiopian highlands for better carbon cycling and soil conservation. The farms that are closer to the homestead tend to have less barley straw as soil mulch and are, therefore, more prone to erosion. Farmers with more remote plots tend to leave excess amounts of barley straw as mulch, which is a wastage of biomass.

4.4.2.2. Role of extension

Our results highlight the significance of agricultural extension in encouraging the use of barley straw as mulch in mixed farming systems. Similar results were found by other researchers (Alkhtib et al., 2017; Bekele & Drake, 2003; Feather & Amacher, 1994; Jaleta et al., 2015; Jansen, et al., 2006; Martin, et al., 1995; Smil, 1983; Somda, et al., 2002) who reported the importance of extension when it comes to farmer adoption of conservative agricultural practices. Extension outreach can also help encourage more efficient use of equines to transport crops and crop residues. Our current study shows that the farmers who have more equines, which is the only way to efficiently transport farm products in Ethiopia, were better at optimising the use of barley straw for soil mulch. Extension workers could thus improve the profile of barley straw use by encouraging a culture of equine exchange within mixed farming systems. This would help the farmers with remote cropping plots to carry more straw to the household to feed the livestock and leave the optimal amount on the plot as soil mulch.

Plot slope did not influence farmers' intention to increase the use of barley straw as soil mulch. This is in contrast with other studies (Bai et al., 2008), which found a positive association between plot slope and the use of crop residues for soil mulch. Steeply sloped plots in barley-livestock systems in Ethiopia are prone to severe soil erosion as they do not receive optimal amounts of straw mulch. Households with fields on greater slopes need more extension service outreach on the importance of soil mulching when it comes to reducing soil erosion.

An efficient extension approach to optimising the use of barley straw should consider the differences in household characteristics. The extension service in the study area should be target-oriented. For example, households with steep plots close to the homestead, households with more remote plots, or those that have more equines advised as to the appropriate amount of barley straw that should be left for mulching".

Currently, extension services discourage farmers from using more than 15% of their barley straw for soil mulching. This could be due to the limited feed options in these systems. The mission of the formal extension service to encourage optimal soil mulching could be facilitated by improving the feed supply. The current study indicates that higher barley straw biomass production may allow for the enhanced use of barley straw for soil mulch. This is in line with previous studies (Bai et al. 2008; Bojo & Cassells 1995; Jaleta, Kassie, & Erenstein 2015), which reported that easing the pressure on crop residues, by providing new feed resources to livestock, would encourage farmers to leave more crop residues in fields, therefore improving barley straw biomass in terms of yield.

Improving feed nutritive value through genetic selection may have important long-term effects, such as increased mulching as a strategy against soil erosion. In addition, other management practices that might improve barley straw biomass utilisation include optimising animal bedding, mulching of the soil with non-edible residues and optimal timing of harvest to avoid the decrease in the nutritive value of straw as a result of over-maturity (FAO, 2001). Most Ethiopian households store crop residues in exposed heaps (Bojo & Cassells 1995), which might lead to heavy losses in biomass and nutritive value due to feed spoilage. Consequently, improved crop residue storage may improve the nutritive value of straw, thus avoiding wastage. This may result in an increased supply of straw for soil mulching and livestock feeding on farms. However, future research considering the feasibility of these solutions is important and would enhance the design of efficient biomass utilisation and appropriate intensification strategies.

4. 5. Conclusions

There is pressure to use barley straw as livestock feed in barley-livestock mixed farming systems in Ethiopia due to low straw yield, which is further constrained by competing uses and low nutritive value. Generally, farmers tended to use barley straw for livestock feeding rather than for soil mulching. This is because farmers allocate barley straw to different uses based on the short-term benefits. Farming land in barley-livestock farming systems is, therefore, expected to deteriorate, leading to a decrease in grain and straw production.

Agricultural extension in the Ethiopian highlands should focus more on the long-term benefit of soil mulching to preserve soil health. Formal extension outreach had a statistically significant effect on farmers' greater use of barley straw as soil mulch. Interventions, training and extension services promoting context-specific crop residue management for both agriculture and livestock components are imperative to facilitate the optimal utilisation of barley straw in Ethiopian mixed farming systems.

Introducing new feed resources in barley-livestock farming systems would increase the feed supply to livestock. This would increase the use of barley straw as soil mulch. Improving straw yield besides grain yield via breeding would increase the supply of straw to not only meet livestock feed needs but also provide enough crop residues for soil mulching. More studies on decreasing post-harvest loss in barley straw should be undertaken. To discourage the excessive application of barley straw as mulch, agricultural extension workers should focus on farmers with remote crop fields and with limited access to equines. This can be part of a process that could evenly distribute and effectively utilise crop residues in mixed farming systems in Ethiopia, as well as other regions of the world.

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5

Chapter 5: Using Morphological Traits as Proxies for Selection of Food-Feed Barley Cultivars

Adapted from

Mulugeta Tilahun Keno, Taye Tolemariam, Solomon Demeke, Ashraf Alkhtib, Jane Wamatu Geert P. J. Janssens. (2022). Using morphological traits as proxies for selection of food-feed barley cultivars (submitted)

Abstract

Barley is a major crop in the world, widely used as food, malt and livestock feed. There is a need for a reliable and rapid screening method to be used as a proxy for on-farm screening of barley cultivars. This study evaluated the potential of morphological traits to screen barley cultivars for yield and nutritive quality traits of grain and straw, using 40 barley cultivars of food and malt barley types in two locations (Bekoji and Kofele) in Ethiopia. Straw and grain samples were analysed using near infrared reflectance spectroscopy for crude protein (leaves: 6.5-10.4%; stems: 2.3-3.2%), neutral detergent fibre (leaves: 65-68%; stems: 80-86%), acid detergent lignin (leaves: 4.7-5.4%; stems: 10-11.2%), and metabolisable energy (leaves: 6.7-7.1 MJ/kg DM; stems: 3.3-4.6 MJ/kg DM). Plant height (range: 91-111 cm), number of internodes (range: 4.5-8.7), number of spikes (range: 30-75), stem length (range: 89-105 cm), spike length (range: 6.9-15.9 cm), and leaf-to-stem ratio (range: 30-50%) were taken as morphological measurements. Multivariate regression analysis showed that morphological traits significantly predicted ($P<0.05$) grain and straw yield and quality traits, but with a weak degree of determination ($R^2<0.34$). Therefore, the studied plant morphology traits are not reliable proxies in food and malt barley cultivars for straw yield and nutritive value.

Keywords: *Hordeum vulgare*; straw; grain; feed; predictions

5.1. Introduction

Barley (*Hordeum vulgare L.*) is a multi-purpose crop with high economic and social importance. It is grown to produce grain for human and livestock consumption and malt for brewing (Kaso & Guben, 2015). Growing barley is associated with the production of large quantities of straw, which is extensively used as ruminant feed, especially during dry seasons in lower-income countries. In mixed farming systems, there is competition for the use of crop residues due to a high demand for the biomass for soil mulching and nutrients for livestock feeding (Alkhtib et al., 2017). Failure to ease this pressure might result in an increase in soil degradation and decrease in livestock productivity within farming units. Improving the nutritive value of crop residues using physical and chemical treatments, though hindered by technical and socio-economic factors, still does not ease this pressure because the treatments do not result in an increase in crop residue biomass.

Applying an appropriate breeding approach to improving straw yield and nutritive value requires the scanning of large quantities of cultivars for straw yield and nutritive value (Sharma et al., 2010). The use of the botanical structure of barley straw to rank cultivars for yield and nutritive value presents an alternative that is potentially cheaper, easier and faster to undertake compared with standard methods (e.g., direct measurement of straw yield and conventional laboratory determination of nutritive value). The genetic variation in morphological traits of barley straw are promising proxies for overall cultivar performance (Capper, et al., 1992; Habib et al., 1995; Goto et al., 1991; Ramanzin et al, 1986; Thomson et al., 1993). However, the available data do not confirm the possibility of using straw morphology to determine yield and nutritive value in barley, since the robustness of this method is not validated against large quantities of genotypes at multiple locations. Therefore, the current study aimed to test the hypothesis that morphological traits can be used to select for straw yield as well as for nutritive traits in barley to improve selection of superior food-feed cultivars in barley breeding.

5.2. Materials and methods

5.2.1. Grain and straw samples

Twenty genotypes of malt barley and twenty genotypes of food barley were triplicated separately in two locations in randomised complete block trials with plot sizes of 1.2m*2.5m each. Distance between plots and between blocks was 0.5 m and 1 m, respectively. The trial was undertaken during the main rainy season (June to September) at Kolomsa Agricultural

Research Centre at the Bekoji and Kofele sites. The Bekoji site is located at 7º 22' N and 39º15'E, with an elevation of 2800m above sea level, an average annual rainfall of 957 mm, and minimum and maximum temperatures of 2.3ºC and 20.5ºC, respectively. The Kofele site is located at 7 ºN and 38º 45' E, with an elevation of 2650 m above sea level, an average annual rainfall of 951 mm, and minimum and maximum temperatures of 3.3ºC and 20.5ºC, respectively. Both areas have acidic and loam soils and the agro-climatic condition of the areas is wet, and both have a unimodal rainfall pattern with extended rainy season from March to September, the peak rainy season being from June to August (Limeneh et al., 2021).

All plots received the same agronomic practices as per recommendations for barley growing in Ethiopia (Abera, 2018). Ten plants were randomly collected from each plot before harvest to measure plant height and number of internodes per plant. All above ground biomass of each plot was measured after harvesting at physiological maturity, air-dried for two weeks to a constant moisture, then threshed. Straw yield of each plot was calculated by subtracting grain yield from total biomass yield. Straw harvested from each plot was fractionated to determine proportion of leaf and stem. Representative samples of straw were taken from each plot, ground to pass through a 1-mm sieve, and then stored for nutritional analyses.

5.2.2. Grain and straw analyses

All grain and straw samples were analysed for crude protein (CP), neutral detergent fibre (NDF), acid detergent lignin (ADL), *in vitro* organic matter digestibility (IVOMD), and metabolisable energy (ME), using a combination of wet chemistry analyses and near-infrared reflectance spectroscopy (NIRS; Instrument FOSS 5000 Forage Analyzer with WINISI II software package in the 1108-2492 nm spectra range). A goodness-of-fit barley NIRS equation (Wamatu & Asmare, 2019) was used for the prediction of dry matter (DM), nitrogen, NDF, ADL, IVOMD, and ME. Validation of the NIRS equation was undertaken by analysing 20% of representative samples using conventional wet chemistry.

The standard error of calibration (and prediction) for barley straw was 0.37% (0.508%) for CP, 2.26% (2.38%) for NDF, 0.99% (0.36%) for ADL, and 1% (1.2%) for ME.

All chemical analyses were performed at the International Livestock Research Institute (ILRI) Animal Nutrition Laboratory in Addis Ababa, Ethiopia.

5.2.3. Calculations and statistical analyses

Average space between internodes was calculated by dividing plant height by the number of internodes. Stem length was calculated by subtracting spike length from plant height (Fig 2).

The potential of morphological traits as proxies for grain and straw yield and quality traits were analysed with the general linear model procedure in SPSS (IBM Corp., 2020).

Variation in morphological traits of studied barley cultivars was analysed according to the following model:

$$Y_{ijk} = M + G_i + Lo_j + B_k(L_i) + (G\times Lo)_{ij} + E_{ijk}$$

Where Y_{ijk} is the response variable, M is the mean, G_i is the effect of barley genotype I, L_j is the effect of the location j, $B_k(L_i)$ is the effect of the block k within k location I, $(G\times L)_{ij}$ is the interaction between the genotype and the location, and E_{ijk} is the random error.

Data for the nutritive value of straw fractions were analysed according to the following model:

$$Y_{ijkl} = M + G_i + Lo_j + F_k + B_l(L_i) + (G\times L)_{ij} + (G\times F)ik + (Lo\times F)jk + (G\times Lo\times F)ijk + E_{ijkl}$$

Where Y_{ijkl} is the response variable, M is the overall mean, + G_i the effect of genotype, Lo_j the effect of location. F_k is the effect of fraction, $B_l(Lo_i)$ is the effect of block within location, $(G\times L)_{ij}$ is the interaction between genotype and location, $(G\times F)_{ik}$ is the effect of the interaction between genotype and fraction, $(Lo\times F)_{jk}$ the effect of the interaction between location and fraction, $(G\times Lo\times F)_{ijk}$ is the effect of genotype-location-fraction interaction, and E_{ijkl} is the residual. Least significant difference at $P\leq0.05$ was used for the multiple comparisons.

5.3. Results

5.3.1. Variation in morphological traits

Morphology parameters of straw were significantly ($P<0.05$) influenced by genotype, location, and their interaction in food and malt barley. Genotype, location fraction, genotype-location interaction significantly ($P<0.05$) affected plant height, number of internodes per plant, number of spikes/plant and proportion of leaf in food and malt barley.

A wide variation was observed in plant height, ranging from 84 to 121 cm and 93 to 115 cm for food and malt cultivars, respectively. Stem length ranged from 77 to 113 cm and 78 to 107 cm for food and malt cultivars, respectively; the number of internodes per plant ranged from

4.4 to 5.6 and 4.4 to 5.6 for food and malt cultivars, respectively; the number of spikes per plant ranged from 5.3 to 7.6 and 2.7 to 9.2 for food and malt cultivars, respectively. Finally, the leaf proportion ranged from 0.19 to 0.51 and 0.26 to 0.59 for food (Table 5.1) and malt (Table 5.2) cultivars, respectively.

Table 5.1: Variation of morphological traits of food barley cultivars grown at two locations

Cultivar	PH	NI	SPL	STL	NS	Leaf proportion
ICARDA GP P# 44	112	5.3	7.2	105	62	0.4
IBON HI 13/14-P# 53	105	5.1	6.9	99	70	0.4
IBON HI 13/14-P# 74	109	5.2	7.0	102	67	0.3
HB1966	104	5.2	7.0	97	71	0.3
MBF4 P#+2015	108	5.1	7.5	101	73	0.4
ICARDA GP P# 127	105	5.0	7.4	97	71	0.3
IBON HI 13/14-P# 85	102	4.9	7.2	94	72	0.3
IBON HI 14/15-P# 155	108	5.4	7.0	101	71	0.4
IBON HI 13/14-P# 91	101	4.9	7.0	94	71	0.3
IBON HI 13/14-P# 113	109	5.3	7.0	102	60	0.3
EH1493	104	5.0	7.2	97	70	0.3
HB1307	101	5.2	7.1	94	68	0.3
IBON HI 13/14-P# 23	102	5.1	7.1	95	70	0.3
IBON HI 13/14-P# 109	110	5.3	7.0	103	71	0.3
MBF4 +2015 P# 1	102	4.8	7.5	95	74	0.3
IBON HI 14/15-P# 165	107	5.3	7.7	99	75	0.4
IBON HI 14/15-P# 116	104	5.3	7.2	97	67	0.3
IBON HI 13/14-P# 81	111	5.3	7.2	104	69	0.4
IBON HI 14/15-P# 143	111	5.5	6.9	104	66	0.3
IBON HI 13/14-P# 31	102	5.2	7.5	95	73	0.4
Mean	106	5.17	7.18	99	70	0.34
SEM	5.437	0.249	0.512	5.54	6.13	0.017
LSD (0.05)	10.82	0.495		10.84	12.2	0.34
CV (%)	5.1	4.8	7.1	5.6	8.8	5

PH, plant height (cm); NI, number of internodes per plant; SPL, spike length (cm); STL, stem length (cm); NSP, number of spikes per plant; LP, leaf proportion; LSD, least significant difference; CV, coefficient of variation.

