EFFECT OF THE INCLUSION OF THYME (*Thymus schimperi.* R) LEAVES AS FEED ADDITIVES ON GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, AND MEAT QUALITY OF HARARGHE HIGHLAND SHEEP, AND CONSUMERS' PERCEPTION OF HARARGHE HIGHLAND SHEEP MUTTON IN META WOREDA, EAST HARARGHE ZONE

MSc. THESIS

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Effect of The Inclusion of Thyme (*Thymus schimperi.* R.*)* Leaves as Feed Additives on Growth Performance, Carcass Characteristics, and Meat Quality of Hararghe Highland Sheep, and Consumers' Perception of Hararghe Highland Sheep Mutton in Meta Woreda, East Hararghe Zone

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As thesis Research Advisors, we hereby certify that we have read and evaluated this thesis prepared, under our guidance, by Raya Daba Galata, entitled: **Effect of The Inclusion of Thyme (*Thymus schimperi.* Ronniger) Leaves as Feed Additives on Growth Performance, Carcass Characteristics and Meat Quality of Hararghe Highland Sheep, and Consumers' Perception of Hararghe Highland Sheep Mutton in Meta Woreda, East Hararghe Zone.** We recommend that it be submitted as fulfilling the thesis requirement.

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DEDICATION

I dedicate this thesis manuscript to my hero, who was a guiding light in my life, artist **Hachalu Hundessa**, and who passed away on June **29, 2020**.

STATEMENT OF THE AUTHOR

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BIOGRAPHICAL SKETCH

The author, Raya Daba, was born on November 11, 1997, in G.C. in Chobi Town, West Showa Zone, Oromia Region, Ethiopia, from his father, Daba Galata, and his mother, Warkitu Diribsa. He completed his primary education at Ganji Ofu and Digo elementary schools in 2012, G.C.

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ABBREVIATIONS AND ACRONMYS

ADF	Acid Detergent Fiber
ADFI	Acid detergent Fiber Intake
ADG	Average Daily Gain
ADL	Acid Detergent Lignin
ADLI	Acid Detergent lignin intake
AIBPs	Agro-Industrial by Products
AMSA	American Meat Science Association
AOAC	Association of Official Analytical Chemists
BW	Body Weight
BWC	Body Weight Change
CCW	Cold Carcass Weight
CDP	Commercial Dressing Percentage
CHL	Chilling Loss
CL	Cooking Loss
CP	Crude Protein
CPI	Crude Protein Intake
CRD	Completely Randomized Design
CSA	Central Statistical Agency
DADF	Digestible Acid Detergent Fiber
DCP	Digestible Crude Protein
DDM	Digestible Dry Matter
DL	Drip Loss
DM	Dry Matter
DMI	Dry Matter Intake
DNA	Deoxyribonucleic Acid
DNDF	Digestible Neutral Detergent Fiber
DOM	Digestible organic Matter

Continues…

DPSW	Dressing percentage on Slaughter weight
EBW	Empty Body Weight
EIAR	Ethiopian Institute of Agriculture Research
FAO	Food and Agricultural Organization of the United Nations
FBW	Final Body Weight
FCE	Feed Conversion Efficiency
FCR	Feed Conversion Ratio
FL	Fasting Loss
FT	Fat Thickness
FWBPs	Fermented Wheat Bran Polysaccharides
GIT	Gastrointestinal Tract
HCW	Hot Carcass Weight
HHS	Hararghe Highland Sheep
IBW	Initial Body Weight
LHCC	Left Half Cold Carcass
MEI	Metabolizable Energy Intake
NDFI	Neutral Detergent Fiber Intake
NIS	National Institute of Standardization
NS	Not Significant
NSC	Noug Seed Cake
OM	Organic Matter
OMI	Organic Matter Intake
RCBD	Randomized Complete Block Design
RDP	Real Dressing Percentage
REA	Rib Eye Area
SAS	Statistical Analysis System
SBW	Slaughter Body Weight

Continues…

SEM	Standard Error mean
SL	Significance Level
SPSS	Statistical Package for Social Sciences
TDN	Total Digestible Nutrient
TEOC	Total Edible Offal Components
TL	Thawing Loss
TMR	Total Mixed Rations
TNEOC	Total Non-Edible Offal Components

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Effect of the inclusion of Thyme (*Thymus schimperi.* Ronniger) Leaf as Feed Additives on Growth Performance, Carcass Characteristics, and Meat Quality of Hararghe Highland Sheep, and Consumers' Perception in Meta Woreda, East Hararghe Zone.

ABSTRACT

This study was conducted at Haramaya University, a goat farm, and Meta Woreda in the East Hararghe Zone to evaluate the effect of thyme (Thymus schimperi R.) leaves as feed additives on the growth performance, carcass characteristics, and meat quality of Hararghe Highland Sheep (HHS) and assess consumer perceptions of sheep mutton consumption trends in Meta Woreda. Eighteen finishing rams with an average initial body weight of 23.13 ± 0.02 kg were purchased from local markets. The experimental design utilized was a randomized complete block design (RCBD) with six replications, where the animals were blocked according to their initial body weight and randomly assigned to three dietary treatment groups: T1 (0 g thyme), T2 (100 g thyme), and T3 (200 g thyme). Each treatment consisted of concentrate mixtures formulated from wheat bran, noug seed cake, table salt, and vitamin and mineral premixes provided at 2.5% of the rams' body weight on a dry matter basis, with pasture grass hay offered ad libitum. The digestibility trial was carried out for 7 days, followed by a feeding trial of 60 days and carcass evaluation. The feed offered and refusals were recorded for each animal during both the digestion and feeding trials, whereas feces voided during the digestibility trial were recorded daily. The body weight changes of the animals during the feeding trial were recorded within a ten-day interval. Compared with those fed the control diet (T1), the rams fed diets containing 100 and 200 grams of dried thyme leaf (DTL) as a feed additive exhibited larger average DM, OM, CP, NDF, ADF, and ADL intakes. On the other hand, there was a significant difference ($p<0.05$) in the DM digestibility coefficient among the treatments, indicating that rams fed T2 had the highest digestible DM and OM coefficients (82.0 vs 80.4%) compared with those in T3 (79.9 vs 77.3%) and T1 (70.1 vs 67.3%), respectively. These findings suggest that the T2 diet is more effective at improving the digestibility of dry matter in the diet. Similarly, Hararghe Highland rams fed T2 (100 g DTL) supplemented with the concentrate mixture had shown the highest FBW, ADG, and FCE. The mean slaughter body weight (SBW), empty body weight (EBW), hot carcass weight (HCW), dressing percentage based on SBW and EBW, rib-eye muscle area, total edible proportion (TEP), and total usable products were significantly higher ($P<0.05$) for dried thyme leaf-supplemented rams than for the control diet. In addition, the inclusion of DTL as a natural feed additive in the diets of HH rams had enhanced meat color, water holding capacity, flavor, juiciness and tenderness, and chemical composition compared with those of the control diet.

Finally, the survey assessment conducted on perceptions of consuming sheep meat in Meta Woreda indicated that majority of the respondents (54.2% and 33.3%) said that they rarely eat mutton during religious holidays and wedding ceremonies, respectively. The major reason for the rare consumption of sheep meat was the bad smell of the meat (100%) due to the inherent excess fat content of the sheep (50%) and the feed source (33.3%). Moreover, the major mechanisms for alleviating its bad smell were washing live animal skin ahead of slaughtering (40.8%), hot carcass spicing (30.0%), and the application of a special cooking method (29.2%). Thus, from the results of this study, it was concluded that the inclusion of DTL at 100 g per day in the diet of finishing HH rams is optimal for enhancing feed intake, nutrient utilization efficiency, growth, carcass yield, and physical, chemical, and meat eating quality parameters. In addition, proper sheep feeding management and consumers' perception improving training are essential to enhance sheep meat consumption habit in the study area.

***Keywords*:** body weight changes, carcass yields, dried thyme leaves, finishing rams, meat qualities

1. INTRODUCTION

Ethiopia has the largest animal population in Africa, with 70 million cattle, 42 million sheep, 52 million goats, 8 million camels, and 56 million chickens (CSA, 2021). Small ruminants are well known for their ability to produce high-quality products with limited resources, adaptability across different agro ecological zones, resilience to climate change, and low environmental impact (Sejian *et al.*, 2021). They serve vital functions in the food and nutritional security of millions of rural people, particularly landless, marginal, and small farmers in arid, semiarid, and rain-fed regions of developing countries (Kumar *et al*., 2013).

Sheep are among the most important meat-producing ruminant animals in Ethiopia and are reared under an extensive production system with poor growth (Getahun, 2014). The average hot carcass weight of slaughtered sheep in Ethiopia is less than 10 kg, with animals slaughtered at ages ranging from 12-36 months (Abdi *et al*., 2019). The low productivity of these animals could be a result of inadequate year-round feed supply, poor nutrition, non-market-oriented animal production practices, inbreeding, and management factors (Feleke *et al*., 2015; Solomon *et al*., 2004). In addition, live animal and meat exports rely on young animals offered to the market from traditional pastoral and agro-pastoral farming systems, as the meat animals from highland areas have a short shelf life due to dark cutting and eating quality problems (Sileshi *et al*., 2022). To date, many studies have been conducted using commercial feeds and agro-industrial byproducts to increase the growth performance, productivity, and qualities of carcasses and meat obtained from different sheep breeds in the country (Shashie and Mengistu, 2019; Sileshi *et al*., 2022). However, these feed resources are costly, and the supply is very limited to specific areas where factories are near some livestock producers (Adugna *et al*., 2014). In addition, relying solely on cereal grains as the main feed ingredient for animals causes intense competition with human consumption, which ultimately leads to increased costs for animal production. Thus, it is vital to identify low-cost and locally available feed resources to improve sheep production and productivity in the country (Shashie *et al*., 2021). In this context, nonconventional feed resources are among the locally available feeds, which are alternative sources of carbohydrates and protein for animals and reduce the cost of production while also decreasing the amount of cereal grains consumed by animals.