Table 5.2: Variation of morphological traits of malt barley cultivars grown at two locations

Cultivar	PH	NI	SPL	STL	NS	Leaf proportion
IBON-HI14/15-104	104	4.5	7.9	96	42	0.4
NDICARDAMB-190	109	5.3	8.0	101	36	0.5
NDICARDAMB-320	103	5.1	8.8	94	39	0.5
HB1963	103	4.9	7.3	95	36	0.4
USDF5-27	107	5.2	8.3	99	36	0.4
IBON-HI14/15-144	104	5.0	7.8	96	46	0.4
IBON-HI13/14-129	103	4.6	7.5	96	47	0.4
MBHIBYT-22	104	5.2	7.8	96	52	0.4
Traveller	110	5.3	6.9	103	49	0.4
IBON-HI13/14 -49	101	4.9	7.5	93	36	0.4
NDICARDAMB-185	105	4.8	8.2	96	37	0.4
IBON-HI14/15-148	91	4.8	7.5	84	43	0.5
MBBELGIUM-30	98	5.0	7.4	91	38	0.4
IBON-HI13/14-128	110	5.0	7.8	102	34	0.4
IBON174/03	105	4.9	7.9	97	33	0.3
IBON-HI14/15-153	103	4.9	7.4	95	42	0.4
ICARDA GP-75	97	4.9	7.3	90	36	0.5
ICARDA GP-67	102	4.9	7.4	94	30	0.5
IBON-HI14/15-126	96	4.6	7.2	89	36	0.5
USDF5-11	105	5	7.9	89	35	0.4
Mean	103	4.9	7.7	95	39	0.42
SEM	6.14	0.22	0.38	0.49	6.14	0.07
LSD(0.05)	12.2	0.44	0.76	8.9	12.22	0.14
CV (%)	6	4.5	4.9	0.5	15.7	16.7

PH, plant height (cm); NI, number of internodes per plant; SPL, spike length (cm); STL, stem length (cm); NSP, number of spikes per plant; LP, leaf proportion; LSD, least significant difference; CV, coefficient of variation.

5.3.2. Effect of location, genotypes and plant fraction on straw nutritive value

Effects of genotype, location, fraction, location×fraction and genotype×location×fraction on CP, NDF, ADL and ME were significant ($P \leq 0.05$) in food (Table 5.3) and malt barley (Table

5.4). Leaves of malt barley had higher CP and less NDF compared to stems of either malt or food barley across both locations. Leaves also had higher ME compared with stems across the locations.

Table 5.3: Nutritional composition of the straw of food barley cultivars grown at two locations

Cultivar	Fraction	CP (% of DM)	ADL (% of DM)	NDF (% of DM)	Metabolisable energy MJ/kg DM
ICARDA GP P# 44	Stem	2.7	11.0	85	3.4
	Leaf	7	5.1	68	6.8
IBON HI 13/14-P# 53	Stem	2.4	11.1	86	3.4
	Leaf	7.6	5.0	67	6.8
IBON HI 13/14-P# 74	Stem	2.8	10.9	85	3.7
	Leaf	7.1	5.4	66	6.8
HB1966	Stem	2.6	10.9	85	3.3
	Leaf	6.4	5.4	68	6.8
MBF4 P#+2015	Stem	2.9	11.1	85	3.8
	Leaf	8.8	4.9	65	6.9
ICARDA GP P# 127	Stem	3	10.2	83	4.3
	Leaf	7.6	5.0	66	6.9
IBON HI 13/14-P# 85	Stem	2.8	10.2	83	3.9
	Leaf	6.5	5.0	67	6.9
IBON HI 14/15-P# 155	Stem	2.9	10.9	84	3.3
	Leaf	6.6	4.9	66	7
IBON HI 13/14-P# 91	Stem	2.3	10.9	86	3.4
	Leaf	7.5	5.2	66	7
IBON HI 13/14-P# 113	Stem	2.5	10.8	85	3.5
	Leaf	7	4.7	66	6.8
EH1493	Stem	2.9	10.5	83	3.5
	Leaf	6.9	5.1	65	7
HB1307	Stem	3.1	10.0	82	4
	Leaf	7.1	5.1	66	6.8
IBON HI 13/14-P# 23	Stem	2.9	10.4	84	3.8
	Leaf	8.4	5.2	64	7
IBON HI 13/14-P# 109	Stem	2.4	11.2	86	3.3

	Leaf	6.7	5.0	67	6.8
MBF4 +2015 P# 1	Stem	2.7	10.7	84	3.7
	Leaf	7.3	4.9	67	6.9
IBON HI 14/15-P# 165	Stem	2.6	10.6	84	3.6
	Leaf	7	5.3	66	7
IBON HI 14/15-P# 116	Stem	2.7	10.8	85	4
	Leaf	6.8	4.9	67	6.9
IBON HI 13/14-P# 81	Stem	2.8	10.8	84	3.9
	Leaf	6.8	5.1	67	6.7
IBON HI 14/15-P# 143	Stem	2.4	10.9	85	3.4
	Leaf	6.4	5.0	67	6.9
IBON HI 13/14-P# 31	Stem	2.7	10.7	85	3.9
	Leaf	7.2	5.1	67	7
Mean	Stem	2.7	10.7	84	3.7
	Leaf	7.1	7.9	66	6.9
SEM		0.9	0.27	1.2	0.27
LSD (0.05)		2.5	1.04	3.5	0.73

DM, dry matter; LSD, least significant difference; CP, crude protein; NDF, neutral detergent fibre; ADL, acid detergent lignin.

Table 5.4: Nutritional composition of the straw of malt barley cultivars grown at two locations

Cultivar	Fraction	CP (% of DM)	ADL (% of DM)	NDF (% of DM)	Metabolisable energy
IBON-HI14/15-104	Stem	2.8	10.1	83	4.5
	Leaf	8.1	5.2	67	6.9
NDICARDAMB-190	Stem	3	9.4	81	4.6
	Leaf	9.1	5.2	66	6.8
NDICARDAMB-320	Stem	3	9.2	80	4.6
	Leaf	9.3	5.4	66	6.9
HB1963	Stem	2.5	10.2	84	3.9
	Leaf	8	6.2	69	6.8
USDF5-27	Stem	2.8	9.9	82	4.3
	Leaf	8.8	5.2	66	6.9
IBON-HI14/15-144	Stem	2.9	10.4	83	3.9
	Leaf	9.3	6.4	69	6.9
IBON-HI13/14-129	Stem	2.8	9.3	82	4.7
	Leaf	7.8	5.0	66	7.1
MBHIBYT-22	Stem	3.2	10.0	82	4.4
	Leaf	9.3	5.3	66	7.2
Traveller	Stem	2.6	10.1	84	4.6
	Leaf	8	4.9	66	6.7
IBON-HI13/14 -49	Stem	2.6	9.9	83	4.4
	Leaf	7.8	5.0	67	7
NDICARDAMB-185	Stem	3.1	10.3	82	4.1
	Leaf	8.8	5.2	66	7.1
IBON-HI14/15-148	Stem	2.9	9.7	82	4.1
	Leaf	9.4	5.3	65	6.9
MBBELGIUM-30	Stem	2.4	9.8	82	4.3
	Leaf	7.3	4.8	66	7
IBON-HI13/14-128	Stem	2.7	10.2	82	3.9
	Leaf	8.3	5.4	67	6.7
IBON174/03	Stem	2.8	9.7	82	4.4
	Leaf	7.9	4.8	65	7
IBON-HI14/15-153	Stem	2.6	10.4	83	3.7
	Leaf	8.2	5.1	66	7
ICARDA GP-75	Stem	3	10.0	84	4.8
	Leaf	8.3	5.4	68	6.8

ICARDA GP-67	Stem	2.8	9.9	82	4.4
	Leaf	8.8	4.8	66	7
IBON-HI14/15-126	Stem	2.6	9.8	83	4.5
	Leaf	7.9	4.9	67	7
USDF5-11	Stem	2.9	9.6	82	4.5
	Leaf	10.4	5.1	64	7.1
Mean	Stem	5.7	9.9	74	4.3
mean	Leaf	8.5	5.2	66	6.9
SEM		0.95	0.45	1.75	0.27
LSD (0.05)		2.6	0.95	4.9	0.76

DM, dry matter; LSD : least significant difference; CP, crude protein; NDF, neutral detergent fibre; ADL, acid detergent lignin.

5.3.3. Potential of morphological traits to predict grain and straw yield and grain and straw nutritive value

As presented in Table 5.5, multivariate regression revealed a significant but weak prediction of straw yield through morphology traits (($F(5,234)=16.572$, $p<0.001$, $R^2=0.262$), a similar result was noted for straw CP ($F(5,234)=20.798$, $p<0.001$,$R^2=0.307$), straw NDF ($F(5,234)=4.043$, $p<0.005$, $R^2=0.080$), and straw ME ($F(5,234)=8.551$, $p<0.001$, $R^2=0.154$).

Again, multivariate regression revealed a significant but weak prediction of grain yield through morphology traits ($F(5,234)=24.019$, $p<0.001$, $R^2=0.339$), similar results were observed for grain CP ($F(5,234)=18.156$, $p<0.001$, $R^2=0.279$), for NDF ($F(5,234)=4.212$, $p<0.005$, $R^2=0.063$), and for ME ($F(5,234)=27.417$ $p<0.001$, $R^2=0.369$).

Table 5.5: Linear regression coefficient of yield and nutritive values of straw and grain of barley cultivars based on morphological traits of food and malt barley grown at two locations in the Ethiopian highlands during the 2018 cropping season.

	Constant	Morphology					R^2	P
		NI	SPL	STL	NSP	LP		
Straw yield	1.557	0.035	0.195	0.057	-0.035	-0.991	0.262	<0.001
	(1.078)	(0.096)	(0.056)	(0.009)	(0.005)	(0.841)		
Straw CP	-2.379	-.0146	0.255	0.067	-0.016	2.297	0.307	<0.001
	(0.912)	(0.081)	(0.047)	(0.008)	(0.005)	(0.711)		
Straw NDF	69.989	0.027	-0.151	0.067	-0.002	-1.671	0.080	0.001
	(2.150)	(0.191)	(0.112)	(0.018)	(0.011)	(1.676)		
Straw ME	5.787	0.009	0.032	-0.006	-0.005	0.379	0.154	<0.001
	(0.249)	(0.022)	(0 .013)	(0.002)	(0.001)	(0.194)		
Grain yield	1.402	-0.058	0.197	0.048	-0.028	-0.954	0.339	<0.001
	(0.756)	(0.067)	(0.039)	(0.006)	(0.004)	(0.589)		
Grain CP	6.362	-0.124	0.257	0.064	-0.026	-1.894	0.279	0.002
	(1.048)	(0.093)	(0.054)	(0.009)	(0.005)	(0.817)		
Grain NDF	31.730	-0.724	-0.128	0.171	0.020	-4.428	0.063	0.001
	(5.594)	(0.497)	(0.290)	(0.047).	(0.028)	(4.362)		
Grain ME	6.762	-0.136	0.336	0.071	-0.054	-0.505	0.369	<0.001
	(1.182)	(0.105)	(0.61)	(0.010)	(0.006)	(0.923)		

Predictors in the model: NI, number of internodes per plant; SPL, spike length (cm); STL, stem length (cm); NSP, number of spikes per plant; and LP, leaf proportion. CP, crude protein; NDF, neutral detergent fibre; and ME, metabolisable energy. Values in parentheses are standard errors.

Figures 4, 5, 6 and 7 show the predicted and measured value of straw yield, CP, NDF, and ME, respectively.

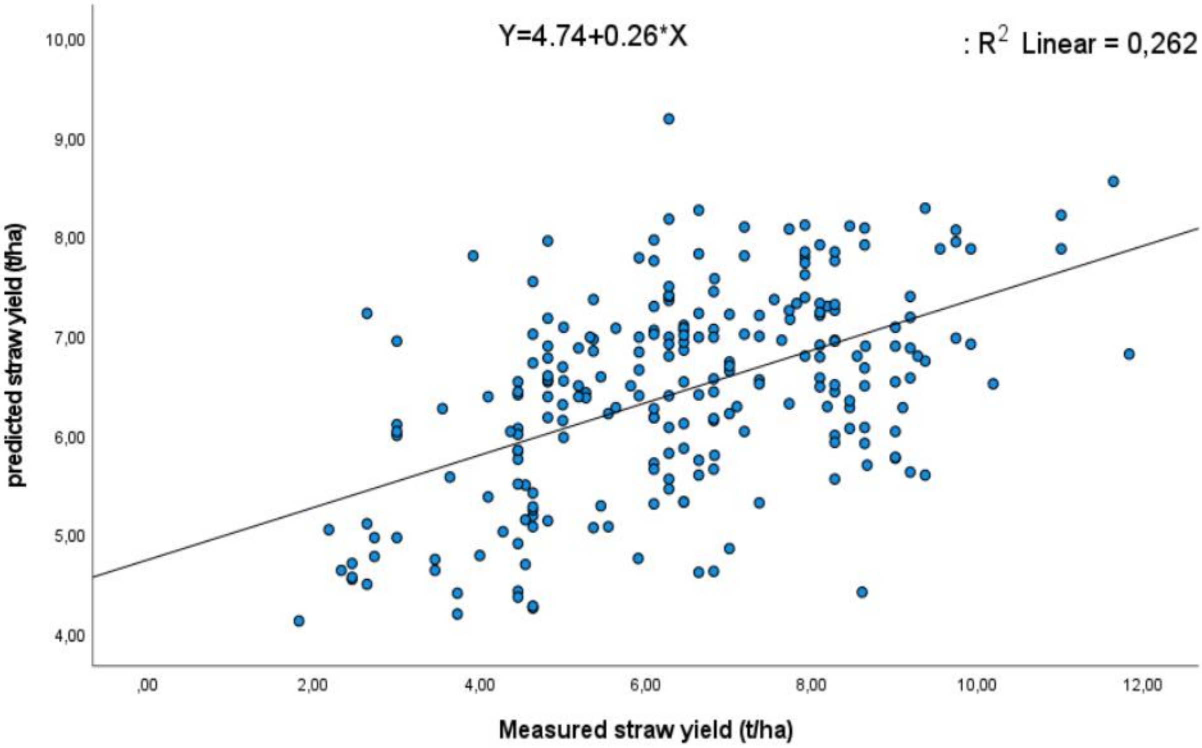

Figure 4. Predicted *versus* measured value of straw yield of barley varieties grown at two locations in the Ethiopian highlands during the 2018 cropping season.