Thus, evaluating and developing locally produced, easily available, and inexpensive alternative feedstuffs is highly indispensable. Among the various sources, the inclusion of Thyme leaves (*Thymus schimperi*) in the regular diet of sheep, particularly those raised in places where the plant is readily available, is among the possible options for enhancing their growth performance and meat sensory qualities. Thyme is a medicinal plant that includes essential oils, which are volatile aromatic molecules composed of terpenoids and phenylpropanoids, both of which have antibacterial characteristics (Michalak *et al*., 2021). Many species of this plant have been reported from various parts of the world and are categorized under different genera of the Lamiaceae family. *Thymus serrulatus* and *Thymus schimperi* are locally known as *'Tossign*' are endemic to Ethiopia (Tesfaye *et al*., 2021). The former grows in some parts of the country (Tigray, Gondar, and Bale, in the highlands of Semien Showa, and Wollo). *Thymus schimperi* is widely distributed in most parts of the country. These medicinal plants can also aid in stimulating appetite and digestion, hence improving animal performance when used as feed additives (Afshar *et al*., 2012).

However, few studies have been conducted on the feeding of thyme leaves, particularly *Thymus serrulatus and Thymus schimperi*, either at inclusion levels or by partly replacing concentrate diets. In this context, Mekuanent *et al*. (2020) reported that the replacement of 75 g and 100 g of dried *Thymus schimperi* leaves in the concentrate of Arsi-Bale sheep improved the aroma and flavor of mutton to a greater extent than the consumption of barley straw and 300 g of concentrate alone. On the other hand, Tewodros *et al.* (2012) reported that adding 100 g and 200 g of dried *Thymus serrulatus* leaves increased the feed intake, digestibility, growth performance, and meat quality of Menz sheep compared with those of those fed hay alone or hay + 300 g concentrate. However, the effects of inclusion of the dried thyme leaves may vary with plant species, animal breed, sex, age, harvesting stage and environment. To date, there is no generated information on the inclusion levels of *Thymus schimperi* leaves as feed additives supplemented with concentrate diet in Ethiopian livestock feeding practices.

General Objective

To evaluate the effects of the inclusion of Thyme (*Thymus schimperi.* R.*)* leaves as a feed additive on feed intake, digestibility, body weight changes, carcass characteristics, and meat qualities of Hararghe Highland Sheep and consumers' perceptions of Hararghe Highland Sheep Mutton Consumption in Meta Woreda, East Hararghe Zone.

Specific Objectives

- To assess consumers' perceptions of Hararghe Highland Sheep Mutton Consumption in Meta Woreda, East Hararghe Zone.
- To evaluate the effects of the inclusion of thyme leaves as a feed additive on the feed intake and digestibility of Hararghe Highland Sheep.
- To evaluate the effects of thyme leaf inclusion levels on body weight changes and feeding efficiency in finishing sheep.
- To evaluate the effects of thyme leaf inclusion as a feed additive on the carcass characteristics and meat qualities of Hararghe Highland Sheep.

2. LITERATURE REVIEW

2.1 Sheep Genetic Resources in Ethiopia

Sheep in Ethiopia are adaptable to a variety of conditions, including harsh ones. Understanding their genetic diversity is vital for improving breeding techniques and mapping quantitative trait loci related to productivity (Edea *et al*., 2017). It has a diverse genetic make-up, with more than 42 million sheep spread across different agro ecologies ranging from the cool alpine climate of the mountains to the arid pastoral areas of the lowlands, and Ethiopia is second in Africa in terms of the sheep population (CSA, 2021). Sheep were domesticated as dual-purpose animals, producing both wool and meat, and early people prized sheep milk as well (Ahmedin, 2019). Ethiopia is thought to be one of the important crossroads for domestic sheep migration from Asia to Africa, with a diverse indigenous sheep population.

On the basis of their ecological distribution, tail type (fat-tail versus thin-tail), tail form or shape, and fiber type, sheep can be divided into four groups: subalpine short- and fat-tailed, highland long- and fat-tailed, lowland fat-rumped, and lowland thin-tailed (Solomon *et al*., 2008). Ethiopia has 14 traditional sheep populations that are classified into six breed categories on the basis of DNA and physical data (Meseret, 2020). The major sheep groups and sheep types present high levels of morphological and ecological variety. Sheep types, ethnic groups, and production systems are strongly associated. Ethiopian sheep have focused on a few distinct sheep varieties in the country, such as Horro, Menz, Afar, and Bonga, and/or on a small number of animals (Getachew *et al*., 2010).

Hararghe Highland sheep are a type of indigenous sheep found in the eastern Hararghe Highlands. The entire productivity of the flock and the economic return from sheep production operations are determined by the growth performance and survival of the flock (Campbell and Waldron, 2006). According to Helen *et al*. (2015), the average age at sexual maturity, age at first lambing, and lambing interval of Hararghe Highland sheep are 7.24±1.74, 13.8±0.14, and 8.58±0.14, months respectively.

The lambing interval reported by Helen *et al*. (2015) was longer than that previously reported for this sheep breed, which was 6.5 months (Wossenie, 2012). Twin births are rare (Helen *et al*., 2015). According to these writers, the ages at sexual maturity for males and females were 8.58 and 7.4 months, respectively. Compared with Afar sheep, Hararghe Highland sheep perform better in terms of dry matter and nutrient intake, live weight gain, and feeding efficiency (Sileshi *et al*., 2021).

2.2. Feed Resources for Sheep in Ethiopia

Green fodder/grazing or natural pasture (54.54%), crop residual (30.8%), hay (7.35%), improved forage (0.57%), industrial byproducts (2.03%), and other or nonconventional feed (4.37%) are the main feed resources utilized by livestock keepers in Ethiopia (CSA, 2021). Crop stubble, fallow grazing, roadside grazing, browsing, improved grain forages, and nontraditional feeds such as household food leftovers, weeds from crop fields, tillers from dense crop fields, fillers, and traditional brewer byproducts (locally known as *atella*) are also examples (Shapiro *et al*., 2015). Similarly, according to Addis (2015), the available feed resources for sheep are natural pasture, crop residue, cultivated forage, and industrial byproducts, as well as other feed resources that come from herbaceous forages, trees, and shrubs; food crop wastes; agro-industrial byproducts; mineral supplements; and other byproducts.

Similarly, Belay and Janssens. (2021) reported that the majority of livestock feeds in Ethiopia are acquired from natural pastures, followed by crop residues, with very few from agro-industrial byproducts. The principal types of grazing for sheep are communal grazing land, roadside grazing, private grazing, riverbank grazing, and indigenous grazing. Although there is variation in utilization throughout the months of the year, communal grazing lands are used all year (Sisay and Kefyalew, 2015). The primary feed resources available to Hararghe Highland sheep are crop residue and natural pastures (Bikila and Tigist, 2016). In comparison with oat grains, giving Ficus sur fruits to Hararghe Highland sheep as a supplement to a natural pasture hay-based diet with sufficient protein supplementation increased carcass production and pH (Diriba *et al*., 2015).

2.2.1 Natural pasture and hay

Natural pastures consist of grasses, legumes, herbs, shrubs, and tree foliage that grow naturally and are used as animal feed. However, altitude, rainfall, soil type, and cropping intensity all influence the quality and availability of these pastures (Alemayehu *et al*., 2017). The expansion of cropping to meet the ever-increasing human population's subsistence needs, the expansion of urbanization at the expense of grazing land, and poor management and utilization systems (overgrazing) have led to serious land degradation, resulting in a reduction in grazing land in high-elevation land farming systems (Fekede *et al*., 2011).

Hay is another source of roughage feed, either as standing hay or as hay that has been artificially dried and stored. Hay harvested at the proper time of development can be a good maintenance diet. Unfortunately, the tropics produce very little good hay. Hay is the most practical kind of stored fodder and an ideal forage conservation option for small-scale farmers and pastoralists with limited resources. During times of scarcity, hay is the primary source of energy and protein (Alemu *et al*., 2008). Mature grass, especially weather-leached grass, is low in digestible energy, protein, soluble carbohydrates, carotene, and specific minerals (Wu, 2018**)**. According to Abuye *et al*. (2018) and Mezgebu *et al*. (2019), the CP contents of hay are 7.07 and 7.12%, are gathered from communal and private grazing pastures in different locations in Ethiopia, respectively.

2.2.2 Agro-industrial byproducts

Agro-industrial byproducts from food processing industries, such as oil seed byproducts and grain byproducts, are now valued livestock feeds. In Ethiopia, the major agro-industrial byproducts (AIBPs) are oilseed cakes, wheat bran, middling and grains, brewery byproducts, and pulse grain byproducts (Fekede *et al*., 2015). They are high-energy, protein, mineral, and vitamin feeds that are useful in ruminant rations to supplement low-quality feeds, particularly roughages. Agro-industrial byproducts have less fiber and a higher nutritional content than crop residues and other roughages (Mengistu *et al*., 2016). Oil cake (rapeseed cake, noug cake, and sunflower cake), bran, and brewery residue account for 2.03% of the total feed sources generated in Ethiopia (CSA, 2021). However, they are too expensive for smaller growers.

2.2.2.1 Wheat bran

In Ethiopia, WB is the most common milling byproduct used as a possible nutrient source for cattle. Wheat bran is considered one of the most abundant and cost-effective sources of dietary fiber, vitamins, minerals, and bioactive substances and is a great culinary ingredient (Babu *et al*., 2018). Because of its swelling and water-retaining capacity, it is highly tasty and well known for its laxative properties (Adugna, 2007). This is because it contains many fiber and non-starch carbs. It is a concentrated energy source that contains easily digestible carbohydrates (linked polysaccharides). These feeds are easily digested in the rumen and have high energy-producing potential. The bran is the seed's outermost layer, and it is high in fiber. It has a superior amino acid balance to whole wheat and is one of the richest of all popular feeds in terms of phosphorus (1 to 1.3%) but has a low calcium (0.1 to 0.13%) content and is a moderately decent source of most water-soluble vitamins except niacin, which is completely unavailable (Adugna, 2007).

Furthermore, the fiber concentration of wheat bran makes it a better supplement for ruminants than for monogastric animals. Mixing WB with protein-containing foods enhances intake, digestibility, growth performance, total DMI, and dressing percentage in Gumuz sheep (Alemu, 2016). Wheat bran is provided when combined with grain- and CP-rich diets such as oil seed meals and brewery-dried grain (BDG). According to Awoke (2011), wheat bran-supplemented groups presented considerably greater total DMI than did the control group. According to Mekuanent *et al.* (2020), the wheat bran contents of DM%, ash, CP, NDF, and ADF are 95.6, 3.6, 18.5, 47.4, and 12.6 respectively. According to Awet and Solomon. (2009), compared with no supplemented Afar sheep, wheat bran supplementation improved the digestibility of all nutrients except NDF and ADF. Plant polysaccharides, fermented wheat bran polysaccharides (FWBPs), have been shown to improve lamb growth performance, although little is known about their influence on rumen bacteria (Wang *et al*., 2022).

2.2.2.2 Noug seed cake

Niger (*Guizotia abyssinica*) is an oil-seed crop cultivated in Ethiopia's highlands (Bayissa *et al*., 2023). It is known locally as noug, and its seeds are a rich source of edible oil. The byproduct that remains after extracting oil from the noug seed is called noug.

In Ethiopia, noug seed cake is a primary source of protein and energy for livestock production. Noug seed cake contains a high quantity of protein, ranging from 25.2 to 38%. Noug (*Guizotia abyssinica*), an economically important oilseed crop, originated and is primarily grown in Ethiopia (Sewalem, 2023). Niger (*Guizotia abyssinica*) is a major oilseed crop native to Ethiopia, where it is produced in rotation with cereals and pulses (Heuzé *et al*., 2016). It accounts for 50% of Ethiopian oilseed production. Niger oil cake is a high-protein, oil-and-fiber feed that is devoid of toxins and is suitable for all types of animals that can digest fibrous diets. The oil industry produces noug seed cake as a byproduct. Processes that impact the efficiency of edible oil manufacturing have an equivalent impact on meal quality. According to Abebe *et al.* (2008), the chemical compositions of noug seed cake for OM, CP, NDF, ADF, ADL, and Ash are 88.6, 30.8, 32.4, 29.7, 11.7, and 11.4% ash, respectively, on a DM basis. According to Dea *et al.* (2020), feeding sheep with the maximum level of Noug seed cake, final body weight gain and average daily body weight gain make it possible to infer that supplementing lambs with 200 g of noug seed cake was both feasible and economically beneficial.

2.2.3 Nonconventional feed resources

Nonconventional feed resources are any feeds that have not been traditionally used in animal feed or are not commonly found in commercially produced livestock rations. Whereas traditional crop feeds are primarily from annual crops, unconventional feeds generally comprise a variety of feeds from perennial crops as well as feeds of animal and industrial origin. Brewery grain, oil palm byproducts, single-cell proteins, plant and animal feed materials, and low-quality cellulosic roughages from farm residues, such as stubbles, haulms, and vines, are examples of these feed sources (Aschalew, 2015). Feeds such as residues of local drinks and chats left over, known as geraba, fruits, and vegetables, are examples of unconventional feed resources (Yeshitila, 2008).

2.3 Description and Chemical Properties of Thyme

Thyme is an aromatic plant in the Lamiaceae family. It is an evergreen herb. The generic name is derived from the Greek verb thyme, which refers to perfume, in allusion to the plant's powerful and pleasant aroma (Nieto, 2020). It is a tiny, perennial plant that grows around the ground and rarely reaches 40 cm. It blooms in the summer (June to October), and its flowers are few, with pink spikes and a pleasant smell. According to Mekuanent *et al*. (2020), the DM%, ASH%, CP%, NDF%, and ADF% of thyme leaves (*Thymus serrulatus)* are 96%, 5%, 14%, 41.1%, and 10.2%, respectively. According to Feyissa. (2023), the CP content of thyme leaves (*Thymus schimperi)* is 7.1%. This plant also contains nutrients such as vitamin A, vitamin C, iron, manganese, and copper. The predominant bioactive chemical component of *Thymus schimperi*, which grows naturally around Dinsho in the Bale area of the country's Oromia region (Damtie *et al*., 2018), thyme essence, especially the phenolic components thymol and carvacrol, shows antibacterial activity against gram-positive and gram-negative bacteria, mainly due to their effects on the bacterial membrane (Jafari *et al*., 2020). The thymus has traditionally been utilized to alleviate hyperactive airway problems (Rehman *et al*., 2021).

2.3.1 Botanical distribution of thyme in Ethiopia

Thyme is mostly a temperate plant that is rare in the African tropics. Thyme, an aromatic plant in the Lamiaceae family, has been identified in several parts of Ethiopia. Thymus is a genus of the Lamiaceae family and is represented in Ethiopia by two endemic species, *Thymus serrulatus* and *Thymus schimper*, both of which are used by the public as tea and food additives (Destaw *et al*., 2017). Thymus grows on roads, open grasslands, bare rocks, and slopes at elevations ranging from 2200 to 4000 meters. Both species are perennial herbs that are woody at the base and grow to a height of 5–40 cm (Gebrehana and Shimelis, 2013). Thymol is an isomer of carvacrol and a naturally occurring phenol monoterpene derivative of cymene. Thymol (10–64%) is a prominent ingredient of thyme essential oils (*Thymus vulgaris L.*, *Lamiaceae*), which are medicinal herbs with a variety of therapeutic effects (Salehi *et al*., 2018).

However, overutilization of *Thymus serrulatus* and *Thymus schimperi* is a major issue in Ethiopia because of their appropriateness as forages for cattle, sheep, and goats, as well as local residents' perceptions that animals fed these plants provide good beef, mutton, and milk (Destaw and Yalemtsehay, 2015).

2.3.2 Thyme plant as Medicinal value

2.3.2.1 Ethno medicinal properties of thyme

Currently, more than 20,000 plants are utilized to flavor, aromatize, odorize, and color food; for medical and aromatic plants; and for their antioxidant, anti-inflammatory, anti-allergic, anti-depressive, and antibacterial activities in addition to their aromatic properties, such as taste and aroma, which depend on the active chemicals in their contents (Kaptan and Sivri, 2018). Spices and herbs have long been used in medicinal practices because of their presumed health benefits and ability to improve the aroma, flavor, and color of food and beverages. They also protect the human body from a variety of acute and chronic diseases and infections (Singh *et al*., 2020). Spices and herbs are antimicrobial, anticarcinogenic, anti-inflammatory, glucose-lowering, and antioxidant and can provide a wide range of health advantages due to the presence of bioactive components such as polyphenols, sulfur-containing compounds, alkaloids, thymol, and piperine, among others (Singh *et al*., 2020).

2.3.2.2 Thyme as a natural ant-oxidative property

Spices and herbs have been used as flavoring, coloring, scent-enhancing, and preservation agents in foods, and the addition of herbs and spices or their extracts to various dairy products allows these products to function as carriers for nutraceuticals (El-Sayed and Youssef, 2019). Because of their antibacterial and antioxidant activities, bioactive compounds isolated from medicinal plants can be employed as natural preservative additives in dairy products in addition to their taste and aromatizing purposes (Kaptan and Sivri, 2018). As spice and food additives, medicinal and aromatic herbs are used for aromatic, coloring, preservative, and ant-oxidative functions. Thyme *(Thymus vulgaris)* can increase the sensory qualities of dairy products, such as scent, taste, color, and overall quality (Regu *et al*., 2016). The use of plant essential oils (EOs) has increased the number of natural plant applications in livestock (Nehme *et al*., 2021).

3. MATERIALS AND METHODS

3.1 Description of the Study Area

The survey was conducted in the Meta Woreda, Eastern Hararge Zone, and Oromia Regional State, where the experimental animals were purchased. The Meta Woreda is located 445 km from Addis Ababa and 80 km west of Harar. The Meta Woreda is located at 9°0′09″ to 9°0′31″N latitude and 41°0′29″ to 41°0′44″E longitude (Meta Woreda Livestock Office, 2015). The Meta Woreda reaches 2830 m above sea level. The annual rainfall ranges from 600 to 900 mm, while the temperature ranges from 15°C to 37°C. The experiment was conducted at the goat farm of Haramaya University, which is located 515 km east of the capital, Addis Ababa. The site is situated at an altitude of 2006 m above sea level, 9°41'N latitude, and 42°4'E longitude. The mean annual rainfall in the area is 790 mm, and the annual mean temperature is 17°C, with mean minimum and maximum temperatures of 14°C and 23.4°C, respectively (Kbrom *et al*., 2016).

3.2 Assessment of Consumers’ Perception of Mutton Consumption

A total of 120 respondents were randomly selected from farmers (80) and meat consumers (40) from rural and urban areas. The rural area respondents were both sheep producers and consumers, and their homesteads in the villages were also visited. Three rural kebeles, namely, *Biftu Ganama, Oda Chafe* and *Waligalte Bali’na*, were purposively selected on the basis of sheep production potential and accessibility, whereas urban (*Kulubi and Chelenko*) consumers were selected.

3.2.1 Data collection

The questionnaires prepared to gather primary data on meat preferences and perceptions of consumers about sheep meat consumption were pretested. A total of 120 producers and consumers in rural and urban areas were interviewed. The survey data were collected by trained enumerators through door-to-door consumer interviews.

3.3 Experimental Animals and Management

A total of 18 growers of Hararghe Highland rams were purchased from local markets in the East Hararghe Zone, Meta Woreda. The average initial body weight of those animals was 23.13 ± 0.02 kg. The age of the animals was determined by their dentition and information obtained from the owner. After arriving at the research station, the rams were acclimatized to the research site for 21 days. During this period, all the animals were ear-tagged, drenched with an anthelmintic against internal parasites, and sprayed with an acaricide against external parasites. Moreover, all rams were vaccinated against common diseases (sheep pox, anthrax, and ovine pasteurella) in the area and penned individually.