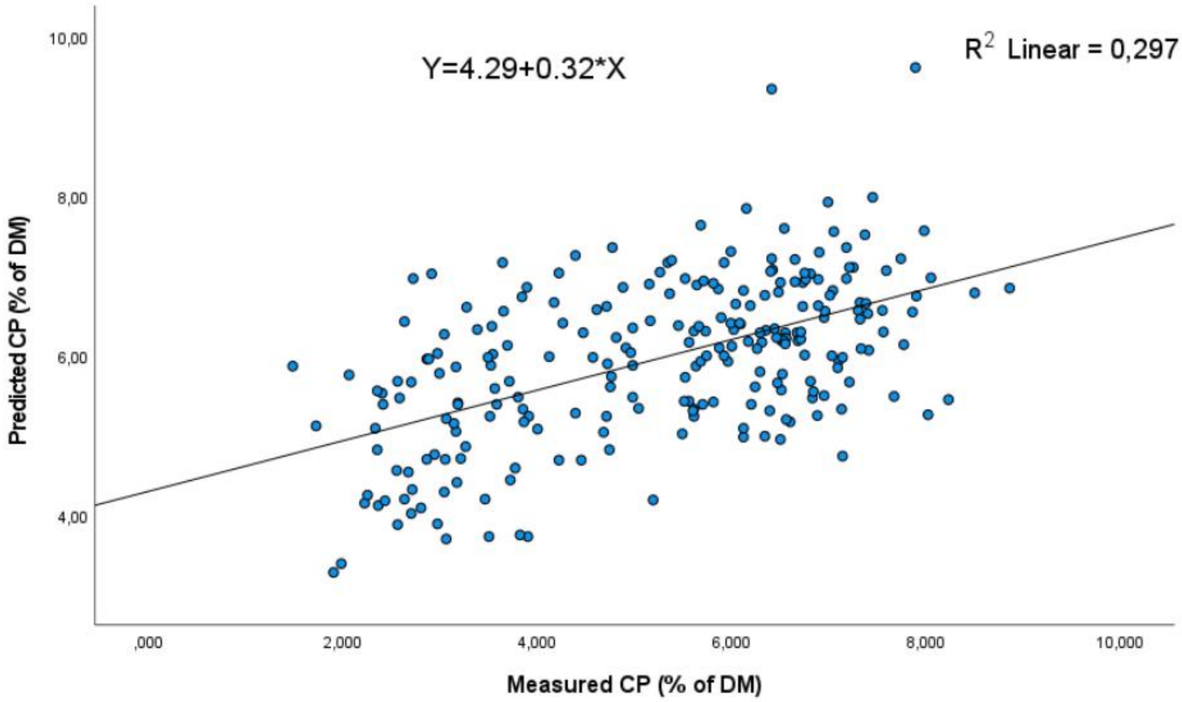

Figure 5. Predicted *versus* measured value of straw crude protein concentrations of barley varieties grown at two locations in the Ethiopian highlands during the 2018 cropping season.

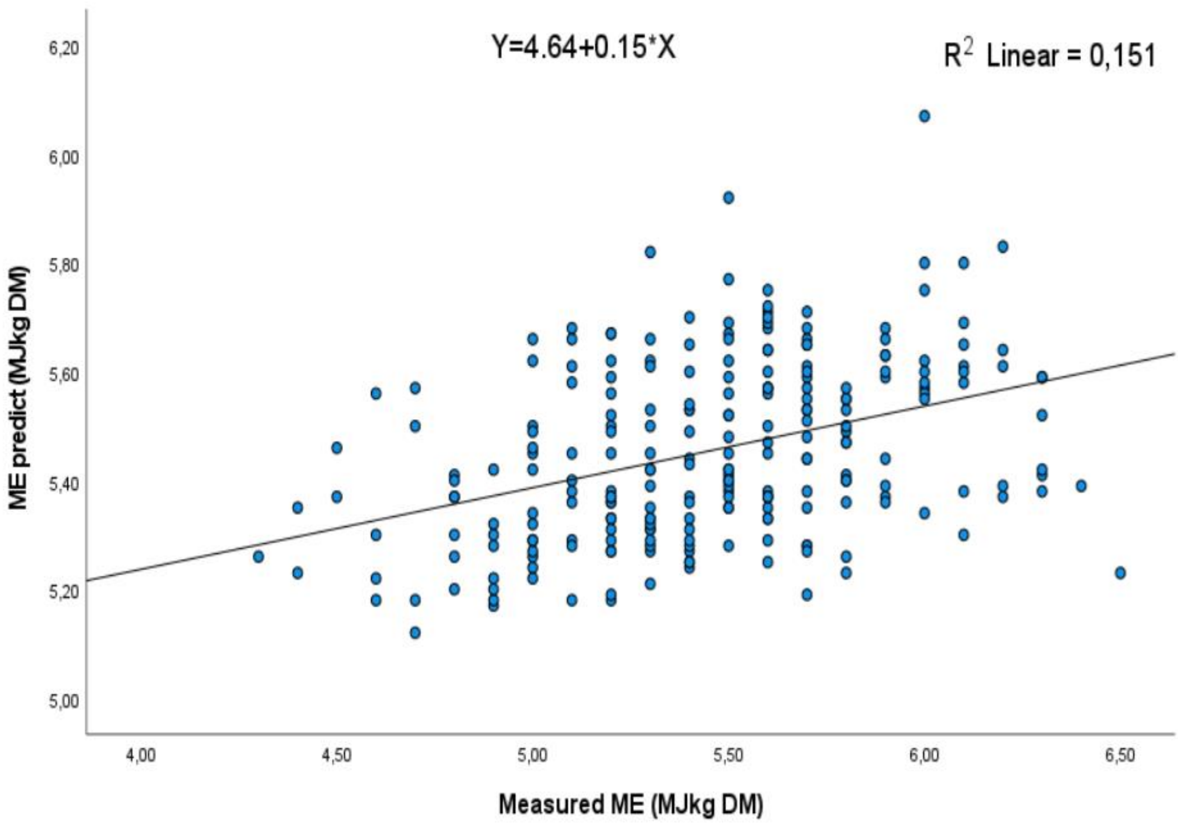

Figure 6. Predicted *versus* measured metabolisable energy concentrations of straw nutritive value of barley varieties grown at two locations in the Ethiopian highlands during the 2018 cropping season.

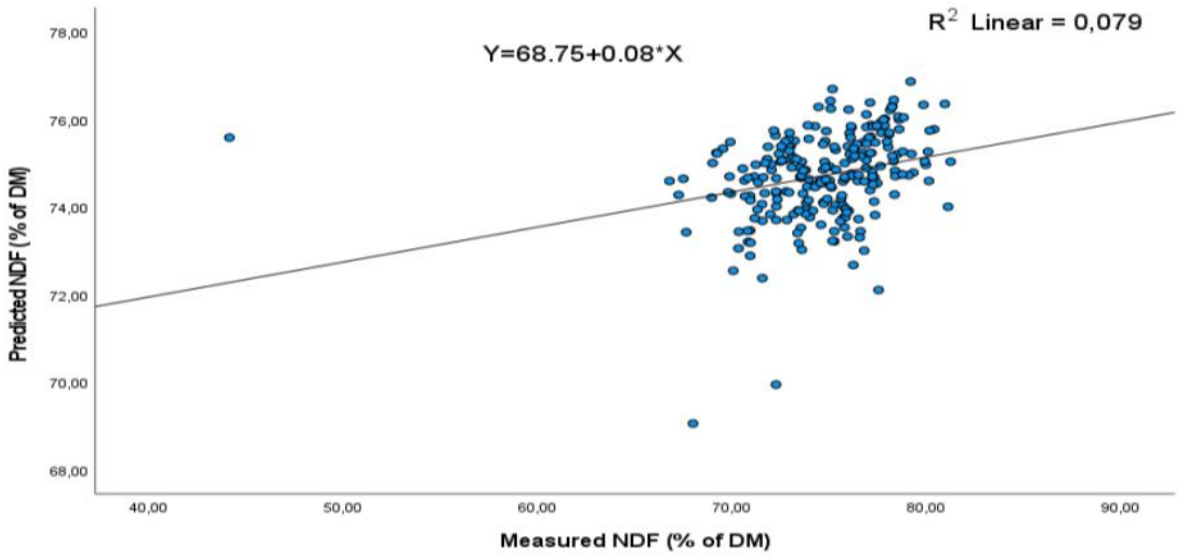

Figure 7. Predicted *versus* measured value of straw neutral detergent fibre concentrations of barley varieties grown at two locations in the Ethiopian highlands during the 2018 cropping season.

5.4. Discussion

For the selection of superior food-feed cultivars, a rapid but reliable method of screening cultivars for grain yield, straw yield and nutritive value is warranted (Sharma et al., 2010). Because dual-purpose use is mostly aimed for by tropical farmers, the main criteria to select new cereal cultivars are straw yield and nutritive value, in addition to grain traits. Measuring straw yield and nutritive value is time-consuming and laborious. The use of plant morphology traits as proxies to straw yield and nutritive value would therefore have been a time- and cost-saving strategy. The wide variation in plant morphology observed among the studied genotypes at least suggested the potential of using plant morphology as selection criteria.

The multivariate regression analysis indeed showed that plant height, stem length, number of internodes per plant, and number of spikes per plants significantly predicted the straw yield. Unfortunately, the low determination coefficients point to a rather low reliability of the models, leaving about 75% of variation explained by other, unknown factors. Hence, the morphological traits studied here were not strong enough to screen barley cultivars for straw yield, straw CP, straw NDF, or straw ME.

Until other easy-to-measure parameters are identified, straw yield should still be directly recorded in breeding programmes targeting straw yield improvement of food and malt barley. Studies in chickpea and sorghum also failed to find strong relationships between plant morphology and performance (Blümmel, et al, 2010; Ertiro et al., 2013; Wamatu et al., 2017) but no information was available on barley prior to this study.

Leaf material of food and malt barley straw had generally superior ME concentrations compared with stem across all locations, but not in all genotypes, which means that straw with more leaf does not necessarily supply greater ME. Therefore, leaf proportion cannot be used to rank food and malt barley genotypes for straw nutritive value. Furthermore, CP, NDF, and ME of food and malt barley straw should be directly determined in any barley breeding programme targeting improving straw nutritive value.

Although the regression equations showed a low predictive strength, the sense of the associations between plant morphology traits, on the one hand, and yield and nutritive value, on the other hand, were logical. For example, a plant with more internodes likely contains more fibre to support these nodular structures. The number of internodes related positively with the NDF concentration, at the expense of the CP concentration.

A remarkable negative impact of the number of internodes was observed on the grain performance, suggesting that the effort to make internodes reduces the plant's capacity to invest in its seeds. Spike length behaved rather differently, since its length seemed to relate to the plant's investment in seed production, although it was still positively associated with straw yield. The latter may point to the fact that larger spikes go with larger plants. This agrees with the data on stem length, which relates positively to straw yield, but also to grain yield and its nutritive value. Whereas one might postulate that the number of spikes per plant may determine its grain yield, this was not the case and was even associated with lower grain nutritive value. We speculate that a greater number of spikes may have required too much energy and nutrients, leading to smaller spikes with less nutritive grains.

Finally, a higher leaf proportion obviously gave a higher nutritive value for the straw (more CP and ME, less NDF) because of the lower degree of lignification in leaves versus stems, but this was at the expense of the overall straw and grain yield, as well as the nutritive value of the grain. It is most likely that these cultivars developed more slowly, hence still showing many leaves but not yet using energy and nutrients to form large spikes and grains, in line with the report of Wang (2014).

5.5. Conclusions

In conclusion, morphological parameters (plant height, stem length, number of spikes per plant, number of internodes per plant, and space among internodes) are not reliable proxies for straw yield and nutritive value in food and malt barley cultivars. Accordingly, straw yield and nutritive value should still be measured directly in any barley breeding programme. Yet, the associations observed between plant morphology and cultivar performance may help in setting specific selection goals.

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6

Chapter 6: Food-Feed Performance of Food and Malt Barley Cultivars in Ethiopian Highlands

Adapted from

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Abstract

In Ethiopia, barley selection has focused on grain yield traits. Limited information is available on straw yield and its nutritive value. The aim of this study was to screen cultivars for grain and straw yield and nutritive value, using forty cultivars of food and malt barley types at two locations in Ethiopia (Bekoji and Kofele) in 2018. Food-fodder quality traits investigated were crude protein (CP), neutral detergent fibre (NDF), and metabolisable energy (ME) of grain and straw. Location, cultivar, and their interaction affected the performance in malt as well as food barley types. Wide cultivar differences were observed within food and malt types, respectively; grain CP: 10.2-12.2% and 11.41-13.3%, grain NDF: 40.2-52.7% and 38-42.9%, grain acid detergent lignin: 0.8-1.5 and 0.7-1.3%, grain *in vitro* organic matter digestibility: 78.3-83.9 and 82-88 %, grain ME: 9.9-12.3MJ/kg and 12.1-14.5 MJ/kg, straw CP: 4.1-5.7% and 4.9-6.2%, straw NDF: 73.5-76.7% and 72.9-76.1%, and straw ME: 5-5.6 MJ/kg and 5.3-5.8 MJ/kg. Across locations, IBON174/03 produced the most grain (6.95 t/ha), Traveller produced the most straw (9.1t/ha), and HB1963 was relatively high in both straw (8.4t/ha) and grain yield (6.4t/ha), making it an interesting food-feed cultivar.

Therefore IBON174/03, Traveller, and HB1963 are promising barley cultivars for the study area.

Key words: food-feed, cultivar, barley, straw

6.1. Introduction

Barley (*Hordeum vulgare L.*) is the fourth most important cereal crop in terms of worldwide grain production (FAOSTAT, 2017). The lower-income countries contribute to more than half of the land area planted with barley crops. Moreover, barley is a multi-purpose crop with high economic and social importance. It is grown to produce grain for human consumption, straw for livestock consumption, and malt for brewing (Kaso & Guben, 2015). However, growing barley is associated with the production of large quantities of straw, which is used extensively as ruminant feed, especially in lower-income countries during dry seasons.

According to the report of Jaleta et al. (2015), cereal straws (barley teff and wheat) appear to be preferred as livestock feed by the farmers and contribute about 77-88% of animal feed in mixed crop-livestock system. However, of the cereals, barley is higher than teff and wheat for livestock feed (Bediye et al., 2020).

It has been reported that crop residue biomass and nutritive value are key determinants in varietal selection by farmers in mixed crop-livestock systems (Schiere et al., 2004; Traxler and Byerlee, 1993; Capper et al., 1988, 1986a). Consequently, livestock researchers and crop breeders have launched research themes to upgrade straw yield and nutrient composition alongside grain yield using plant breeding approaches in pulses (Alkhtib et al., 2017; Blümmel et al., 2010; Wamatu et al., 2017) and cereals (Bezabih et al., 2018; Ertiro et al., 2013; Jensen et al., 2011; Schiere et al., 2004).

Exploiting differences in feed traits of barley types could provide novel breeding targets for new barley varieties with potentially higher food and livestock feed value that would be particularly useful in a range of diverse environments in mixed crop-livestock systems. Thus, the current study aimed to identify superior cultivars in terms of grain yield, straw yield and food-feed potential (dual-purpose use) for mixed farming systems in the Ethiopian highlands.

6.2. Materials and methods

6.2.1. Experimental sites and design

The study was conducted at Kulumsa Agricultural Research Centre’s Bekoji and Kofele experimental sites. The agro-ecological description of the experimental sites is presented in Table 6.1.

Table 6.1: Altitude, soil types and climatic variables of the study sites for barley cultivar evaluation

Site	Altitude (m)	Ecology	Soil type	Rainfall (mm)	Temperature (°C)	
					Minimum	Maximum
Bekoji	2780	Highland	Clay (nitosols)	1020	7.9	18.6
Kofele	2620	Highland	Eutric vertisols	1036	7.5	19.6

The experiment comprised twenty food cultivars and twenty malt cultivars. The cultivars were planted using randomised complete block design with three replications during the main cropping season (June to November) under rain-fed condition, with a plot size of 2.5 m × 1.2 m. Spacing between plots and blocks was 0.5 m and 1 m, respectively. All plots were equally managed as per recommended agronomic practices for barley growing in Ethiopia.