3.3.1 Experimental feed preparation and feeding

The experimental diets were composed of different amounts of dried thyme leaves, grass hay as a basal diet for *ad libitum* feeding, and a concentrate mixture composed of 74% wheat bran, 25% Noug Seed Cake (NSC), and 1% of (table salt, ruminant vitamins and mineral premixes). The concentrate mixture ration was formulated according to the NRC (2007). Fresh thyme leaves were collected in the September 2023 G.C. and transported from *Kersa Woreda*, specifically the *Watar* area by transport vehicles. Then dried in the shade for five consecutive days. Then crushed by hand and stored in sacks until use. At the end of the acclimatization periods, the animals were adapted to the experimental diets and individual pen management for 14 days by randomly assigning them to their respective dietary treatment groups. The animals were housed in individual pens with feed and water troughs, which were cleaned daily before morning feeding. The experimental animals were fed at 2.5% of their body weight of the concentrate mixture (g/kg) on a dry matter basis and involving 500 g/kg per day of the grass hay as basal diet, and dried thyme leave as feed additives. The diet was provided in two equal amounts at 8:00 AM and 04:00 PM to ensure the same in the feeding methods. The quantities of the diets offered were revised every ten days on the basis of body weight changes. The animals had free access to clean drinking water in their respective pens throughout the experimental period. They were carefully observed for health-related problems, and records were kept throughout the entire experiment.

3.4 Experimental Design and Treatments

The experimental design used was a randomized completely blocked design (RCBD) with six replications in which the animals were blocked on the basis of their initial body weight and randomly assigned to each dietary treatment. The three experimental treatments are shown in Table 1.

Table 1. Experimental dietary treatments.

Treatments	Dietary arrangement	Natural Grass Hay
T1	Concentrate mixture + 0 g DTL	*Ad libitum*
T2	Concentrate mixture + 100 g DTL	*Ad libitum*
T3	Concentrate mixture + 200 g DTL	*Ad libitum*

DTL = dried thyme leaves.

3.5 Digestibility Trial

Digestibility was determined via the total collection method. During the collection period, there were 3 days of adaptation to carry fecal collection bags and 7 days of actual fecal collection. The complete collection of feces from finishing rams was carried out in plastic bags daily in the morning, after which the samples were weighed and stored at −20°C. At the end of the collection period, the collected feces from each animal were thoroughly mixed, and then 20% of the fecal subsamples were taken, wet weighted, coded, and kept in paper bags for oven drying at 65°C for 72 hours. The dried feces were subsequently reweighted and made ready for laboratory analysis following the methods of the AOAC (2005). On the other hand, feed offers and refusals during the 7 days of digestibility were recorded daily for each animal. On this basis, dry matter intake was calculated as the difference between the offer and refusal. The apparent digestibility coefficient of DM and nutrients was calculated via the following equations, as per McDonald *et al*. (2002):

Apparent DM digestibility coefficient $= \frac{DMI - Fecal\ out\ put}{DMI}\ X100$

Digestible DM and nutrient intake $= \frac{Nutrient\ Intake - Nutrient\ in\ feces}{Nutrient\ Intake}\ x100$

3.6 Feeding Trial and Feed Intake

The actual feeding trial was conducted following the digestibility trial. This feeding trial was continued by using all the animals for 60 days and being provided with their respective treatment diets. The quantity of hay and concentrate offered and refused during the feeding trials was recorded per animal via a weighing balance every morning prior to meals until the end of the trials. These data were used to calculate the feed intake of each animal. Refusals from each animal were cleaned from feces and other non-feed contaminants. At the end of the feeding trial, the composite samples of feed offered and refusals per animal were mixed thoroughly and subsampled per animal for laboratory analysis. DM and nutrient intake were subsequently calculated as the difference between the amount of diet offered and that of the refusals and the difference between the nutrient contents of the diet offered and that of the refusals, respectively.

3.7 Body Weight Changes and Feed Conversion Efficiency

During the feeding trial, the animals were weighed every ten days via a spring balance before being offered feed and water in the morning. The final body weight was taken after overnight withdrawal of feed and water, and total body gain was calculated as the difference between the final body weight and the initial body weight. The average daily weight gain of the rams in the fattening experiment was calculated via the following formula:

$$Average\ daily\ gain = \frac{Final\ body\ weight - Initial\ body\ weight}{Number\ of\ fattening\ days\ (60)}$$

The feed conversion efficiency (FCE) and live weight gain were monitored at ten-day intervals until the end of the experiment and calculated as follows:

$$\text{Feed conversion efficiency (FCE)} = \frac{Daily\ Weight\ gain}{Amount\ of\ feed\ consumed}\ x100$$

The metabolized energy Mcal/kg DM intake and Total digestible nutrient proportion (% TDN was determined via the equation: ME, Mcal/kg DM = DE X 0.82 and DE, Mcal/kg DM= (TDN %) X 0.04409, as described by NRC (2007).

3.8 Slaughtering Procedures

Prior to slaughter, the body weight of each ram was recorded to determine the slaughter body weight after fasting for 16 hours to empty its intestinal tract to facilitate the removal of viscera without contamination of the carcass. Slaughtering was carried out in a Haramaya University abattoir house. All the experimental animals were slaughtered. The rams were slaughtered according to the standard halal procedure of Kadim *et al.* (2003). Bleeding was affected by severing the carotid arteries and jugular vein. The esophagus was tied close to the head to prevent flows of digesta before it was weighed. The head was removed at the atlanto-occipital joint, and the fore and hind feet were removed at the carpus-metacarpal and tarsus-metatarsal joints, respectively (Safari *et al.*, 2009; Bonvillani *et al*., 2010).

3.8.1 Non-carcass component evaluation

The non-carcass components were weighed immediately after slaughter. The gastrointestinal tract with and without the contents, liver, heart, rumen, reticulum, abomasum, omasum, tail, testicles, kidney, small intestine, and tongue were weighed and recorded as edible offal, whereas the head without the tongue, skin, spleen, gall bladder, lungs with the trachea and esophagus, blood, large intestine, four feet, fat depots (scrotal, pelvic, kidney, omental, and mesenteric fats), penis, and gut content were weighed and recorded as nonedible offal. The total edible proportion was calculated as the slaughter body weight minus the contents of the gastrointestinal tract, skin, head, feet, lungs, and trachea. Moreover, the total nonedible proportion was calculated as the SBW minus the total edible proportion. The amount of total edible offal components was taken as the sum of blood; empty gut, kidney, and heart; and liver with gall bladder, tongue, tail, and testis (Bonvillani *et al.* 2010). The total nonedible offal components were taken as the sum of the feet, gut contents, head, lung with trachea, large intestine, penis and urinary bladder, skin, spleen, total visceral fat (gut fat (omental + mesenteric fat), and fat depots (scrotal fat, pelvic, heart, and kidney). The total edible products were calculated as the sum of the carcass components and total edible offal. The total number of usable products was computed as the sum of the carcass components, total edible offal and skin.

3.8.2 Carcass yield evaluation

Carcass is defined as a "primary unit of meat resulting from the slaughter, bleeding out, skinning, gutting, and removal of the head, genital organs, and extremities at the level of the metacarpal joint and tarsal metatarsal" according to Chilean government standards (INN, 2002). Carcass components were weighed immediately after slaughter. Empty body weight (EBW) was also computed as the SBW at slaughter minus the digestive tract contents. The whole carcass was weighed approximately 1 hour after dressing, which was designated the hot carcass weight. The hot carcass weight was computed by excluding the contents of the thoracic, abdominal, and pelvic cavities; head; skin; feet (cut off at the proximal end of the canon bone); and tail of the animal. The dressing percentage was calculated as a proportion of hot carcass weight to slaughter weight and empty body weight.

After the hot carcass weight was measured, the carcass was placed in a cold room at 4°C for approximately 24 hours, after which the cold carcass weight (CCW) was measured and recorded. Hence, the real or biological yield (BY) of the carcass was measured from the proportion of HCW and EBW (empty body weight) according to the methodology described by Silva Sobrinho (2001): EBW is the weight of an animal minus the contents of its gastrointestinal tract, fasting loss (FL) = {[(BW, kg – SBW, kg)/SBW, kg] × 100} and chilling loss (CHL) = {[(HCW, kg – CCW, kg)/HCW, kg] × 100}.

3.8.2.1 Carcass linear measurement

Carcass conformation describes carcass shape in terms of convex or concave profiles and indicates the amount of flesh (muscle and fat) in relation to the size of the bones (Fozooni and Zamiri, 2007). Carcass conformation can be assessed subjectively by a human classifier or objectively by carcass measurements (Lawrence and Fowler, 2002). After the carcass weight and yield data were collected, the cold carcass was suspended on hooks of constant width (20 cm) between the hind legs, and the following carcass conformation measurements were taken (Teixeira *et al.*, 2004). Carcass length (CL, cm) was measured from the base of the tail to the base of the neck. The width of the buttocks (WB, cm) was measured via a measuring caliper at the level of the proximal edge of the patellae. The width of the chest (WC, cm) was measured at the greatest width of the chest.

The width of the shoulders (WS, cm) was measured at the greater width of the shoulders. The anterior circumference of the buttocks (ACB, cm) was measured via a tape held horizontally around the buttocks at the level of the maximum width of the trochanter. The posterior circumference of the buttocks (PCB, cm) was measured via a tape held horizontally around the buttocks at the level of the caudal insertion.

3.8.2.2 Carcass quality measurement

3.8.2.2.1 Fat thickness and rib eye muscle area measurements

Back fat thickness (cm) and the rib-eye muscle area (cm^2) were measured on the *longissimus dorsi muscle* at the 12th and 13th rib positions (Amha, 2008; Iowa State University, 2013). Back fat thickness measures the accumulation of subcutaneous fat, and it was measured via a plastic ruler on the rib eye muscle cut at the 12th and13th rib positions.

The rib-eye muscle area determines lean muscle accumulation. It was measured by tracing on the transparent paper on the left and right sides of each animal's cold carcass muscle at the 12th and 13th rib positions. The area was calculated via a calibrated plastic grid prepared for small ruminant meat measurements (Iowa State University, 2013). The mean of the right and left cross-sectional areas was taken as the rib-eye muscle area.

3.8.2.2.2 Carcass composition/Dissected Carcass evaluation

After cold carcass weight measurement, the carcasses were then longitudinally halved along the spine (vertebral column) with a band saw to the left and right halves. The left-half of the carcass was subsequently fabricated into five anatomical regions (commercial cuts): the neck, shoulder (including the foreleg and breast), ribs, loin, and hind leg (including the posterior arm) (Furusho-Garcia *et al.*, 2004). Each cut was weighed separately. After weighing, each commercial cut was dissected into fat muscle, lean and bone and finally weighed separately. The total length of each cut obtained was calculated according to Moreno *et al.* (2010). The composition of whole carcasses was estimated from dissected tissues of the left-half carcass as per the procedures of Kassahun (2000).