6.2.2. Data collection and sampling

At physiological maturity, all above ground biomass of each plot was harvested and air-dried for two weeks to a constant moisture. Plots were manually harvested over 4 middle rows of each plot and the total biomass yield was taken, then threshed. Straw yield of each plot was calculated by subtracting grain yield from total biomass yield. Representative samples from each plot were taken and ground to pass through a 1-mm sieve, then stored for nutritional analyses.

6.2.3. Laboratory evaluation

Grain and straw samples were oven-dried for 24h at 100°C, sieved through a 1 mm mesh, and analysed for crude protein (CP), neutral detergent fibre (NDF), acid detergent lignin (ADL), metabolisable energy (ME), and *in vitro* organic matter digestibility (IVOMD) using near-infrared spectroscopy (NIRS). The NIRS analyses were performed on 3 g of ground sample using Foss NIRS 5000 in the 1108-2492 nm range with a 8 nm step. Before scanning, the samples were pre-dried at 60°C overnight in an oven to standardise moisture conditions.

The standard error of calibration (and prediction) for barley straw was 0.37% (0.508%) for CP, 2.26% (2.38%) for NDF, 0.99% (0.36%) for ADL, 1% (1.2%) for ME, and 0.5% (0.7%) for IVOMD, respectively. The standard error of calibration (and prediction) for barley grain was 0.403 (0.982) for CP, 1.63 (0.944) for ND, 0.36 (0.98) for ADL, 0.52 (0.85) for IVOMD, and

0.045 (0.8832) for ME. All chemical analyses were performed at the International Livestock Research Institute (ILRI) Animal Nutrition Laboratory in Addis Ababa, Ethiopia.

6.2.4. Calculations and statistical analyses

A general linear model was used to test the effect of cultivar on grain yield, straw yield and potential utility index (PUI).

PUI, which estimates the proportion of utilisable portion of total barley biomass for food and feed was calculated according to the following equations:

$$PUI = \frac{GY + 0.01 \times IVOMD \times SY}{GY + SY}$$

Where PUI is potential utility index (W/W), GY is grain yield (t/ha), SY is straw yield (t/ha), and IVOMD is *in vitro* organic matter digestibility (analysed by NIRS and expressed as %).

HI, which estimates the proportion of grain yield (GY) to total barley biomass (GY+SY) was calculated as:

$$HI = \frac{GY}{GY + SY}$$

Where HI is harvest index (W/W), GY is grain yield (t/ha), and SY is straw yield (t/ha).

Data from the study were subjected to the analysis of variance according to the following model:

$$Y_{ijk} = M + G_i + Lo_j + B_k(L_i) + (G \times Lo)_{ij} + E_{ijk}$$

Where Y_{ijk} is the response variable, M is the mean, G_i is the effect of barley cultivar i, L_j is the effect of the location j, $B_k(L_i)$ is the effect of the block k within k location i, $(G \times L)_{ij}$ is the interaction between the cultivar and the location, and E_{ijk} is the random error.

6.3. Results

6.3.1. Grain yield, straw yield, and potential utility index cross locations

The grain yield performance of malt barley ranged from 5.2 t/ha to 6.9 t/ha. The highest grain yield was recorded for cultivars IBON174/03 (6.9 t/ha), USDF5-27 (6.5 t/ha), and IBON-HI13/14-49 (6.4 t/ha), and the lowest yield was recorded for cultivar IBON-HI14/15-126 (5.2 t/ha) (Table 5.2).

Table 6.2: Grain yield, straw yield, potential utility index, harvest index and rank of twenty malt barley cultivars grown in the highlands of Ethiopia in the 2018 cropping season

Cultivar	Grain yield t/ha	Straw yield t/ha	PUI t/t	HI	Rank
IBON-HI14/15-104	5.9	5.9	0.696	0.504	4
NDICARDAMB-190	6.2	7.5	0.683	0.458	12
NDICARDAMB-320	5.8	7.0	0.682	0.462	15
HB1963	6.4	8.0	0.704	0.431	2
USDF5-27	6.5	7.0	0.692	0.483	5
IBON-HI14/15-144	5.3	6.7	0.683	0.444	13
IBON-HI13/14-129	6.1	7.0	0.683	0.470	14
MBHIBYT-22	5.2	6.8	0.672	0.433	20
Traveller	6.1	9.1	0.697	0.401	3
IBON-HI13/14 -49	6.5	7.9	0.692	0.449	6
NDICARDAMB-185	5.8	7.1	0.679	0.453	17
IBON-HI14/15-148	4.6	5.6	0.692	0.465	7
MBBELGIUM-30	5.4	7.2	0.674	0.433	19
IBON-HI13/14-128	6.5	7.4	0.691	0.466	8
IBON174/03	6.9	8.0	0.723	0.465	1
IBON-HI14/15-153	5.5	6.5	0.690	0.467	9
ICARDA GP-75	5.6	7.1	0.687	0.446	11
ICARDA GP-67	5.7	7.2	0.677	0.442	18
IBON-HI14/15-126	5.2	6.6	0.681	0.443	16
USDF5-11	6.1	7.3	0.689	0.458	10
Mean	5.9	7.2	0.688	0.454	
SEM	0.6	0.9	0.016	0.024	
LSD(0.05)	1.7	2.6	0.050	0.071	
CV%	10.2	12.5			

PUI, potential utility index; HI, harvest index; LSD, least significant difference; CV, coefficient of variation. Cultivars are ranked according to PUI value. Averages combining both growing locations (Bekoji and Kofele) are shown.

The straw yield performance of malt barley ranged from 5.5 t/ha to 9.1 t/ha. Traveller (9.1 t/ha), HB1963 (8.4 t/ha), and IBON174/03 (8.0 t/ha) showed the highest grain yield whereas IBON-HI14/15-148 showed the lowest (5.6 t/ha) (Table 5.2). The potential utility index of malt barley ranged from lowest in MBHIBYT-22 (0.69) to highest in IBON174/03 (0.72) (Table 6.2).

The grain yield performance of food barley ranged from 4.0 t/ha to 5.8 t/ha. The highest grain yield was recorded for cultivars EH1493 (5.8 t/ha), ICARDA GP P# 44 (5.4 t/ha), and IBON-HI 13/14-P# 113 (5.2 t/ha), whereas the lowest yield was obtained for IBON-HI 13/14-P# 31 (4.0 t/ha) (Table 6.3).

The straw yield of food barley ranged from 4.0 t/ha to 6.9 t/ha. Cultivars EH1493 (6.9 t/ha), IBON-HI14/15 P#155 (6.5 t/ha), and HB1966 (6.4 t/ha) produced the most straw. The lowest straw yield was recorded for IBON-HI 13/14-P#31 (4.5 t/ha) (Table 6.3).

The potential utility index of food barley ranged from 0.67-0.70. Based on the PUI, IBON-HI 13/14-P# 85 (0.70), ICARDA GP P# 44 (0.70), and IBON-HI 14/15-P# 165 (0.70) were the three best cultivars (Table 6.3).

Table 6.3: Grain yield, straw yield, potential utility index, harvest index and rank of twenty food barley cultivars grown in the highlands of Ethiopia in the 2018 cropping season

Cultivar	Grain yield t/ha	Straw yield t/ha	PUI t/t	HI	Rank
ICARDA GP P# 44	5.4	6.0	0.701	0.521	2
IBON HI 13/14-P# 53	4.4	5.6	0.669	0.569	19
IBON HI 13/14-P# 74	4.7	5.6	0.688	0.541	9
HB1966	5.2	6.4	0.677	0.552	17
MBF4 P#+2015	4.6	5.7	0.680	0.559	15
ICARDA GP P# 127	4.4	5.3	0.690	0.537	7
IBON HI 13/14-P# 85	5.1	5.6	0.703	0.516	1
IBON HI 14/15-P# 155	5.1	6.5	0.676	0.560	18
IBON HI 13/14-P# 91	4.9	5.5	0.688	0.535	10
IBON HI 13/14-P# 113	5.2	6.4	0.678	0.550	16
EH1493	5.8	6.9	0.683	0.551	13
HB1307	5.2	6.2	0.686	0.538	11
IBON HI 13/14-P# 23	4.7	5.6	0.694	0.544	6
IBON HI 13/14-P# 109	4.4	5.3	0.696	0.537	5
MBF4 +2015 P# 1	4.5	5.9	0.668	0.565	20
IBON HI 14/15-P# 165	4.4	5.0	0.700	0.522	3
IBON HI 14/15-P# 116	4.2	4.9	0.689	0.539	8
IBON HI 13/14-P# 81	4.5	5.4	0.683	0.548	14
IBON HI 14/15-P# 143	4.9	5.9	0.684	0.540	12
IBON HI 13/14-P# 31	4.0	4.5	0.699	0.524	4
Mean	4.8	5.7	0.687	0.542	
SEM	0.6	0.8	0.018	0.026	
LSD(0.05)	1.7	1.1	0.050	0.036	
CV (%)	12.5	14			

PUI, potential utility index; HI, harvest index; LSD, least significant difference; CV, coefficient of variation. Cultivars are ranked according to PUI value. Averages combining both growing locations (Bekoji and Kofele) are shown.

6.3.2. Grain and Straw Nutritive Quality

A wide range in grain nutrient and energy concentration was observed across the cultivars for food and malt barley cultivars, respectively, as follows: grain CP was 10.2-12.2% and11.4.1-13.3%, grain NDF was 40-2-52.7% and 38-42.9%, grain ADL was 0.8-1.5 and 0.7-1.3%, grain IVOMD was 78.3-83.9 and 82-88 %, and grain ME was 9.9-12.3MJ/kg and 12.1-14.5 MJ/kg (see Table 5.4 for malt type barley and Table 6.5 for food type barley). Also, for straw, high variation in nutritive value was found across cultivars for food and malt barley cultivar, respectively, as follows: straw CP was 4.1-5.7% and 4.9-6.2%, straw NDF was 73.5-76.7% and 72.9-76.1%, straw ADL was 7.6-8.1 and 7.2-8.4%, straw IVOMD was 41.2-43.8 and 38.7-49.3% straw, and ME was 5-5.6 MJ/kg and 5.3-5.8 MJ/kg (see Table 5.4 for malt type barley and Table 5.5 for food type barley).

Multiple differences were found between cultivars, but with a significant cultivar-location interaction, meaning that the growing location had an impact on the performance of the cultivars and their concomitant PUI ranking. The overall grain quality in Kofele was superior to that in Bekoji. The difference between low and high yielding cultivars is presented in Table 6.6 (food barley) and Table 6.7 (malt barley).

Table 6.4: Nutritive value of grain and straw of malt barley cultivars grown in the highlands of Ethiopia in the 2018 cropping season.

Cultivar	Grain					Straw				
	CP %	NDF %	ADL %	IVOMD %	ME MJ/kg	CP %	NDF %	ADL %	IVOMD %	ME MJ/kg
IBON-HI14/15-104	11.8	42.5	1.1	87.1	13.8	5.5	75	7.6	38.7	5.7
NDICARDAMB-190	12.2	39.5	0.7	85.8	14	6.2	73.4	7.3	41.6	5.7
NDICARDAMB-320	12.7	38	0.7	83.1	13.3	6.1	72.9	7.3	41.0	5.8
HB1963	12.2	38.7	0.8	85.2	14.3	5.4	76.1	8.2	48.0	5.4
USDF5-27	11.4	41.2	1.1	84.1	13.5	5.8	74.1	7.5	40.3	5.6
IBON-HI14/15-144	12.3	40.2	1	82.8	13.2	6	75.4	8.4	43.0	5.4
IBON-HI13/14-129	12.1	41.8	1.2	84.9	13	4.9	73.6	7.2	40.3	5.9
MBHIBYT-22	12.2	41.3	1.2	81.9	12.1	6.1	73.9	7.7	42.2	5.8
Traveller	11.7	40.2	0.9	85.2	13.7	5.3	75.2	7.5	49.3	5.6
IBON-HI13/14 -49	11.9	42.8	1.1	86.2	13.5	5.2	74.3	7.5	44.2	5.7
NDICARDAMB-185	12.7	41.4	0.9	88.0	14.5	6	74	7.8	41.3	5.6
IBON-HI14/15-148	11.7	41.7	1.1	83.6	13	6.1	73.8	7.5	42.2	5.5
MBBELGIUM-30	12.1	41.4	1	84.6	13.5	4.9	74.8	7.3	42.5	5.7
IBON-HI13/14-128	12	41.3	1	86.3	13.5	5.6	74.3	7.8	42.1	5.3
IBON174/03	12.2	40.4	1	84.6	13.2	5.4	73.9	7.2	48.3	5.7
IBON-HI14/15-153	12.2	41.9	1.2	85.0	13.3	5.4	73.9	7.8	41.5	5.4
ICARDA GP-75	12.9	39.8	1.1	84.9	13.6	5.6	75.9	7.7	43.6	5.8
ICARDA GP-67	13.3	43.1	1.3	86.6	13.6	5.8	74.1	7.4	42.0	5.7
IBON-HI14/15-126	11.5	42.9	1.2	86.9	14.6	5.4	75.2	7.4	42.9	5.8
USDF5-11	12.6	40.4	1	85.0	13.8	6.6	73	7.3	42.5	5.8
Mean	12.2	41	1.03	85.1	13.5	5.6	74.3	7.56	42.9	5.6
SEM	0.5	1.9	0.16	1.38	0.85	0.6	1.3	0.41	1.08	0.21
LSD(0.05)	1.4	5.2	0.58	5.25	2.18	1.7	3.5	0.8	4.09	0.57

CP, crude protein; NDF, neutral detergent fibre; ME, metabolizable energy; LSD, least significant difference. Averages combining both growing locations (Bekoji and Kofele) are shown.

Table 6.5: Nutritive value of grain and straw of food barley cultivars grown in the highlands of Ethiopia in the 2018 cropping season

Cultivar	Grain					Straw				
	CP %	NDF %	ADL %	IVOMD %	ME MJ/kg	CP %	NDF %	ADL %	IVODM %	ME MJ/kg
ICARDA GP P# 44	11.1	44	1	82.4	11.2	4.1	**76.7**	8.0	42.7	5.1
IBON HI 13/14-P# 53	12	44	1.2	81.7	11.3	5	76	8.1	41.7	5.1
IBON HI 13/14-P# 74	10.8	51	1.1	78.3	10.6	4.8	75.7	8.1	42.2	5.3
HB1966	10.2	53	1.4	82.3	10	4.6	75.7	8.1	41.6	5
MBF4 P#+2015	11	47	1.5	80.8	11.1	5.7	74.8	8.0	42.6	5.4
ICARDA GP P# 127	11	46	1.4	81.2	11.1	5.2	75	7.6	42.4	5.6
IBON HI 13/14-P# 85	11.5	45	1.2	82.3	11.2	4.7	74.7	7.6	42.5	5.4
IBON HI 14/15-P# 155	12.2	42	1	80.4	11.1	4.7	75.3	7.9	42.1	5.2
IBON HI 13/14-P# 91	10.6	52	1.2	79.2	9.9	4.8	75.9	8.1	41.5	5.2
IBON HI 13/14-P# 113	11	43	1	78.9	10.4	4.8	75.7	7.8	41.5	5.1
EH1493	11.9	44	1	85.4	12.3	4.9	74.2	7.8	42.2	5.2
HB1307	11.8	42	1	82.6	11.2	5.1	74.3	7.5	41.8	5.4
IBON HI 13/14-P# 23	11.2	44	1.2	81.4	11.2	5.4	73.5	7.8	43.8	5.4
IBON HI 13/14-P# 109	11	42	1	80.2	11	4.8	75.2	8.1	43.3	5.1
MBF4 +2015 P# 1	12.2	40	0.8	81.6	12.1	4.8	76	7.8	41.2	5.3
IBON HI 14/15-P# 165	11.6	45	1.1	82.9	10.9	4.8	75	8.0	42.6	5.3
IBON HI 14/15-P# 116	11.2	42	0.9	82.2	11	4.7	76.1	7.9	42.2	5.5
IBON HI 13/14-P# 81	11	44	1.1	83.9	11.7	4.8	75.4	8.0	42.0	5.3
IBON HI 14/15-P# 143	11.1	45	1.2	83.8	11.8	4.5	76.1	7.9	41.6	5.1
IBON HI 13/14-P# 31	11.7	42	1.2	75.7	11.2	5	75.7	7.9	42.6	5.5
Mean	11.3	45	1.1	81.4	11.1	4.9	75	7.9	42.2	5.3
SEM	0.8	4.5	0.15	2.33	0.76	0.5	1.9	0.3	0.56	0.56
LSD(0.05)	2.2	13	0.55	8.8	2.1	0.7	2.7	0.5	2.23	2.23

CP, crude protein; NDF, neutral detergent fibre; ME, metabolisable energ; LSD, least significant difference. Averages combining both growing locations (Bekoji and Kofele) are shown.