3.9 Physicochemical Meat Quality Measurement

3.9.1 Physical meat quality measurement

3.9.1.1 Water holding capacity

Meat quality parameters were determined on meat samples taken from the right and left sides of each animal's cold carcass of the *longissimus dorsi* muscle. An indirect method was used to evaluate the water holding capacity of the meat. The direct method (filter paper method) was not available and was costly for imports from countries abroad. The indirect method is based on easily measuring water loss parameters such as thawing, cooking, and drip loss, which are inversely related to the WHC (Warner, 2014). The water loss from thawing is termed thawing loss. Each frozen meat sample was weighed (W1) and thawed at 4°C for 24 h. The plastic bag containing the frozen meat sample was opened, and the muscles were then blotted dry with filter paper and weighed (W2).

The thawing loss (%) was subsequently calculated as follows: $(\frac{W1-W2}{W1})X\ 100$

Drip loss was determined via the suspension method of Torres Filho *et al*. (2017). Meat samples taken from each ram were put into the net and suspended in a plastic bag, ensuring that there was no contact between the sample and the bag. The samples were stored at 4°C for 24 hrs. The weight of each sample was recorded before and after being suspended. Drip loss was expressed as a percentage of weight loss after suspension relative to the initial weight of the slice. For determination of cooking loss, samples were weighed (W3) in watertight bags and then cooked in a thermostatically controlled water bath set at 80°C for 60 min as described by Hoffman *et al*. (2003). Then, the meat samples were cooled for 4 h, and the samples were removed from the bags, dried with a cotton sheet, and reweighed (W4). Cooking loss was expressed as the percentage of water loss relative to the initial weight: (W3–W4/W3) ×100.

3.9.1.2 Meat color measurement

The color of meat is an important factor influencing consumer purchasing decisions (Moore *et al*., 2003). Color is influenced by the chemical status of the myoglobin in the meat. After 60 minutes of exposure to the air to allow blooming, cross sections were made on the third raw steak at the sample surface to expose the myoglobin to oxygen, as described by (Mancini and Hunt, 2005). The three color values (L* (lightness), a* (redness), and b* (yellowness)) were measured with Mini Scan XE Plus and CM 2600 spectrometers. This instrumental color measurement approach is based mainly on the American Meat Science Association guidelines for meat color measurement (King *et al*., 2023). Three fundamental aspects of meat color reflectance or coordinates are considered: luminosity (L*), red tones or redness (a*), and blue–yellow tones or yellowness (b*).

3.9.2 Meat eating quality evaluation

3.9.2.1. Taste panels selection and facilities

Sensory analysis was conducted at Haramaya University Resource Center using consumer panelists. Consumer panelists were selected on the basis of the set criteria for the selection of panelists for sensory evaluation and the administration of screening questionnaires. A screening questionnaire was administered, and respondents were considered eligible for participation if they were regular consumers of beef/mutton steaks and were the primary household shopper for beef/mutton steaks. The panelists were given training, verbal instructions and orientation to the evaluation task before being seated in individual testing booths for cooked product evaluation. Ultimately, 15 eligible consumer panelists aged between 25 and 35 years were. They were selected on the basis of their meat consumption habits or experiences, sensory capability, and health conditions and were free from any addictions and frequent use of perfume or deodorants. Each panelist involved in the taste test was given a score sheet, where they marked their findings of the sensory attributes of the meat samples. Moreover, each member was provided with utensils, including a fork, a knife, a paper plate, napkins, one glass cup with warm water for mouth cleansing after each sample test, and one plastic garbage for spitting as per the AMSA (2016) guide line.

Sensory evaluation was conducted in a room where disturbance to sensory stimuli was minimized, away from distracting noise and odors, and with neutral lighting. Influences and disturbances from fellow panel members and other personnel were minimized. The meat samples designated for consumer panelist product testing were thawed at 4°C overnight and then individually foil-wrapped with independent code. The electric oven was preheated at 175°C to an internal temperature of 40°C. The samples were put on cooking trays and placed in different layers of a cooking oven. Then, the mixture was flipped and cooked to a final internal temperature of 71°C for 30 minutes. At the time of service, the samples were unwrapped and set directly on the plates and then presented to the panelists in a sequential monadic manner. The panelists independently rated the flavor, tenderness, juiciness and overall acceptance of the samples. The panelists used 7-point category scales (hedonic scales) to evaluate the following traits: texture (1–very much tender; 7–very much tough); juiciness (1–very much juicy, 7–very much dry); lamb taste flavor intensity (1–very much strong, 7–very much weak); and overall acceptability (1-like very much, 7- dislike very much) (Andrés *et al*., 2007).

Table 2. Seven-hedonic scales for meat eating quality evaluation.

Meat Flavor	**Meat Tenderness**	**Meat Juiciness**	**Over all acceptability**
(7) Very desirable	(7) Very Tender	(7) Very juicy	(7) Like very much
(6) Moderately desirable	(6) Moderately Tender	(6)Moderately Juicy	(6) Like moderately
(5) Slightly desirable	(5) Slightly Tender	(5) Slightly Juicy	(5) Like slightly
(4) Slightly undesirable	(4) Slightly Tough	(4) Slightly dry	(4) Neither like nor dislike
(3) Moderately undesirable	(3) Moderately Tough	(3) Moderately dry	(3) Dislike slightly
(2) Very undesirable	(2) Very Tough	(2) Very dry	(2) Dislike moderately
(1) Extremely undesirable	(1) Extremely Tough	(1) Extremely dry	(1) Dislike very much

3.10 Laboratory Analysis

3.10.1 Feed and feces sample analysis

The offered feed samples, refusals, and feces were dried in an oven at 65°C for 72 hours, milled to pass through a 1 mm sieve screen, and kept in an airtight plastic bag pending analysis. Dry matter, and nitrogen contents were determined according to the procedures of AOAC (2005), and neutral detergent fiber, acid detergent fiber, and acid detergent lignin contents were analyzed according to Van Soest *et al*. (1991). The crude protein content was estimated as N * 6.25.

3.10.2. Meat sample analysis

The meat samples taken for proximate analysis were thawed at room temperature (20°C) and ground separately in a meat grinding apparatus. Chemical composition analysis was conducted to determine the protein, fat, water, and mineral (ash) contents of each meat sample to establish the nutritive and economic value of the products. Then, the epimysium (subcutaneous and intermuscular fat and visible connective tissues) was trimmed or removed, and each sample was finely chopped with a knife on a wooden plate. After this, the meat samples were coded, spread on aluminum foil, and placed in a forced ventilation oven at 55°C for 72 hours. The partially dried meat samples were reweighed and kept in polythene bags for proximate analyses.

All the components of the chemical analysis were determined. After these procedures, the samples were defatted via extraction with ether in a Soxhlet apparatus (AOAC, 2005) to obtain total lipids. After extraction, the samples were ground in a ball mill and stored in closed containers. The dry matter contents were determined by placing the samples in an oven at 105°C until a constant weight was reached. The ash and crude protein levels were determined on fat-free samples through the Kjeldahl method (CP = N × 6.25) as per the AOAC (2005) procedure.

3.11 Statistical Analysis

The data were analyzed using the General Linear Model procedures available in JMP 17 Pro software (Klimberg, 2023). This analysis aimed to evaluate the effects of thyme leaf inclusion on several parameters, including feed intake, digestibility, carcass characteristics, and meat quality. To assess the significance of the effects of varying levels of dried thyme leaves on these parameters, the Tukey test was employed to identify means that were statistically different.

$Yij = \mu + Ti + Bj + eij$, where

Y = response variables;

μ = the overall mean;

T_i =ith treatment effects (T1=0, T2=100, T3=200)

B_j = jth block effect (B1, B2, B3, B4, B5, B6)

Eij = the random error;

The survey data collected were subjected to a thorough analysis utilizing descriptive statistics, which was executed using the SPSS software program (version 26) as outlined by Abu-Bader (2021).

4. RESULTS AND DISCUSSION

4.1 Chemical Composition of the Experimental Diets

Table 3 shows the chemical compositions of the experimental feeds used for this study. The dry matter (DM) of the grass hay recorded in the current study is consistent with previous results of 91.4 and 91.98% DM reported for grass hay elsewhere in Ethiopia (Bimrew *et al*., 2010; Woretaw *et al*., 2021). The crude protein (CP) content of the grass hay utilized in this study was 8.41%, suggesting that the hay used as a basal diet in the present study could fulfill the optimum maintenance rumen nitrogen requirement of the sheep. This finding agrees with the results of a recent study by Feyissa *et al*. (2022), who reported an 8.6% CP content of natural pasture hay from the Holeta area, Central Highlands of Ethiopia. Similarly, the CP content noted in this study was consistent with previous findings by Kahsu *et al.* (2021) and Shashie and Mengistu (2019), who reported that the CP content of hay ranged from 7.9-9.91% in many locations in Ethiopia.

The CP content of the wheat bran in the current study was 15.7%. This result was similar to those of other studies (Kahsu *et al*., 2021; Shashie and Mengistu, 2019 and Tibebu *et al*., 2019), which revealed a range of 15.5–17.31%. The CP content of NSC in the present study was 34.6%. This was comparable with the results of previous studies by Feyissa *et al*. (2022) and Kahsu *et al*. (2021), who reported values of 33.4% and 34.52%, respectively. In the present study, the DM%, CP%, ADF%, NDF%, ADL%, and ash contents of the dried thyme leaves were 86.6%, 10.86%, 15.8%, 14.2%, 5.3%, and 10.9%, respectively. The DM% of the thyme leaves in the present study was lower than that reported in a previous study by Mekuanent *et al*. (2020), who reported a value of 96%. The CP content of the dried thyme leaves in the present study was greater than that reported by Feyissa *et al*. (2022), who reported a 7.1% CP content in the thyme leaves, whereas it was lower than that reported by Mekuanent *et al*. (2020), who reported a 14.0% CP content. The variation may be attributed to the variation in the fraction of thyme leaves and the growing conditions and environment of the plant. The CP and fiber contents linearly increased to the optimum level requirements, as the inclusion level of the inclusion of dried thyme leaves increased in the diet of fattening sheep.

This study suggested that the dietary inclusion of the dried thyme leaves possibly enhanced the rumen function and performance of the animals. The inclusion of powder from the leaves and twigs of *Thymus schimperi* plants up to an optimum level of 16% feed can reasonably stimulate the growth and activity of certain rumen microbes that promote an improvement in ruminal DM degradability in the diet supplemented with thyme (Feyissa *et al*., 2022).

Table 3. Chemical composition of the feed ingredients and dietary treatments.

Feed ingredients	Dry matter and nutrients proportions (%)						
	DM	OM	CP	ADF	NDF	ADL	Ash
Grass Hay	89.1	88.4	8.41	32.4	39.8	26.1	11.6
Noug Seed Cake	89.7	89.8	34.6	18.6	21.3	8.7	10.2
Wheat Bran	89.5	95.3	15.7	17.4	19.5	3.4	4.7
Dried Thyme Leaf	86.6	89.1	10.86	13.8	14.2	5.3	10.9
Treatment 1	90.27	93	19.9	14.45	40.8	13.5	7
Treatment 2	90.33	92.2	22.34	16.38	44.1	16.1	7.8
Treatment 3	90.35	92.4	25.56	16.48	49.44	15.68	7.6

DM= Dry Matter; OM= Organic Matter; CP= Crude Protein; NDF= Neutral Detergent Fiber; ADF= Acid Detergent Fiber; ADL= Acid Detergent Lignin.

4.2 Nutrient Intake

Table (4) shows the mean daily nutrient intake of the Hararghe Highland sheep. The present study revealed that the dietary inclusion of the dried thyme leaves significantly (P<0.05) increased the nutrient intake of Hararghe Highland rams compared with that of the control group. Higher intakes of DM, OM, CP, and ADL were observed in sheep receiving 100 g DM/day thyme leaves in their diet than in the control and other treatment groups in the present work. Similarly, the intakes of NDF and ADF were greater in the sheep fed diets inclusion with thyme leaves at a level of 200 g DM daily in this study. This might be due to the dietary inclusion level of the thyme leaves in this study, which may increase the level of nitrogen and fiber to the optimum level of rumen requirements, thus stimulating rumen function and intake.

Additionally, the chemical substances in the thyme plant may stimulate rumen function and digestive system secretion, resulting in increased nutrient intake in animals. In line with the present result, the inclusion of thyme in the diet of dairy cows reasonably at a level of 80 g/day/head improved ($P<0.05$) DM, OM, NDF, ADF, and estimated metabolisable energy intakes of the dairy cows (Feyissa, 2023). Furthermore, thyme supplementation significantly improved the feed intake of sheep (Tewodros *et al*., 2013; Mokenint *et al*., 2020). In general, dietary protein supplementation has a positive effect on the rumen microbial population and efficiency, increasing the breakdown of the digesta and increasing feed intake (Van Soest, 1994).

Table 4. Average daily nutrient intake of Hararghe Highland sheep.

Parameters	Treatment diets			SEM	P value
	T1	T2	T3		
DMI (g/day)	796.7^{b}	1015.0^{a}	950.0^{ab}	39.8	0.0045
OMI (g/day)	695.3^{b}	942.0^{a}	857.3^{a}	37.0	<.0001
CPI (g/day)	97.3^{b}	131.5^{a}	117^{ab}	6.2	0.0054
ADFI (g/day)	192.4^{b}	243.8^{a}	250.7^{a}	9.6	0.0012
NDFI (g/day)	250.8^{b}	369.9^{ab}	392.4^{a}	33.1	0.0185
ADLI (g/day)	126.6^{a}	111.7^{b}	117.9^{ab}	7.3	0.0348

$^{a\text{-}b}$*Means bearing different superscripts within factors across columns are significantly different at p < 0.05=significant; p < 0.0001=highly significant; DMI= Dry Matter Intake; OMI= Organic Matter Intake ; CPI= Crude Protein Intake; NDFI= Neutral Detergent Fiber Intake; ADFI= Acid Detergent Fiber Intake; ADLI= Acid Detergent Lignin Intake; SEM= Standard Error mean; T1= Concentrate mixture + 0 g Dry thyme leaf + Hay ad libitum; T2= Concentrate mixture + 100 g Dry thyme leaf + Hay ad libitum; T3= Concentrate mixture + 200 g Dry thyme leaf +Hay ad libitum.*

4.3 Digestible DM and nutrient intake and the apparent digestibility coefficient

The digestible DM and nutrient intakes and their apparent digestibility coefficients are shown in Table 5. The present study indicated that DTL inclusion levels of 100 and 200 g in sheep diets significantly ($p<0.05$) improved digestible DM, CP, OM, NDF, and ADF intake. This may be because thyme leaves can improve the digestion of nutrients, resulting in greater nutritional utilization. Compared with T1 (70.1%) and T3 (79.9%), T2 had the highest DDM (82.0%). These findings suggest that T2 is more effective at improving the digestibility of dry matter in the diet. The highest digestibility coefficient of crude protein was exhibited by the inclusion of 200 g of dried thyme leaf mixture (T3) (83.0%), whereas it was 70.0% for the control (T1) and 77.9% for the 100 g of thyme leaf mixture (T2). This could be due to the high protein content of the dried thyme leaves. The study revealed that the nutritional digestibility of the experimental diets differed due to differences in the CP content.

Compared with that of the control sheep, the DOM of the Hararghe Highland sheep in the present study was significantly greater (T2 at 80.4% and T3 at 77.3%) than that of the control sheep (T1 at 67.3%). Thyme leaves at an inclusion level of 100 g per day are believed to improve OM digestibility because the chemical substances in the thyme leaves increase some rumen microbial activity. These findings are in line with those of Caroprese *et al.* (2020), who reported that herbal plant extracts are effective rumen modifiers because of their antimicrobial activity against microorganisms. Feyissa *et al.* (2022) reported that the dietary inclusion of an edible fraction of the thyme plant (leaves and twigs) improved the degradability characteristics of the TMR of dairy cows. Herb plants can also aid in stimulating appetite and digestion, hence improving animal performance when used as feed additives (Afshar *et al*., 2012). In addition, the inclusion of thyme in diet at a level of 80 g DM/day reasonably improved ($P<0.05$) the DM, CP, and fiber (NDF and ADF) digestibility in dairy cows (Feyissa, 2023). Furthermore, the dietary inclusion of Thyme (*Thymus schimperi*) herbs collected from the Central Highlands of Ethiopia significantly improved the DM and nutrient digestibility of Menz sheep in Ethiopia (Tewodros *et al*., 2013). However, Mokenint *et al.* (2020) reported that the dietary inclusion of thyme did not improve DM or nutrient digestibility in Arsi-Bale sheep.

The variations between the results might be due to differences in agro ecology, parts of the additive plant material used, the harvesting stage, and the additive plant material and its postharvest management.

Table 5. Digestible DM and nutrient intake and apparent digestibility coefficient (%) of HHS.

Parameters	Treatments diets			SEM	P value
	T1	T2	T3		
Digestible DM and nutrients intake (g/day)					
Digestible Dry Matter	629.3^{b}	802.0^{a}	779.6^{a}	48.4	0.0031
Digestible Organic Matter	547.4^{b}	784.13^{a}	721^{a}	43.9	0.0041
Digestible Crude Protein	87.4^{b}	101.7^{ab}	113.5^{a}	4.3	0.0032
Digestible Neutral Detergent Fiber	129.16^{c}	235.8^{a}	216.6^{b}	4.25	<.0001
Digestible Acid Detergent Fiber	541.4^{a}	420.6^{b}	466.1^{b}	31.6	0.0021
Apparent Digestibility coefficient (%)					
Dry Matter	70.1^{c}	82.0^{a}	79.9^{b}	0.45	<.0001
Organic Matter	67.3^{c}	80.4^{a}	77.4^{b}	0.27	<.0001
Crude Protein	70.0^{c}	77.9^{b}	83.0^{a}	0.37	<.0001
Neutral Detergent Fiber	58.8^{b}	64.6^{a}	65.8^{a}	1.0	0.0006
Acid Detergent Fiber	60.1^{c}	65.9^{b}	71.9^{a}	0.2	<.0001
Digestible energy (Mca/kgDM)	4.54^{b}	7.34^{a}	5.78^{ab}	0.35	0.0034
Total Digestible Nutrient	45.3^{b}	58.54^{a}	53.6^{ab}	0.47	0.0021

$^{a\text{-}c}$ Means bearing different superscripts within factors across columns are significantly different at $p < 0.05$ =significant; $p < 0.0001$ =highly significant; SEM= Standard Error mean.

4.4 Growth Performance and Feed Conversion Efficiency

Table (6) shows the growth performance and feed conversion efficiency of the Hararghe Highland sheep fed diets with different inclusion levels of dried thyme leaves in this study. The results revealed that the final body weight, average daily gain, total body weight gain, gain rate, feed conversion efficiency, feed conversion ratio, and metabolizable energy intake significantly differed ($P < 0.05$) between the treatments. Rams fed a diet containing 100 g of dried thyme leaf (T2) exhibited the highest FBW, ADG, TBWG, and FCE among the treatments.

The addition of dried thyme leaves increased the ADG of sheep from 105.8 to 168.3 g/day, which was considerably greater ($p<0.05$) than that of the control group (79.5 g/day). This finding is in line with the previous results of Mekuanent *et al*. (2020) and Tewodros *et al*. (2013), who reported that dietary inclusion of thyme improved the growth performance of local sheep in Ethiopia. In general, the addition of dried thyme leaf to the diet up to a level of 100 g/day in the diet of Hararghe Highland sheep increased the performance of the animals related to the thyme inclusion, which contains phenolic compounds content that might enhanced the nutrient digestion, absorption, and utilization efficiency of the animals. Similarly, the feeding of dairy cows with Thyme (*Thymus schimperi*) leaves and twigs to a level of 80 g/day has a rumen metabolic modulatory effect by decreasing the level of ruminal NH_3-N that is nutritionally beneficial in increasing the efficiency of nitrogen and energy utilization in animals (Feyissa, 2023). The inclusion of dried thyme leaves into feed increased the conversion efficiency, CP intake, and digestibility, indicating improved nutritional availability for sheep growth.