Table 6.6: Yield and nutritive value of grain from food and malt barley cultivars grown at two locations (Bekoji and Kofele) in the Ethiopian highlands

	Food type				Malt type			
	Yield t/ha	CP %	NDF %	ME MJ/kg	Yield t/ha	CP %	NDF %	ME MJ/kg
Bekoji								
Mean	3.9	9.2	39	9	5.6	12.0	39	9
Min	2.9	7.2	30	6.7	4.4	10.9	33	6.7
Max	5.2	10.7	54	11	6.9	13.3	44	10.9
Kofele								
Mean	5.7	13.4	5	11.1	6.2	12.4	43	13.5
Min	4.8	11.3	45	9.8	5.1	11.6	41	11.7
Max	6.7	14.4	52	13.7	7.3	13.2	46	15.6

Crude protein (CP) and neutral detergent fibre (NDF) are in % of dry matter, while metabolizable energy (ME) is in MJ/kg dry matter.

Table 6.7: Yield and nutritive value of straw from food and malt barley cultivars grown at two locations (Bekoji and Kofele) in the Ethiopian highlands

	Food				Malt			
	Yield t/ha	CP %	NDF %	ME MJ/kg	Yield t/ha	CP %	NDF %	ME MJ/kg
Bekoji								
Mean	4.7	3.2	73	5.4	6.8	5	73.5	5.7
Min	3.0	2.7	71	5.2	4.9	4.2	72	4.7
Max	6.6	3.9	75	5.7	8.6	6.1	77	5.9
Kofele								
Mean	6.7	6.5	77	5.1	7.5	6.3	75.2	5.6
Min	5.2	4.9	71	4.8	4.9	5.1	72.6	5.1
Max	8.0	7.6	80	5.5	9.6	7.8	77	5.9

Crude protein (CP) and neutral detergent fibre (NDF) are in % of dry matter, while metabolizable energy (ME) is in MJ/kg dry matter.

6.3.3. Food-fodder correlation

Table 6.8 presents the relationship between straw yield and nutritive value, as well as grain yield and nutritive value across food and malt barley cultivars. The correlation between grain yield and straw yield was positive for both food and malt barley cultivars, regardless of the location ($r > 0.7$). Grain yield had a weak-moderate correlation ($r < 0.39$) with straw nutritive value parameters for both food and malt barley in both locations.

Generally, the linear correlations between nutrient composition of grain (grain CP, grain NDF, and grain ME). and nutrient composition of straw (straw CP, straw NDF, and straw ME) were weak to moderate ($r < 0.44$) for food and malt barley in Bekoji and Kofele.

Table 6.8: Relationship between grain and straw traits in food and malt barley cultivars grown in the Ethiopian highlands.

		Straw traits			
Location	Grain traits	Yield	CP	NDF	ME
			Food Type		
Bekoji	Yield	0.22	Ns	-0.50	0.39
	CP	Ns	0.29	-0.27	0.26
	NDF	Ns	0.39	Ns	Ns
	ME	Ns	Ns	-0.43	Ns
Kofele	Yield	0.22	-0.27	Ns	Ns
	CP	Ns	Ns	Ns	Ns
	NDF	Ns	Ns	Ns	Ns
	ME	Ns	Ns	Ns	Ns
			Malt Type		
Bekoji	Yield	0.32	Ns	Ns	Ns
	CP	Ns	Ns	Ns	Ns
	NDF	Ns	Ns	Ns	Ns
	ME	Ns	Ns	Ns	Ns
Kofele	Yield	0.25	Ns	Ns	Ns
	CP	Ns	Ns	Ns	Ns
	NDF	Ns	Ns	0.32	-0.33
	ME	Ns	Ns	Ns	Ns

Ns, $P>0.05$ otherwise $P\leq0.05$; CP, crude protein; NDF, neutral detergent fibre; ME, metabolisable energy

6.4. Discussion

Exploiting differences in feed traits of barley types could provide novel breeding targets for new barley varieties with potentially higher food and livestock feed value, which would be particularly useful in a range of diverse environments in mixed crop-livestock systems. These genotypes would promote sustainable use of resources in the farming systems by increasing biomass production for human and livestock production.

Cultivar improvement of straw traits along with grain traits requires information on the cultivar-environment interactions between grain and straw traits, and the relationship between these traits across different environments. The current study showed that cultivar variation in yield and quality traits depends on location. This means that the selection of an optimal barley cultivar should be based on location. Further research is therefore warranted to identify the parameters (e.g., soil type, precipitation, and slope) that could predict the location effect on barley performance.

Some genotypes perform better in one location than in others; this is known to be due to the existence of an interaction between growing location and genotype, which is similar to the report of Alkhtib et al. (2018) who reported a significant interaction for chickpea. Also, Ertiro et al., (2013) reported a significant interaction between cultivars and location in maize.

Genotype-environment interactions are known to account for the variation in nutritive value of cereal straw (Bediye, et al., 2019). Birhanu et al. (2020) also identified IBON 174/03 as a high grain yielder, although only grain quality and not straw quality was evaluated in that study. Our study evaluated both grain and straw quality and included HB1963 and Traveller, in addition to IBON 174/03. Large variation in food and malt barley cultivars has been demonstrated in several studies (Pearce et al., 1988; Reed, 1986; Wamatu et al., 2019). Our study aligns with these, but also adds the insight that not only grain quality, but also straw quality exhibited an interesting range of use for selection.

A factor that complicates the ease of selection for superior cultivars is the impact of growing location observed in both barley types. Thomson et al. (1993) already identified this effect but our study clarifies that some traits are more sensitive to changes in growing conditions than others. For instance, there was a large difference between locations in ME, compared with other traits. The ME at the Kofele site was higher than the ME in Bekoji which may originate from the high rainfall in Kofele compared to Bekoji. High rainfall was correlated to high ME in straw (Acone & Wootton, 1999).

It was not the purpose of this study to compare malt barley with food barley, but malt barley outperformed food barley in both yield and nutritive value. This difference was expected because of the basic difference between malt and food barley types. The higher grain and straw yield observed in malt barley type might be related to the high germination rate as a criterion for malt barley (Macleod, 2013). At the least, our study points to the necessity of considering the impact of location when selecting parental varieties (or potential food-fodder genotypes) of food and malt barley for breeding programmes. This is especially the case for food-feed use of barley, since features of grains and straw were clearly affected by location with different effect sizes, meaning that the overall value of food-feed barley may vary more widely than just grain yield.

6.5. Conclusions

The wide cultivar variation in straw yield and nutritive value, combined with the poor association between yield and nutritive value for grain as well as straw, allows for the upgrading of straw yield and its nutritive value without decreasing grain yield and its nutritive value. This improvement could be achieved by employing appropriate breeding approaches.

Considering the environmental impact on the cultivar performance, three superior varieties were identified; IBON174/03 (as a grain yielder), HB1963 (as a grain and straw yielder), and Traveller (as a straw yielder). To evaluate how well the straw of these cultivars suits animal nutrition, a trial with regional livestock is required to evaluate the digestive and metabolic responses to the identified promising barley cultivars.

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7

Chapter 7: Effect of Barley Variety on Feed Intake, Digestibility, Body Weight Gain and Carcass Characteristics in Fattening Lambs

Adapted from

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Abstract

Twenty lambs (18 ± 0.22 kg initial body weight) were blocked by weight and individually assigned to pens to evaluate the effects of barley straw variety on digestibility, growth performance and carcass characteristics. The following four treatments were tested: (1) a local barley straw (as control), (2) HB1963 (high grain and straw yields), (3) Traveller (high straw yielder), and (4) IBON174/03 (high grain yielder). A concentrate (50:50 wheat bran and noug seed cake) was offered constantly (300 DM g), whereas the straw was offered *ad libitum*. The digestibility trial lasted 22 days (15 days to adapt to dietary treatments and 7 days for sampling). The growth performance trial lasted 90 days. At the end of the study, all the lambs were slaughtered, and their carcasses were evaluated. Lambs fed the IBON174/03 variety had a higher ($p < 0.05$) intake of organic matter and crude protein, a higher dry matter and organic matter digestibility than the control, and a faster growth than the control group. The feed-to-gain ratio was similar among treatments. The slaughter and empty body weights of lambs in the IBON174/03 group were higher than the control variety ($p < 0.05$).

Keywords: crop residue growth performance, carcass parameters

7.1. Introduction

Barley (*Hordeum vulgare L.*) is a multi-purpose crop with high economic and social importance. It is grown to produce grain for human and livestock consumption and malt for brewing (Kaso, & Guben, 2015; Taner et al., 2004). The breeding and selection of barley has been focused on the optimisation of grain production, without due consideration of the yield and quality of straw as livestock feed. Newly improved varieties and cultivation methods have led to a decrease in straw yields (Austin et al., 1980; Gowda et al., 1988; Riggst et al., 1981). Improved varieties have been rejected because of poor straw traits in crops, including barley (Capper et al., 1986; Capper et al., 1988) and finger millet (Seetharam, 1986).

In mixed crop-livestock farming systems, the use of crop residues for livestock feeding is important due to the expansion of cropland and the subsequent productivity decline of natural pastures (Alkemade et al., 2013). Kelly et al. (1991) reported that straw had become an important part of total crop value. The contribution of genetic as opposed to non-genetic factors to grain and fodder yields, as well as straw digestibility varies between crop species and between the varieties within a crop species. Varietal differences in the chemical composition and feeding value of crop residues have been reported in wheat, rice, sorghum and maize (Reddy et al., 2003).

The authors Wamatu & Alkhtib (2019) showed the high genotypic variability in grain yield, straw yield and the nutrient composition of straw in naked barley landraces. Likewise, others (Grove & Hepton 2003; Ramanzin & Orskov 1986; Reed, 1986, 1986) have found a varietal variation in the intake and nutrient digestibility of barley straw when fed to sheep. A significant effect of genotype, row type and morphology was observed for the nutritive value of barley straw (Capper, et al., 1992; Ramanzin, et al., 1986). The chemical composition and ruminal fermentability of barley straw was significantly affected by the planting date, the irrigation level and the cultivars (Grove & Hepton, 2003). The effects of variety on the performance of straw-fed animals still need to be determined.

The objective of this study was to evaluate the effect of straw from different barley cultivars on the feed intake, digestibility, body weight gain and carcass characteristics of Horro lambs. We hypothesised that the digestibility and growth performance in straw-fed sheep can add crucial information to the decision-making process when selecting the optimal barley variety for dual-purpose use.

7. 2. Materials and methods

7. 2.1. Animal care

Animal care, handling and maintenance throughout the experiment were in accordance with the animal welfare regulations of Jimma University.

7. 2.2. Study sites and plant materials

The feeding trial experiment was conducted at Jimma University, College of Agriculture and Veterinary Medicine (Latitude 7^0 41'3.39"N and Longitude 36^0 49'31.79"E, elevation 1780 m.a.s.l, average temperature 29 °C). Barley varieties were grown at Kolumsa Agricultural Research Centre, Kofele site, located in the West Arsi zone of Oromia Regional State, Ethiopia. The cente is located 280 km southwest of Addis Ababa, the capital city of Ethiopia at 06°50′ to 07°09′ N latitude and 38°38′ to 39°04′ E longitude, and at an altitude of 2650 m above sea level. The average annual maximum and minimum temperatures are 21 and 4 °C, respectively. The average annual rainfall is 950.6 mm. Soil type is loamy and acidic (Kelly et al., 1991).

Three improved varieties were initially selected from 40 food and malt barley varieties that had been evaluated at Kofele and Bekoji, Ethiopia, under the National Variety Trials of the Ethiopian Barley Improvement Programme. The varieties, IBON174/03, Traveller and HB1963, were selected as a high grain yielder, a high straw yielder, and food-feed (high in grain yield as well as straw yield), respectively. The three selected improved varieties and one local (control) were then planted at the Kofele site in Ethiopia.

All cultivars received the same agronomic practices as per recommendations for barley growing in Ethiopia. The above-ground biomass of each plot was manually harvested at physiological maturity, air-dried for two weeks to a constant moisture, then threshed. The straw was chopped to a theoretical length of 2 cm, put in plastic bags and stored for one month until the start of the feeding trial.

7.2.3. Animals, experimental design and diets

Twenty Horro yearling lambs with an initial body weight of 18.0 ± 0.2 kg were obtained from a local market. The Horro breed is primarily maintained for meat in the study area. The lambs were quarantined for three weeks. Experimental lambs were vaccinated against ovine pasteurellosis using a *Pasteurella maltocida* type A vaccine and sheep pox using a live lyophilised capripox vaccine, and dewormed against external and internal parasites using ivermectin. Based on their initial weight, the lambs were arranged into four groups, each with five lambs, in a randomised complete block design. They were placed in individual pens; the pens were 2 m long and 1.5 m wide with concrete floors, an open-air platform and equipped with a drinking and feeding trough.

The following four treatments were tested: (1) a local straw barley (as control), (2) HB1963 (high grain and straw yield), (3) Traveller (a high straw yielder), and (4) IBON174/03 (a high grain yielder). A concentrate (50:50 wheat bran and noug seed cake) was offered at a fixed amount (300 gDM/d), whereas the straw was offered *ad libitum*. A description of the selected varieties is presented in Table 7.1.

Lambs were fed twice a day (0800 h and 1600 h) in equal proportions. Lambs had free access to a salt lick and clean drinking water.

Table 7.1: Description of the barley varieties used in the study

Variety	Grain Yield (t/ha)	Straw Yield (t/ha)	Leaf/Stem (%)
IBON174/03 (High grain yielder)	7.1	7.5	44.7
Traveller (High straw yielder)	6.0	9.1	32.4
HB1963 (Food-feed)	6.4	8.4	38.5
Local (Not improved)	4	4.5	35.3

7.2.4. Digestibility trial

The digestibility trial started before the commencement of the feeding trial. There were 15 days for adaptation to the experimental conditions and feeds, followed by the total collection of faeces for seven consecutive days. The daily feed offered and refused per lamb was recorded. Total faecal output was collected by daily emptying of every faecal collection bag in the morning, prior to offering feed and water. Faeces were weighed fresh, thoroughly mixed and 20% of the faeces were sampled per lamb and stored in a freezer at −18 °C. Samples were pooled per lamb over the collection period and 20% of the composite sample was taken, weighed, and partially dried at 60 °C for 72 h. The apparent digestibility of dry matter (DM) and other nutrients were determined as a percentage of the nutrient intake not recovered in the faeces.

Based on the reported DM digestibility (DMd) for wheat bran (76%) and noug seed cake (86%) (Haddad, 2000; Hamid et al., 2007; Ribeiro et al., 2017), the DMd for the concentrates used in this trial was calculated to be 80.5%. When combining this figure with the proportion in the actual diets, the DM digestibility of straw can be estimated as follows:

$$(\text{DM intake} \times \text{digestibility DM}) - (0.805 \times 300)/\text{straw intake}.$$

7.2.5. Growth

The 90-day feeding and growth experiment was conducted after the completion of the digestibility trial and after a 10-day rest period. The lambs were fed the same treatment during the digestibility and growth trials. The live weight of the lambs was recorded at the start of the trial, and every 10 days subsequently after overnight fasting and before morning feeding, using a hanging scale with a sensitivity of 100 g, for 90 consecutive days. A KERN Scale EWJ 6000 g with a sensitivity of 1 g was used to weigh the feed and refusals. The daily feed offered and the refusals were weighed and recorded per sheep.

Daily feed and nutrient intakes were calculated as the difference between the offered feed and the refusals on a DM basis. Average daily gain (ADG) was calculated as the difference between the final and initial weights, divided by the number of feeding days. The feed-to-gain ratio (FGR) was calculated as the total DMI to the ADG. Samples of the feed offered were collected per batch, whereas samples of the refusals were taken daily from each lamb and stored in plastic bags. Subsamples of offered feed and refusals were dried at 60 °C for 48 h, then ground to pass through a 1-millimeter screen and stored for chemical analyses.

7.2.6. Carcass evaluation

At the end of the experiment, all lambs were slaughtered after 24 h of fasting to determine the treatment's effects on carcass characteristics. Lambs were individually weighed before slaughter. Carcass variables were registered individually. Slaughtering was performed as described by Kadim et al. (2004). The weights of the head (with tongue), feet, skin, blood, liver and gall bladder, heart, kidneys (with fat), lungs and trachea, abdominal fat, testicles and other genitalia, and full and empty gastrointestinal tracts were recorded. Empty body weight (EBW) was calculated as the slaughtered body weight minus gastro-intestinal tract's contents. Hot carcass weight (HCW) was determined as the body after removing the skin, head, forefeet, hind feet and all the viscera and fat deposits. Dressed carcasses were weighed within 1 h and recorded as hot carcass weight and then chilled for 24 h at 4 °C, weighed again and recorded as cold carcass weight. The dressing percentage on a slaughter body weight basis and an empty body weight basis was calculated as the percentage of hot carcass weight to slaughter body weight and empty body weight.

7.2.7. Chemical analyses

All feed and faecal samples were analysed for dry matter (DM; method 934.01) (AOAC, 2003); ash (method 942.05) (AOAC, 2003); nitrogen (method 954.01) (AOAC, 2003) neutral detergent fibre (NDF), which was analysed using the procedure of Van Soest & Robertson (1991), and acid detergent fibre (ADF) (Van Soest & Robertson, 1991). Crude protein content was calculated as N × 6.25.

7.2.8. Statistical analyses

The experimental lambs were blocked according to live weight. Data from the current study were analysed according to the following model:

$$Y_{ij} = \mu + T_i + Bj + E_{ij} \quad (10)$$

where Y_{ij} is the response variable, μ is the overall mean, T_i is the effect of treatment, B_i is the effect of block and E_{ij} is the residual error. Treatment means were separated using the Tukey test, with significance set at $p < 0.05$. The statistical analyses were performed using SPSS (IBM Corp, 2020).

7.3. Results

7.3.1. Chemical composition of the experimental diet

The tested barley cultivar contained relatively more CP than the local straw (control). Numerically, the HB1963 variety was higher in NDF, ADF, ADL, and ash concentrations than the other varieties (Table 7.2).

Table 7.2: Nutrient composition of the barley straw varieties and concentrate mixture used in the study

	IBON174/03	Traveller	HB1963	Local Straw	Concentrate
Dry matter (%)	90.4	91.2	91.3	90.7	91.9
Crude protein (%)	5.5	5.1	5.2	4.3	20.4
Neutral detergent fibre (%)	73.2	77.0	79.3	77.5	47.7
Acid detergent fibre (%)	51.2	55.4	57.7	55.6	23.6
Acid detergent lignin (%)	9.2	11.3	11.7	9.8	8.8
Ash (%)	5.2	7.2	7.4	6.7	7.6

7.3.2. Nutrient intake and digestibility

The lambs ingested more dry matter and protein from the high grain yielder (IBON174/03) than from the food-feed variety (HB1963) (Table 7.3). The organic matter intake was higher from the IBON174/03 than from the HB1963. The lambs on the IBON174/03 treatment consumed 353 g/d organic matter from straw and 277 g/d organic matter from concentrates. The lambs on the HB1963 treatment consumed 289 g/d organic matter from straw and 277 g/d organic matter from concentrate.

The dry matter and organic matter digestibility of straw were higher with the IBON174/03 than with the Traveller and local (control) varieties, whereas the greater crude protein digestibility observed with the control treatment compared with the other cultivars was a reflection of a lower straw intake (325 g/d) and the lower protein content (4.3%) in the local straw. For example, in the local straw treatment, lambs consumed 14 g of protein from straw and 61 g of protein from concentrates (19% of the total protein consumed was low-digestible protein), whereas the lambs fed IBON174/03 consumed 20.5 g of protein from straw and 61 g of protein from concentrates (25% of the total protein consumed was low-digestible protein) (Table 7.3). No difference was observed in the NDF and ADF intake or digestibility between the cultivars.

Table 7.3: Nutrient intake and nutrient digestibility coefficients in Horro lambs fed diets containing straw from different varieties of barley supplemented with a concentrate mixture.

	IBON174/03	Traveller	HB1963	Local	SEM	*P*
Intake (g/d)						
Straw dry matter	372^{a}	356^{ab}	312^{b}	325^{ab}	13.8	0.036
Concentrate mix	300	300	300	300	300	
Total dry matter	672^{a}	656^{ab}	612^{b}	625^{ab}	13.8	0.036
Organic matter	630^{a}	607^{ab}	567^{b}	580^{ab}	12.9	0.021
Crude protein	81.5^{a}	79.6^{ab}	77.4^{b}	75.3^{bc}	0.65	0.001
Neutral detergent fibre	416	417	391	395	10.7	0.243
Acid detergent fibre	261	268	251	251	7.7	0.367
Digestibility (%)						
Dry matter	71.9^{a}	65.2^{b}	68.3^{ab}	63.7^{b}	1.5	0.011
Organic matter	73.4^{a}	68.7^{b}	70.8^{ab}	66.8^{b}	1.4	0.033
Crude protein	67.5^{ab}	66.1^{ab}	59.9^{b}	68.3^{a}	1.94	0.040
Neutral detergent fibre	63.8	60.7	67.7	60.5	1.75	0.041
Acid detergent fibre	62.3	58.3	64.4	57.2	1.81	0.051

^{a,b} Different superscripts indicate significant differences at $p < 0.05$.

7.3.3. Growth performance and carcass characteristics

The average daily gain was higher for lambs on the IBON174/03 treatment compared with the control. A higher intake was observed for the IBON174/03 group than the HB1963 group. The feed-to-gain ratio did not differ between the varieties, but IBON174/03 led to faster growth than HB1963 and the local cultivars, resulting in a higher slaughter and empty body weight than the other cultivars (Table 7.4). None of the carcass components differed between the cultivars (Table 7.4).

Table 7.4: Body weight change and carcass characteristics of Horro lambs fed diets containing straw from different cultivars of barley supplemented with a concentrate mixture.

	IBON174/03	Traveller	HB1963	Local	SEM	*p*
Growth performance						
Initial body weight (kg)	17.8	17.6	17.6	17.8	0.1	0.357
Weight gain (g/day)	40.7^{a}	37.1^{ab}	34.4^{b}	34.2^{b}	1.4	0.025
Feed-to-gain ratio	16.6	17.9	18.2	18.6	2.33	0.506
Carcass characteristics						
Slaughter body weight (kg)	21.5^{a}	20.8^{b}	20.7^{b}	20.9^{b}	0.15	0.020
Hot carcass weight (kg)	7.7	7.1	6.9	7.2	0.17	0.056
Empty body weight (kg)	16^{a}	15.4^{b}	15.3^{b}	15.4^{b}	0.16	0.045
Dressing percentage (%)	35.7	34.2	33.5	34.4	0.6	0.116
Rib eye area (cm^2)	8.0	7.5	7.3	7.3	0.3	0.256
Edible offal						
Blood (g)	1004	1034	1059	973	34	0.343
Liver (g)	305	290	302	273	10	0.175
Kidney(g)	71	70	74	69	2	0.547
Heart (g)	102	109	102	95	5	0.297
Tongue (g)	73	66	71	69	3	0.428
Reticulo-rumen (g)	599	614	589	697	43	0.315
Abomasum-omasum (g)	353	358	351	349	5	0.681
Small intestine (g)	470	437	423	432	29	0.687
Large intestine (g)	507	518	502	506	19	0.940

^{a,b} Different superscripts indicate significant differences at $p < 0.05$.

7.4. Discussion

The crude protein (CP) concentration of the studied barley cultivars ranged from 4.3% in the local variety to 5.5% in IBON174/03, which resembles the values of Haddad (2000). The observed value was below the range of 7–7.5% assumed to be sufficient for maintenance and rumen microbial function of ruminant animals (Van Soest, 1994); therefore, supplementation with concentrate feed with a high protein content is important to fulfil the protein requirement of animals. All of the tested cultivars had a high fibre content (higher in HB1963, lower in IBON174/03), similar to the results of Asmare et al. (2016).

Straw intake was 325, 312, 356, and 372 g for local straw, HB1963, Traveller, and IBON174/03, respectively. This calculation renders a 48% DMd for local straw, which is in close agreement with the digestibility of barley straw determined in a previous report (Sadq, 2012). The estimated DMd for HB1963, Traveller, and IBON174/03 are 56.5, 52.3, and 64.9%, respectively, confirming a higher digestibility of the selected straw varieties compared with the non-selected local cultivar. Although straw digestibility was not a selection target, this feature has been improved through selection.

The higher digestibility coefficient of the total diet in this study was thus due to the combination of straw with a protein-rich concentrate feed (300 g DM/day/lamb). Dietary protein enhances microbial proliferation in the rumen, which enables rumen fermentation (Donald et al., 2010). The higher apparent DM and OM digestibility of the lambs fed IBON174/03 straw was probably due to the high leaf-to-stem ratio (Table 7.1) and its lower NDF and ADL content compared with other barley cultivars, since it is mainly fibre that influences digestibility (Fluharty et al., 1999). The DM and OM digestibility of the lambs fed Traveller straw were probably lower due to its higher NDF and ADF content.

The fibre itself was not better digested (at least not significantly), but it is likely that the lower fibre content improved the accessibility of rumen microbiota and digestive enzymes to their substrates. This hypothesis is supported by the lower protein digestibility in the rams fed Traveller straw that also had the highest fibre concentrations. The negative correlation between the fibre concentration of the straw and the DM intake indicates that fibre concentration in the diet was reducing the voluntary feed intake.

The high voluntary DM intake of the lambs fed IBON174/03 straw might be due to lower fibre content and high leaf-to-stem ratio compared with the other straws. The authors Tolera et al. (2012) and Wegi et al. (2018) demonstrated that high fibre induced a low digestibility and voluntary feed intake, which is in line with the current study. The greater overall feed intake in lambs fed IBON174/03 straw, did not imply a large intake of fibre because the difference in the fibre concentration was compensated for by the difference in intake. Despite the higher fibre content in the diet of the current study, the DM feed intake per kg of body weight in the current study was in the recommended range of dry matter intake for ruminants (2–6% of body weight; Asmare et al., 2016).

The observed differences in the average daily gain between the treatments might originate from differences in the intake and nutrient digestibility. The higher intake in the high grain yielder group was demonstrated, but also the higher DM and OM digestibility will have added to the higher growth performance in this group. Since the digestibility of fibre and protein were not higher, and fat content is very low in straw, we postulate that the leafier material in the high grain yielder straw allowed a faster ruminal escape of the starch in the concentrates, leading to more efficient enzymatic digestion compared with fermentation. It has been demonstrated that leafy material has a faster ruminal escape than stem material in sheep (Poppi & Ellis, 2001). The numerically higher feed-to-gain ratio for the high grain yielder straw (IBON174/03) agrees with this improved efficiency. This hypothesis must be confirmed through measuring ruminal passage, which we were unfortunately unable to perform. It may signify that the effect of the barley variety on the utilisation of a straw-based diet depends on the composition of the total ration, an aspect that warrants further study.

The higher slaughter weight on the IBON174/03 straw diet is an evident outcome of an increased intake and digestibility. The greater carcass yield with the rams fed IBON174/03 was mainly a direct effect of greater growth, since the dressing percentage was only numerically altered. The fact that only a few body parts showed significant differences between the treatments indicates that the better performance with IBON174/03 is a direct effect of the increased intake and digestibility, without apparent changes in the composition of the body. The dressing percentage of the sheep observed in the current study was low (33.5 to 35.7%) compared with the report of Feyera (2011) for the same Horro breed (36.7 to 42.5%). The present study showed that there was no significant difference in the internal organs among the treatments. Internal organs are more affected by the age, breed and sex of the animals, rather than the type of nutrition (Riley et al., 1989).

The high demand for barley straw resources in the mixed farming systems has already been reported (Alkhtib et al., 2017; Jaleta et al., 2013). The grain and straw yield of the local barley variety was low (4 t/ha of grain, 4 t/ha of straw) compared with the improved cultivar, for example IBON174/03 (7.1 t/ha of grain and 7.5 t/ha of straw), while the population of humans and livestock in the mixed system is increasing.

Generally, this study shows the opportunities for choosing barley varieties based on their straw quality, in addition to grain yield. This feature enables the use of all produced plant biomass to meet the high demand of grain for human consumption, as well as straw for livestock feeding in the mixed farming systems of Ethiopia and other tropical countries. The best performing group in this study was fed a IBON174/03 cultivar.

7.5. Conclusions

In conclusion, the growth performance of sheep can depend on the barley variety that provided the straw in their diet. In particular, the IBON174/03 barley cultivar was the most promising in terms of the feeding value of the straw, hence it could be recommended as a more suitable candidate in the study area. The inclusion of straw quality as a selection criterion for barley can help in enhancing livestock productivity in addition to grain yield for human consumption. This study showed the importance of barley cultivars when straw is a substantial part of a ruminant's diet, such as in tropical conditions.

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8

Chapter 8: General Discussion

8.1. Background and outline

Crop-livestock mixed farming systems are the backbone of smallholder livelihoods in lower-income countries (Ryschawy et al., 2012). These countries are characterised by high human and livestock density, urbanisation and increasing income that urge for increased intensification of crop agriculture.

Intensification of crop agriculture in this system therefore requires new crop cultivars as a food resource and their by-products as a major feed resource (Bediye, et al., 2020). Without appropriate land management, this may contribute to low agricultural productivity and also leads to land degradation; reduced quality and degradation of soils is of particular concern in tropical regions where intensive management and year-round warm temperatures can result in high rates of organic matter decomposition. Agricultural practices that improve soil quality and agricultural sustainability is needed in this system, including crop rotation and diversification.