On the other hand, Figure 1 shows the body weight change trends of Hararghe Highland rams per 10 days of body weight data recorded over 60 days of fattening. The inclusion of dried thyme leaves (DTL) to the diet of Hararghe Highland rams insignificantly raised the body weight changes throughout the first ten days of the feeding trial. During this period, a gradual rise in body weight change was observed until the twenty days. After that, the body weight change significantly increased throughout the remaining feeding trial. The presence of DTL in the rams' diet not only raised appetites but also improved overall health by promoting feed intake and improving body weight changes (BWCs) till the fattening stage ended. In contrast, sheep in the control group (T1) did not receive DTL exhibited body weight change at a slower rate. This slower body weight change can be linked to reduced crude protein (CP) intake and feed conversion efficiency (FCE) compared to the rams consuming DTL. The findings suggest that dietary components, particularly those enhancing appetite and nutrient absorption, play a crucial role in optimizing growth performance in sheep. Additionally, the level of thyme leaves increased, total dry matter (DM) and organic matter (OM) intake also increased, leading to better growth outcomes for sheep that received thyme inclusion.

Table. 6. Body weight changes and nutrient utilization efficiency of finished HHS.

Parameters	Treatments diets			SEM	P value
	T1	T2	T3		
Initial Body Weight (kg)	23.11	23.13	23.15	1.2	0.9997
Final Body Weight (kg)	27.9^{b}	33.2^{a}	29.5^{ab}	1.0	0.0094
Total Body Weight Gain (kg)	4.77^{c}	10.1^{a}	6.35^{b}	0.2	<.0001
Gain rate (TBWG/FBW) %	17.1^{b}	30.4^{a}	21.5^{ab}	1	0.0045
Average Daily Gain (g/day)	79.5^{b}	168.3^{a}	105.8^{b}	9.7	<.0001
FCE (ADG/DMI) x100	5^{b}	13^{a}	8^{b}	0.01	0.0017
MEI (Mcal/kg DM)	1.54^{b}	2.58^{a}	2.45^{ab}	0.54	0.0021

[a-c] Means bearing different superscripts within factors across columns are significantly different at P > 0.05 = non-significant; at P < 0.05 =significant; p < 0.0001 =highly significant; DMI=Dry Matter Intake; FCE; Feed Conversion; MEI= Metabolizable Energy Intake; Efficiency; SEM= Standard Error mea.

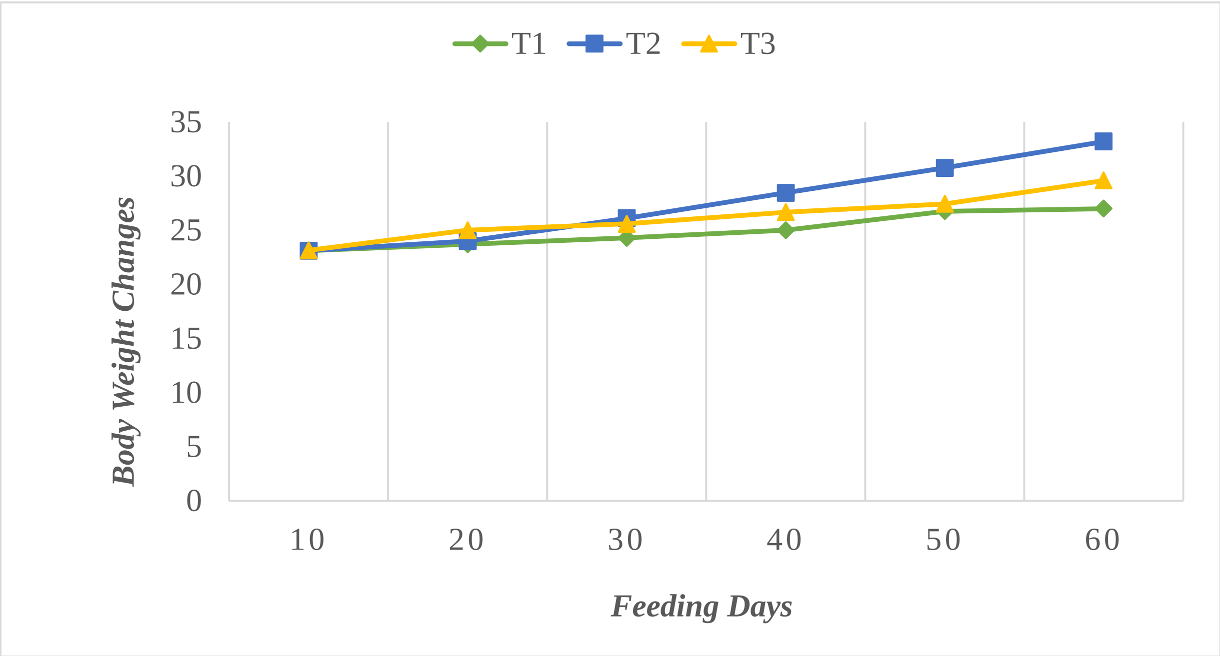

Figure 1. Changes in the body weight of the Hararghe Highlands Sheep

4.5 Slaughtering Performance

4.5.1 Non-carcass components

The edible and non-edible offal components are presented in table 7 and 8 respectively. The dietary inclusion of dried thyme leaves had no significant effect ($P > 0.05$) on edible offal or nonedible offal components such as the skin, feet, pancreas, genital fat, bladder, spleen, trachea, liver with gall bladder, lung, esophagus, blood, head, tongue, heart, kidney, empty gut, testes, penis, liver with bladder, tail fat, depot fat, or gut contents in the sheep. This could be attributed to the DTL herb having a greater effect on nutrient utilization for carcass yield. This finding is consistent with that of Mulu (2005), who reported that the weights of offal components with low metabolic activity, such as the head, feet, and lungs, changed slightly with diet due to their early maturation status.

Table 7. Edible offal components for finishing HHS.

Parameters	Treatments diets			SEM	P value
	T1	T2	T3		
Edible offal components					
Tongue (gm)	75.7	81.3	73.5	4.5	0.4723
Blood (gm)	700	900.4	924.2	0.17	0.2703
Heart (gm)	109.3	110.0	95.8	7.18	0.3157
Kidney (gm)	71.5	69.0	71.5	4.8	0.9125
Empty Gut (gm)	717.4	701.7	748.7	47.7	0.7805
Tests (gm)	277.2	271.5	243.6	30.4	0.1131
Liver with gall Bladder (gm)	319	324	331	28	0.9566
Tail fat (kg)	1.05	0.85	0.82	0.16	0.8872
TEOC (kg)	3.9	3.87	3.8	0.34	0.4027

$p > 0.05$ =not significant; SEM= Standard Error mean; TENEP= Total Edible Offal Components.

Table 8. Nonedible offal components for finishing HHS.

Parameters	Treatments diets			SEM	P value
	T1	T2	T3		
Nonedible offal components					
Skin (gm)	1140.3	1114.2	1111.6	21.23	0.8570
Head (kg)	1.39	1.47	1.46	0.12	0.9872
Feet (gm)	487.5	494.5	574.3	16.43	0.7619
Pancreas (gm)	32.6	32.08	33.1	4.0	0.9819
Penis (gm)	42.1	44.4	39.9	2.56	0.0670
Genital Fat (gm)	103.4	108.4	99.8	18.4	0.3668
Bladder (gm)	24.5	30.2	29.8	2.82	0.3145
Spleen (gm)	45.1	46.1	40.8	3.34	0.5833
Trachea (gm)	59.3	69.6	65.1	10.1	0.5490
Lung (gm)	230.1	245.2	240.0	20.4	0.9698
Esophagus (gm)	40.2	42.5	37.0	3.37	0.5261
Gut content (gm)	4600	4253.9	3996.4	11.5	0.9471
Depot fat (gm)	383.9	367.1	350.8	6.08	0.6454
TNEOC (kg)	7.8	7.7	7.5	0.57	0.9119

$p > 0.05$ =not significant; SEM= Standard Error mean; TNEOC=Total Non-Edible Offal Components.

4.5.2 Carcass linear measurement

Table (9) shows the effects of the inclusion of thyme leaves on the carcass leaner measurement parameters of Hararghe Highland sheep. The results revealed that the inclusion of thyme leaves at a daily level of 100 g or 200 g in the diet did not result in significant differences ($p > 0.05$) on carcass linear measurements in finished Hararghe Highland rams. These findings suggest that dietary dried thyme leaf have little effect on carcass structure and composition in fattening Hararghe Highland rams.

Table 9. Carcass leaner measurement parameters for HHS.

Parameters (cm)	Treatments diets			SEM	P value
	T1	T2	T3		
Carcass Length	51.8	51.6	52.1	1.0	0.6419
Chest Width	6.65	6.7	7.0	0.26	0.1670
Shoulder Width	8.0	8.4	7.7	0.4	0.4568
Hind Leg Width	36.8	36.5	36.8	0.5	0.3145
Posterior Buttock Circumference	55.1	54.6	53.5	1.1	0.7230
Anterior Buttock Circumference	52.5	52.1	51.6	1.5	0.4480
Buttock Width	12.0	12.3	12.2	0.4	0.7698

p > 0.05 =not significant; SEM= Standard Error mean.

4.5.3 Carcass yields and quality parameters

4.5.3.1 Carcass yield

Table (10) shows the results of carcass yields and quality parameters. The dietary inclusion of thyme leaves had shown significant (P<0.05) effects on the majority of the carcass parameters in this study. The slaughter body weight, empty body weight, hot carcass weight, cold carcass weight, left half cold carcass weight, lean meat, rib-eye area, commercial dressing, real dressing, total edible proportion and total usable products were the highest for rams fed on T2 (100g/day inclusion level) as compared to those fed on T3 and T1 diets. However, rams fed on T2 and T3 had similar results on HCW and CCW while fat thickness and rib eye area were highest for rams fed on T1 and T3 respectively. The dietary inclusion of herbal thyme also decreased (P<0.05) fat thickness compared with that of the control group in this work. The current study agrees with Nieto's (2012) findings, which showed that a diet supplemented with dried thyme leaves effectively reduced lipid and pigment oxidation in fresh lamb meat in Segurena sheep. This protective action is due to the presence of phenolic compounds in thyme, which are characterized by conjugated ring structures, hydroxyl groups, and carboxylic acid functions. These chemicals reduce lipid oxidation by processes such as metal chelation and free radical stabilization. An increase in the LHCCW of the sheep was noted for the dietary inclusion of additives up to a daily level of 200 g/head in this study.