Crop diversification includes both the growing of conventional crops and the introduction of new non-conventional crops, which is used to reduce the problem of mono-cropping systems which may threaten future food security due to loss of biodiversity and the occurrence of new pests and diseases (Umesh et al. 2019). Crop diversification is a dynamic tool to ensure food security and achieve the goal of sustainable agricultural development (Behera et al., 2007). Crop diversification is used for conserving natural resources and helps to improve ecosystem biodiversity and strength. This enables the agro-ecosystem to respond better to environmental stress, thus reducing the risk of complete crop failure and providing farmers with an alternative source of income.

The ecological benefits of crop diversification include reduced nutrient losses from soil, improved resource efficiency, higher resource uptake by plants, and increased productivity and stability of the production system (Reich et al. 2001). Other cropping systems like crop rotation could also maintain and improve soil quality (Balota et al. 2003). Likewise, it is also crucial to generate basic knowledge about crop residue utilisation and develop improved technologies for crop residues to optimise the productivity of crops in mixed crop-livestock farming systems.

The households in mixed crop-livestock farming systems in the studied area varied widely in socio-economic factors and biophysical characteristics, which led to different demands of soil mulching volumes of straw and feed supply. The survey in this PhD work pointed out the importance of barley straw for mulching in addition to feed use, but its optimisation is dependent on topography and farmer interest. For example, the household with steep cropping land requires more straw yield to cover the extra soil mulching requirement.

Mulching increases the soil organic carbon (SOC) amount in top soil, improves soil aggravation, and enhances SOC stabilisation (Choudhury et al. 2014). Mulching is recommended as an important method to reduce chemical fertiliser needs, enhance soil organic carbon sequestration, and to improve soil fertility, structure, and water retention (Fan et al., 2013). Numerous studies have demonstrated a linear relationship between SOC storage and crop yield stability (Lal, 2010).

According to Prosdocimi et al. (2016), the use of straw mulch covering 75 g/m^2 or 0.75 t/ha has a positive effect on surface runoff generation and soil loss reduction. However, there was no available information on the amount of straw needed per ha of land in mixed crop-livestock farming systems in Ethiopia. This lack of data has prevented the creation of an algorithm for to predict optimal barley straw utilisation based on the quality of straw and environment in the country. There is a need for future research on the amount of straw to be used per hectare.

This thesis showed that IBON174/03 had 178%, 144%, and 119% more grain yield, straw yield, and growth, respectively, compared with local barley. This cultivar might be suitable where there is high demand for food and low demand for straw mulching. Traveller had 150% and 200% of grain yield and straw yield, respectively (Chapter 7), and would therefore suit households with cropping farms prone to erosion.

The concept of barley straw optimisation in mixed crop-livestock systems in Ethiopia may be different for every farmer and location, based on the relative need of each purpose (e.g., food, fodder, mulching). Therefore, an algorithm should be developed in the future so that farmers can determine which barley cultivar would be best for them, and barley breeders can consider the yield and quality traits of food, fodder and mulching quality, in collaboration with animal nutritionists and soil scientists. Integrating straw yield and nutritive value into barley improvement programmes could enhance the nutrient supply for livestock productivity, sustainable land management and also for sustainable straw production.

Barley straw has a great economic value (Traxler & Byerlee, 1993) and farmers even reject barley cultivars having poor straw quality and yield (Capper & Thomson 1988). The focus on food-feed traits and search for dual-purpose cultivars is quite relevant for the mixed crop-livestock system when attempting to improve both food and feed traits. These opportunities had not been considered in cultivar selection and development processes, due mainly to the very narrow focus of the researchers (primarily plant breeders) and absence of laboratory facilities and procedures for rapid screening of cultivars (Bediye et al., 2020) .

Literature suggested that the use of botanical structure of barley straw to rank cultivars for yield and nutritive value presents an alternative that is potentially cheaper, easier, and faster to undertake compared with standard methods (i.e. direct measurement of straw yield and conventional laboratory determination of nutritive value), but from Chapter 5 it was concluded that plant morphology is not sufficient to predict the straw yield or straw quality. Our findings did not permit the drawing of strong conclusions about using these morphological traits. This calls for more studies under many more conditions because the ability to predict barley performance and nutritive value with easy, cheap, and fast measurements such as plant morphology traits would stimulate progress in cultivar selection in countries where budgets are limited, such as in Ethiopia.

The current advance made in analysis of feed quality using NIRS is another option to consider multiple traits in varietal development or selection. Twenty malt and twenty food barley cultivars were investigated and ranked by screening the cultivar based on yield and chemical composition and categorised as high straw yielders, high grain yielders and food-feed cultivars (Chapter 6). Categorising cultivars this way enables informed choices for farmers, as it was observed during the survey work that the demand of farmers for straw was not equivalent for all farmers across all locations. Optimal cultivar choice depends on the number of livestock owned and the type of land. For example, a farmer having more livestock and sloped land needs more straw.

Further studies integrating farmers demand with the economic importance of traits such as straw yield, grain yield, and both (i.e., food-feed) is needed; this research should involve more than two years and several locations. The identified cultivars were based on their combined results, but some cultivars showed high yield in one location and low yield in the other location, indicating that such cultivars are not stable. It also indicates the importance of location as a factor.

In addition to straw yield and quality based on chemical composition, the feeding value of barley straw including digestibility, intake and effects on animal performance were used to confirm and recommend the best cultivars of barley in the studied areas using 20 lambs (Chapter 7). From this chapter we confirmed that barley cultivars had a significant effect on feed intake, digestibility, and growth performance. Although using *in vivo* techniques for feed evaluation is time-consuming, costly, and labour-intensive, the availability of accurate *in vivo* data is crucial for critical evaluation and validation of any potential *in vitro* methods (Coles et al., 2005).

Integrating *in vitro* methods as a first step in screening cultivars and *in vivo* evaluation as a final tool for cultivar selection is important in barley selection strategies in lower-income countries. Whilst the use of live animals for selection of a large quantity of cultivars may be impractical because of financial limitations in lower-income countries like Ethiopia, using live animals is also crucial to understanding the feeding value of superior cultivars because *in vivo* adds further insights to *in vitro* results. For example, barley cultivars with similar results based on chemical analyses might not be consumed equally; they may be the same in chemical composition but different in palatability or other traits. In such scenarios, our study provided a unique step for barley cultivar selection procedures; in the first step, a large quantity of barley cultivars were evaluated without the use of animals, whereafter the promising cultivars were further studied using live animals. The results indicated that cultivar differences in terms of feeding value of barley are important in the selection of barley for straw quality traits because significant differences were observed between cultivars in terms of feed intake, digestibility and animal performance. Therefore, barley improvement needs collaboration between plant breeders and animal nutritionists.

8.2. Contribution of using dual-purpose crops for improving food security

Food security as a condition exists when all people, at all times have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life (Mohamed, 2017). Ensuring food security is a central aspect of sustainable development goals and the development agenda of the African Union (Neglo et al., 2021). Rapid population growth, drought, land degradation, and fertility decline are some of the driving factors in food insecurity (Jiren et al., 2018).

Global livestock production has increased substantially since the 1960s, but increased livestock production is generally the result of increases in livestock numbers (particularly ruminants) in lower-income countries (Thornton, 2010). As the population growth rate increased, the demand for land for crop production is also increased, and grazing land is converted to crop lands, which aggravates the shortage of animal feeds. As indicated in Figure 8, the contribution of green fodder/grazing for livestock feed in Ethiopia is decreasing, while the contribution of crop residues for livestock feeding is increasing.

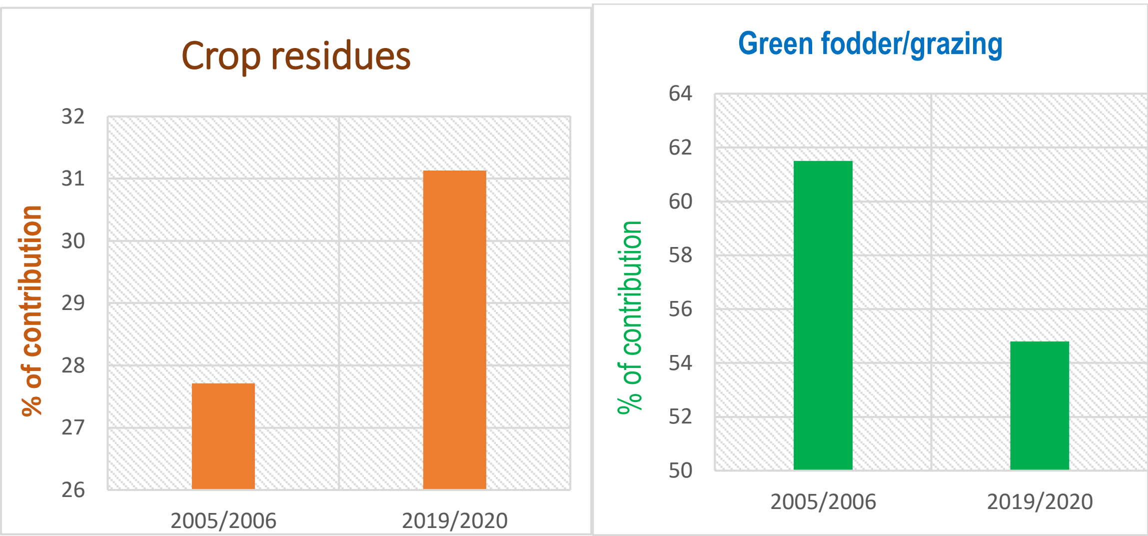

Figure 8. Contribution (%) of crop residues and Green fodder/grazing for livestock feed in Ethiopia (Source: CSA report 2005/2006 and 2019/2020).

However, the production of alternative feeds for ruminants in mixed systems may be constrained by land availability (Herrero, 2009). In such systems, using multi-purpose crops (food-feed) is vital for sustainable development. In the Ethiopian context, livestock has now become one of the important components of the economic sector which helps to attain food security, nutritional interventions, and poverty alleviation.

The results of this thesis provide detailed information about the possibility of improving grain yield, straw yield, and quality traits. In this regard, the positive correlation between grain yield and straw yield is an indicator of the possibility for improving straw yield without negatively affecting grain yield. Also, there was no significant negative correlation between straw quality traits and grain yield and quality traits, indicating the possibility exists for improving straw quality without affecting grain yield and quality traits.

The superior cultivars were identified based on food and feed traits; accordingly, three cultivars, IBON 174/03, HB1963, and Traveller, were selected as a high grain yielder, a food -feed, and a straw yielder, respectively (Chapter 6), in the study area. Hence, using food-fodder crops to enhance the production of both food and feed from a given land is feasible. Increasing straw yield contributes to reducing the impact of land degradation and fertility decline, since straw yield is used for both animal feed and soil mulching. As observed in this study (Chapter 4), the amount of straw yield is one of the determinants that affects the use of straw as soil mulch in mixed farming systems in Ethiopia. When the amount of straw is increased, the farmers tend to leave appropriate amounts of straw on the field for mulching. Soil mulching enhances the sustainable production of both food and feed production. This is in line with sustainable development goals, which integrate both food security and biodiversity conservation to ensure sustainable outcomes in both (Jirean, 2018). The production of crop residues in Ethiopia is 52.7 million tons. An average 5 kg crop residues can be turned in to 1 kg animal live weight. This translates into production of 10.5 million tons of live animals annually.

According to WHO, consumption of protein by an adult should be 60 g/day or 22 kg protein/year. If 100% of this protein consumption is from meat, crop residues could support the protein requirement of 60 million people per year. In practice, 100% of the protein consumption will not be from animal sources; plant source requirements suggest that efficient utilisation of crop residues could produce animal protein that could meet protein needs of a large segment of the Ethiopian population (FAO, 2018).The current study documented information on utilisation of barley straw (Chapter 4), filling an existing gap in barley breeding programme research, and evaluated barley cultivar selection processes to increase both food and fodder value of barley in Ethiopia (Chapter 5, 6, and 7).

In Ethiopia, barley improvement programmes have focused on grain yield. The field trial conducted at two locations in Ethiopia confirmed the possibility of selecting higher straw yield without significantly affecting the grain yield (Chapter 6). To evaluate the quality of animal feed and accommodate the two universal factors of nutritive value and palatability (Marten, 1986), Chapter 6 of this thesis further evaluated the potential cultivars for palatability.

8.3. Barley cultivar variation in chemical composition, morphology and feeding value

Cultivar, agronomic practice, soil, temperature, and stage of growth influence the chemical composition, morphology, and palatability of straws and stovers, in turn leading to differences in digestibility coefficients and intake values. There is considerable variation in the contents of crude protein (CP) and crude fibre (CF) among different crop species and within cultivars of a crop (Daniel, 1988). Cultivar variability in straw yield, morphology, and chemical composition of some cereal and pulse crops were reported in mixed crop farming systems of Ethiopia but did not include any animal evaluation. Previous reports include those for lentil (Alkhtib et al., 2017), chickpea, (Wamatu et al., 2017), maize (Ertiro et al., 2013), and pearl millet (Blümmel, et al, 2010). This thesis (Chapter 5, 6, and 7) demonstrated the variation of barley between locations and cultivars in chemical composition, morphology, and in feeding value including digestibility, intake, and the growth performance of animals.

The high variation observed in the studied barley morphology seemed promising as a proxy for overall cultivar performance, since morphological characteristics have been related with genetic variation in terms of feeding value (Capper, 1988). However, the result of multivariate regression showed that although significant, the prediction of straw yield and straw quality via morphological traits was weak (Chapter 5).

The proportion of leaf-to-stem ratio appears to explain variation in cellulose solubility of straw from different genotypes (Tan, et al,1995). In the current PhD work, sheep fed the cultivars having higher leaf-to-stem ratios showed higher performance, which may be explained by leaves having more organic matter, which subsequently contributes to the organic matter digestibility and available energy for metabolism. This association agrees with the report of Pearce et al. (1988).

Crop residues vary greatly in chemical composition, as does digestibility between crops and within the crops (Reed, 1986). In general, the feeding of crop residues is limited by their poor voluntary intake and low content in nitrogen, energy, mineral, and vitamins, all of which are essential to livestock performance (Alemu et al,1991). It is, however, worthwhile considering genetic variation since the work in this thesis found significant variation in chemical composition; for example, the CP content of the studied barley straw ranged from 4.1 to 6.2% of DM (Chapter 5). There was also variation in terms of digestibility, which ranged from 65.2% of DM to 71.9% of DM, and voluntary feed intake ranged from 312 g of DM/day/lamb to 372 g of DM/day/lamb among sheep fed different barley cultivars (Chapter 7).

This variation is attributed to different factors in addition to cultivar and location which are known to account for variation in nutrient value of straw, in general. Morphological fractions are also one of the factors affecting the nutritive value. For example, Ramanzin et al. (1986) suggested that 20% of the variation in cereal straw quality is explained by morphological fractions, and Capper et al. (1988) suggested about 40% of the variation in feeding value of barley is associated with variation in morphological fractions. Our study also aligns with this literature, whereby barley cultivars with high eaf-to-stem ratios were consumed in higher quantities by the sheep, and also produced greater body weight gain.

The reason for the contribution of leaf-to-stem ratio to the variation in feed intake, digestibility, and feeding value might be related to the fibre content of the feed since the overall fibre content and voluntary feed intake are negatively associated. If the feed has low digestibility and contains a low level of energy (often high fibre), the feed intake is affected by physical factors such as ruminal fill and digesta passage.

Voluntary feed intake for highly digestible diet that contains a high level of energy (often seen in diets with a low level of fibre and high level of concentrate) is affected by the animals' energy demands and by metabolic factors (NRC, 1996).

According to Singh (1992), fibrous feeds with NDF contents of less than 45% were classified as high quality; those with 45-65% were categorised as being of medium quality, and those with more than 65% NDF content were categorised as low quality roughages based on their NDF. Moreover, the proportion of lignin content in NDF is more important in determining the digestibility of NDF, hence, the amount of ADL might be a better predictor of roughage digestibility.

The overall fibre content observed in the current work was high. Such a high content is believed to be negatively correlated with voluntary intake, rate of organic matter fermentation, microcell yield per unit organic matter fermented, and propionate-to-acetate ratio in fermentation end-products. Therefore, supplementation is important for improving the feeding value and quality of residues.

The ability of rumen microorganisms to digest cell wall polysaccharides, consisting mainly of cellulose and hemicellulose is limited by lignin. Fibre is often used as a negative index of nutritive value in predicting the total digestible nutrients (TDN) and net energy (Van Soest, 1988).

The total intake in the current study was within the range of the recommended amount of total intake for ruminant animals, i.e. 2-6% (ARC, 1980). However, the energy density of the straw alone was below the lowest energy density at which sheep do not lose weight, i.e. 8% CP in DM, with growing lambs needing 11% CP (McDonald et al., 2010). As such, the concentrate mixture used in this study should fulfil the minimum requirements of the studied rams as recommended by Tsega et al. (2012), i.e.300 g/day DM concentrate for sheep fed crop residues.

In a study conducted by Bediye et al. (2020) in mixed farming systems in Ethiopia, barley straw ranked as the top crop residue, based on farmers' criteria, such as palatability, straw yield, and leaf proportion. In Chapter 5 of this thesis, barley cultivars were ranked based on potential utility index (PUI) which includes grain yield, straw yield, and straw quality. In fact, screening barley cultivars by NIRS can be the first step in the selection of a large quantity of cultivars, but it cannot measure the exact feeding value for ruminant animals. For example, it cannot measure the palatability of straw or the rumen passage time, so animal trials are needed to select the best cultivar from the promising cultivars to fully understand the quality of barley straw as a ruminant diet. We undertook an animal trial to fully understand the feeding value of only the promising cultivars because it is very expensive to undertake animal trials for a large quantity of cultivars.

In our study, we first tried to find the cheapest way of screening cultivars using NIRS. Compared with conventional wet chemistry methods of analysis, NIRS offers a cheap, fast and reliable method to accurately determine the nutritive value of a range of animal feeds (Gronauer et al., 2011). NIRS technology for feed analysis does not require chemicals and does not have any animal welfare issues related to ruminal cannulation, but the mineral composition of feed is not detectable by NIRS because their structure does not have organic bonds. In this thesis, IBON 174/03 cultivar was ranked first for potential utility index, which was also confirmed by animal evaluation. Despite some differences between *in vitro* and *in vivo* evaluation, this indicates that a match between the potential utility index (which is calculated based on yield and NIRS analysis) and the result of animal evaluation is still possible. This is in agreement with previous studies which reported that NIRS is an accurate method for predicting the nutritional value of animal feed (Adesogan et al., 1998; Alemu et al. 2021).

8.4. Conclusions and future perspectives

This thesis provides a general overview of barley straw utilisation and the means for its improvement in Ethiopian mixed crop-livestock farming systems. Most Ethiopian households store crop residues in exposed heaps which may lead to heavy loss in biomass and nutritive value due to feed spoilage. Hence, application of appropriate storage and management options to avoid wastage or spoilage of the straw is necessary. The high variation in grain and straw yield and quality among barley cultivars points to the possibility of improving yield and quality traits in the study area through selection.

The cultivars that were chosen as the most promising from this PhD work were selected based only on their performance in one year. Including data from at least a second year would have made these conclusions more robust, but the large differences in performance between the growing locations demonstrates the necessity of considering environmental influences, such as geological and climatological conditions, to avoid missing the optimal cultivars for a specific condition. In addition, *in vitro* analysis does not cover all aspects of nutritive value for animals, meaning that, at least for crucial decision steps, animal studies will be needed to get an accurate ranking of barley cultivars.

With the ongoing deterioration of farming land in barley-livestock farming systems, and the concomitant decrease in grain and straw production, methods are needed to further optimise the multi-purpose use of barley straw for food, feed, and soil mulch.

8.5. Take home messages

➢ Optimum utilisation of barley straw in mixed livestock farming is associated with household and farm characteristics including education level of the farmers, family size, distance between cropping land and home, number of equines, and amount of barley straw produced (Chapter 4).

➢ Barley morphological parameters such as plant height, stem length, leaf-to-stem ratio, number of internodes per plant, number of spikes per plant, and stem length were not reliable enough to predict the straw yield and quality traits to use as selection criteria (Chapter 5).

➢ The wide cultivar variation in straw yield and nutritive value, combined with the poor association between yield and nutritive value for grain as well as straw, allows for upgrading of straw yield and its nutritive value without decreasing grain yield and its nutritive value (Chapter 6).

➢ Differences were noted in feeding value of straw from different barley cultivars, including digestibility, intake, and effects on animal performance (Chapter 7).

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Summary

Due to the decline in grazing land, degradation through overgrazing, and the expansion of arable cropping in tropical countries, the contribution of crop residues for animal feeding becomes increasingly important. The overall aim of this dissertation was to improve total barley biomass utilisation for food and feed use through the dual-purpose evaluation of barley varieties for mixed livestock-barley production in the Ethiopia highlands.

A survey conducted in mixed farming systems in six districts of Ethiopia concluded that there was high competition between the two uses of barley straw (soil mulch and animal feeding) in barley-livestock farming systems of Ethiopia. This was due to low straw yield which was further constrained by the low nutritive value. Its utilisation was determined by household and farm characteristics, such as the education level of the farmers, family size, distance between cropping land and home, number of equines, and amount of barley straw produced. Improving straw yield through breeding and selection of dual-purpose barley varieties could increase the supply of straw to not only meet livestock feed demands, but also provide enough crop residues for soil mulch. Interventions, training, and extension services promoting context-specific crop residue management for both agriculture and livestock components are imperative to facilitate the optimal utilisation of barley straw in Ethiopian mixed farming systems. This information will contribute to the design of appropriate biomass utilisation strategies in barley-livestock farming systems.

To improve the quality of barley straw for animal feed, efforts have been undertaken so far through chemical and biological treatments, but these are not accepted by farmers in lower-income countries such as Ethiopia because of social and economic problems. Improving the quality of straw through cultivar selection is an alternative option to select the food-feed cultivar.

A survey indicated that improving straw yield through breeding and selection of dual-purpose food-fodder barley varieties might improve straw yield and quality traits. Selection of many cultivars using conventional laboratory methods is costly and time consuming so that there is a

need for a reliable and rapid screening method to be used as a proxy for screening a multitude of genotypes for selection of superior dual-purpose cultivars in plant breeding. Barley morphological parameters such as plant height, stem length, leaf-to-stem ratio, number of internodes per plant, number of spikes per plant, and stem length were studied for use as proxies for screening barley cultivars in the tropics. However, the results of this dissertation showed that the studied plant morphology traits were not able to sufficiently predict the straw yield and quality traits.

As a first step, twenty malt and twenty food barley cultivars were evaluated for yield and quality traits of their grain and straw when grown at two locations in Ethiopia, using NIRS to categorise them as high grain yielder, high straw yielder and food-feed cultivars. Three superior varieties were identified: IBON174/03 (as grain yielder), HB1963 (as grain and straw yielder), and Traveller (as straw yielder). To evaluate how well the straw of these cultivars performed as a feed resource, a trial with regional livestock (20 rams) evaluated the digestive and metabolic responses to these promising barley cultivars, using a local barley variety as reference. Digestibility, feed intake, and average daily weight gain differed among cultivars, with the IBON174/03 cultivar determined as the most promising in terms of feeding value of the straw, hence it could be recommended as a more suitable candidate in the study area. Including straw quality as a selection criterion for barley can help in enhancing livestock productivity in addition to grain yield for human consumption. This study showed the importance of barley cultivar when straw is a substantial part of a ruminant’s diet, such as in tropical conditions.

In general, the wide variation among barley cultivars in terms of yield, chemical composition, morphology, digestibility, feed intake, and animal performance indicates the possibility of improving cultivar performance though selection of the barley cultivars. Barley breeding and improvement programmes in Ethiopia should consider straw yield and quality traits in addition to grain yield. There is a need for strong collaboration between animal nutritionists and barley breeders in Ethiopia for breeding and releasing cultivars that consider optimising both human and animal feeding goals.

Samenvatting

Door de afname van graasland, de degradatie door overbegrazing en de uitbreiding van akkerbouw in tropische landen, wordt de bijdrage van gewasresten voor veevoer steeds belangrijker.

Het algemene doel van dit proefschrift was om het totale gebruik van biomassa van gerst voor voedsel én voeder te verbeteren door middel van de evaluatie van gerstvariëteiten voor gemengde veeteelt-gerstproductie in de hooglanden van Ethiopië.

Een onderzoek uitgevoerd in gemengde landbouwsystemen in zes districten van Ethiopië concludeerde dat er grote concurrentie was tussen de twee toepassingen van gerststro (bodemmulch en veevoer) in Ethiopië vanwege de lage stro-opbrengst die verder werd beperkt door de lage voedingswaarde. Het gebruik ervan werd bepaald door kenmerken van huishoudens en boerderijen, zoals het opleidingsniveau van de boeren, de gezinsgrootte, de afstand tussen het akkerland en het huis, het aantal paardachtigen en de hoeveelheid geproduceerd gerststro. Het verbeteren van de stro-opbrengst door het selecteren van dubbeldoel gerstvariëteiten zou de aanvoer van stro kunnen vergroten om niet alleen aan de vraag naar veevoer te voldoen, maar ook om voldoende gewasresten voor bodemmulch te verschaffen.

Interventies, training en voorlichtingsdiensten ter bevordering van contextspecifiek beheer van gewasresten voor zowel landbouw als veeteelt zijn absoluut noodzakelijk om het optimale gebruik van gerststro in Ethiopische gemengde landbouwsystemen te vergemakkelijken. Deze informatie zal bijdragen aan het ontwerp van geschikte strategieën voor het gebruik van biomassa in gemengde landbouwsystemen.

Om de kwaliteit van gerststro voor veevoer te verbeteren, zijn tot nu toe inspanningen geleverd door middel van chemische en biologische behandelingen, maar die werden niet geaccepteerd door boeren vanwege sociale en economische problemen in ontwikkelingslanden, waaronder Ethiopië, zodat het verbeteren van de kwaliteit van stro door selectie een alternatieve optie is.
Een onderzoek wees uit dat het verbeteren van de stro-opbrengst door veredeling en selectie van gerstrassen voor voedsel én voeder de stro-opbrengst en kwaliteitskenmerken zou kunnen verbeteren.

Selectie van een groot aantal cultivars met behulp van conventionele laboratoriummethoden is kostbaar en tijdrovend, zodat er behoefte is aan een betrouwbare en snelle screeningsmethode die kan worden gebruikt als een proxy voor het screenen van een groot aantal genotypen voor de selectie van superieure cultivars voor dubbeldoel plantenveredeling. Morfologische parameters van gerst zoals planthoogte, stengellengte, blad-stengelverhouding, aantal internodiën per plant, aantal aren per plant en stengellengte werden bestudeerd om te gebruiken als een proxy voor het screenen van gerstcultivars in de tropen, maar het resultaat van dit proefschrift toonde aan dat de bestudeerde plantmorfologiekenmerken niet in staat waren om de stro-opbrengst en kwaliteitskenmerken voldoende te voorspellen.

Als eerste stap werden twintig mout- en twintig voedergerstcultivars geëvalueerd op opbrengst- en kwaliteitskenmerken van hun graan en stro, geteeld op twee locaties in Ethiopië, met behulp van NIRS om ze te categoriseren als hoge graanopbrengst, hoge stro-opbrengst en voedercultivar. Er werden drie superieure rassen geïdentificeerd: IBON174/03 (als graanopbrenger), HB1963 (als graan- en stro-opbrenger) en Traveller (als stro-opbrenger). Om te evalueren hoe goed het stro van deze cultivars presteerde als voederbron, evalueerde een proef met regionaal vee (20 rammen) de vertering en metabolische reacties op deze veelbelovende gerstcultivars, met een lokale gerstvariëteit als referentie. De verteerbaarheid, voeropname en gemiddelde dagelijkse gewichtstoename verschilden tussen cultivars, waarbij de IBON174/03-cultivar de meest veelbelovende was betreffende voederwaarde van het stro, en daarom zou het kunnen worden aanbevolen als een geschikte keuze in dit studiegebied. Door strokwaliteit als selectiecriterium voor gerst op te nemen, kan naast de graanopbrengst voor menselijke consumptie ook de productiviteit van de veestapel worden verbeterd. Deze studie toonde het belang van gerstcultivar aan wanneer stro een substantieel onderdeel is van het dieet van herkauwers, zoals in tropische omstandigheden.

Over het algemeen wijst de grote variatie tussen gerstcultivars in opbrengst, chemische samenstelling, morfologie, verteerbaarheid, voeropname en dierprestaties op de mogelijkheid om de prestaties te verbeteren door selectie van de gerstcultivars. Bij programma's voor het kweken en verbeteren van gerst in Ethiopië moet naast de graanopbrengst ook rekening worden gehouden met stro-opbrengst en kwaliteitskenmerken. Er is behoefte aan een sterke samenwerking tussen nutritionisten en gerstveredelaars voor het kweken en vrijgeven van cultivars in Ethiopië die rekening houden met zowel optimale voedingsdoelen voor mens als dier.

Curriculum vitae

Mulugeta Tilahun Keno was born on October 31, 1983, in Bilo Nopa District, Oromia regional state, Ethiopia. He completed elementary and high school education at Bilo Nopa Elementary School and Mettu Comprehensive High School, respectively.

He obtained a B.Sc degree in Animal Science from Ambo University, Ethiopia in 2008. He was employed by Bilo Nopa Agricultural and Rural Development office, Ilubabor, Ethiopia, and served as an animal production and fishery expert for one year.

In 2010, he rejoined Ambo University to pursue his Master of Science (MSc) degree and obtained an M.Sc in Aquaculture and Fishery in 2012. Upon completion of his M.Sc degree, he served as an expert in animal production and fisheries at Iluababor Zone, Livestock Production, Health and Fishery Resource Agency for one year. In September 2014, he joined Mettu University and served as a lecturer until he was admitted as a joint Ph.D student to Jimma University and Ghent University in October 2017.

He has attended an International Training Programme short term course at Ghent University's Faculty of Bioscience Engineering in Belgium, and obtained a certificate in International Training Programme in Aquaculture Health Management in 2017.

He conducted his PhD thesis research entitled "OPTIMISING THE USE OF BARLEY STRAW IN TROPICAL RUMINANT DIETS". The results of his PhD project are presented in this thesis.

Mulugeta is author and co-author of six publication in scientific journals. He has presented his work at international conferences.

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Oral presentation

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Poster presentation

Mulugeta Tilahun Keno, Taye Tolemariam, Solomon Demeke, Ashraf Alkhtib, Jane Wamatu Geert P. J. Janssens.(2021). Presented his abstract “Perception of farmers and on-farm evaluation of yield and nutritive value of barley straw” as poster presentation at the. 25th International Congress of the European Society of Veterinary and Comparative Nutrition, Virtual, 2021, Portugal.

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