The findings of the present study are consistent with those of Tewodros *et al*. (2013), who reported that the dietary inclusion of thyme in the diet of local sheep in North Shawa prompted improvements in performance (growth and intake), dressing percentages at slaughter, empty weight, and quality of meat. The final body weight in the study, which was consistent with the final body weight of Arsi-Bale sheep weighing 28.6 and 27.8 kg, was reported by Tesfaye *et al*. (2018) and Wondwosen *et al*. (2013), respectively. Furthermore, the present study revealed a greater final body weight than previous studies reported by Lamrot *et al.* (2018) and Kefyalew *et al.* (2015) for Ethiopian Ferta (22.2 kg) and Hararghe Highland sheep (22.4 kg), which were finished in different feedlots. This variance could be attributed to breed type, age, agro ecology, and dietary additives. The observed improvements in carcass traits with thyme leaf inclusion are likely due to the beneficial effects of the bioactive compounds in thyme, such as thymol and carvacrol, on nutrient utilization, rumen fermentation, and overall animal performance.

In the present study, sheep fed dried thyme leaves with the concentrate mixture presented a greater DP at slaughter body weight than did those in the control group. The DPSB in the present study ranged from 40.1 to 44.6%, which is similar to the values reported by Takele and Getachew (2011) for Horro sheep (36 to 42%). However, (Michaele *et al*., 2017; Amare, 2007; Hagos, 2014) reported values ranging from 46.5 to 49.65%, 47.3 to 48.6%, and 46.0 to 49.0%, respectively, for Begait sheep, Tigray highland sheep, and local sheep. This value is higher than that of the current study. However, Michaele and Yaynshet (2014) for Tigray highland sheep and Mulu (2005) for Wegera sheep reported lower dressing percentages on a slaughter weight basis than did the current study (28.73% to 37.55% and 36 to 38.4%), respectively.

McDonald *et al*. (2002) reported that nutrition, age, sex, genetics, season, and other factors influence the growth and carcass characteristics of animals. The rib-eye area in the current study ranged from 6.5 to 8.6 cm^2. This was consistent with previous studies by Gebreyohannes. (2022) for Tigray Highland Lamb, Michaele, and Yaynshet. (2014) for Tigray highland sheep, and Chala. (2018) for Horro sheep (6.4 to 9.0 cm^2, 5 to 8.73 cm^2, and 7 to 9.4 cm^2, respectively).

T1 had a substantially greater chilling loss rate (4.6%) than did T2 (4.4%) or T3 (4.2%). This finding showed that dietary inclusion of the additive plant could lower the rate of mutton chilling loss during storage. However, the lack of significant differences in fasting loss between treatments suggests that the dietary inclusion of thymus leaves could have little effect on the fasting loss of Hararghe Highland sheep.

Table 10. Carcass yields and physical composition of HHS.

Parameters	Treatments diets			SEM	P value
	T1	T2	T3		
Carcass Yields					
Slaughter body weight (kg)	27.2^{b}	32.6^{a}	28.7^{ab}	1.0	0.0077
Empty Body weight (kg)	21.7^{b}	26.9^{a}	23.2^{b}	0.9	0.0002
Hot carcass weight (kg)	10.9^{b}	14.1^{a}	13.1^{a}	0.4	0.0008
Cold carcass weight (kg)	10.4^{b}	13.1^{a}	12.2^{a}	0.4	0.0094
Chilling Loss%	4.6^{a}	4.4^{ab}	4.2^{b}	1.14	0.0410
Fasting Loss%	1.3	1.0	0.6	0.26	0.2209
Commercial Dressing%	40.1^{b}	43.2^{ab}	44.6^{a}	1.0	0.0031
Real dressing%	47.9^{b}	48.7^{ab}	52.58^{a}	0.24	0.0042
TEP (Total edible proportion) (kg)	16.1^{b}	20.1^{a}	18.4^{ab}	0.17	0.0037
TUP (Total usable products) (kg)	17.2^{b}	21.2^{a}	19.5^{ab}	0.61	0.0024
Physical Carcass Composition and quality parameters					
LHCCW (kg)	5.6^{c}	6.9^{a}	6.2^{b}	0.1	<.0001
Lean (kg)	2.9^{b}	3.7^{a}	3.56^{ab}	0.1	<.0001
Bone (kg)	1.5	1.6	1.6	0.13	0.9080
Fat (kg)	1.2	1.01	0.99	0.15	0.5427
Fat thickness (cm)	1.16^{a}	0.68^{b}	0.66^{b}	0.08	0.0007
Rib eye area (cm^2)	6.5^{b}	8.48^{a}	8.6^{a}	0.15	<.0001

$^{a-c}$ Means bearing different superscripts within factors across columns are significantly different at p > 0.05 =not significant; p < 0.05 =significant; p < 0.0001 =highly significant; LHCCW= Left Half Cold Carcass Weight; SEM= Standard Error mean.

4.5.4 Types of measured meat quality parameters

4.5.4.1 Physical meat quality parameters

Table (11) shows the physical meat quality of the Hararghe Highland sheep fed a diet supplemented with thyme. The present study revealed that T1 had greater cooking loss (30.7%) than did T2 (28.2%) and T3 (23.7%). These findings suggest that sheep maintained on a diet without a dried thyme inclusion contained more moisture, which could have an impact on the overall quality and texture of the meat. Meat from sheep fed higher levels of thyme leaf (T3–200 g/day) had significantly lower cooking loss (23.7%) than did the control group (T1–30.7%). This finding suggests that the dietary dried thyme inclusion possibly improved the water-holding structure of the muscle in fattening animals and thereby retained more moisture in the meat from loss. Meat water retention indicators, such as drip loss (DL) and cooking loss (CL), are linked to the muscle's ability to retain water (Corazzin *et al*., 2019). Therefore, it could be suggested that the inclusion of dried thyme leaves in the diet of meat animals is able to enhance product quality. In contrast, Ayeb *et al*. (2022) reported that adding thyme had no significant effect on cooking loss between groups; however, the percentage of meat treated with the thymus was slightly lower than that of the control (33.29 *vs*. 28.36%). In general, the cooking loss values for mutton in this study were within the range of the standard for technologically good meats (18–34%), as reported by Dhanda *et al*. (1999) and Kannan *et al*. (2001).

In the present revealed that T1 had the highest rate of thawing loss (3.27%), followed by T2 (2.7%) and T3 (1.9%). The declining trend shows that inclusion of dried thyme leaves with the concentrate mixture may reduce thawing loss of Hararghe Highland rams, however not statistically significant ($P > 0.05$). Similarly, T1 (6.5%) also had the greatest drip loss, whereas T2 (6.08%) and T3 (5.9%) showed a decrease. However, the results were not statistically significant ($P > 0.05$). These findings indicate that the inclusion of dried thyme leaves in the diet of Hararghe Highland sheep appears to reduce drip and thawing losses, maybe improving meat quality. In the present study, there were similar color score values ($P > 0.05$) between the meat samples from the dietary additive groups and the control group in terms of lightness or yellowness.

However, the redness (a* value) of Hararghe Highland sheep meat was significantly greater in the thyme inclusion groups (T2 and T3) than in the control group. This is attributed to the antioxidant compounds in the thyme leaves, which reduce pigment oxidation and improve color stability. This finding is comparable to previous study reported by Ayeb, *et al*. (2022), who reported that adding thyme had no influence on the lightness or yellowness of lamb meat. However, it had an effect on the redness of the meat. According to Kannan *et al*. (2001), natural antioxidants can help prevent meat color loss by extending the red color (a*). The average meat color of the current study parameters was comparable to that reported by Anteneh *et al*. (2019), who reported that the average meat color of Ethiopian Rutana, Gumuz, and Washera sheep supplemented with different concentrations of concentrate was 37.11 for lightness, 11.8 for redness, and 11.14 for yellowness. Similarly, this finding is consistent with that of Nieto *et al*. (2010), who reported that the antioxidant effect of the chemical substances in the thyme leaves reduced lipid and pigment oxidation in fresh lamb meat, resulting in increased redness (a* values). Additionally, Tewodros *et al*. (2013) reported that the antioxidant substances in thyme leaf-containing diets reduced color deterioration, lipid oxidation, and bacterial counts and improved the appearance of fresh lamb meat.

4.5.4.2 Meat eating quality evaluation

The results of the sensory evaluation of Hararghe Highland sheep fed on dried thyme plant leaves are shown in Table (11). The sensory evaluation of Hararghe Highland sheep meat revealed significant differences in flavor intensity, tenderness, juiciness, and overall acceptability among the three dietary treatments ($P<0.05$). The present results revealed that mutton (sheep meat) from sheep fed a diet with thyme inclusion at a daily level of 100 g or 200 g had higher perceived flavor intensity scores than did meat from the experimental sheep fed a diet without thyme inclusion (control). This could be related to the chemical substances in the thyme that improved the flavor intensity of the sheep. This finding is consistent with previous studies by Tewodros *et al*. (2013) and Mekuanent *et al*. (2020), who noted that increasing the amount of thyme supplementation led to increased flavor and aroma intensity in mutton.

Additionally, Al-Wabel *et al*. (2007) reported that aromatic and medicinal plants impart flavor to meat and intramuscular fat, which aligns with the findings of the present study. Young *et al*. (1997) reported that the intensity of tastes in mutton may be related to the flavor of volatile compounds in fat. In this study, the meat samples from sheep fed the T2 and T3 diet (with 100 g and 200 g/day of dry thyme leaves added) had significantly greater tenderness and juiciness scores than those from the control group (T1). This finding is consistent with previous reports by Mekuanent *et al*. (2020) on Arsi-Bale sheep, who reported that mutton from sheep fed a diet with 100 g of thyme leaf per day had the highest scores for tenderness compared with those from sheep fed lower levels of thyme leaf inclusion. Nieto *et al*. (2010) reported that including thyme leaves (*Thymus zygis.* gracilis) in ewes' diets during pregnancy improved the sensorial characteristics of lamb meat, likely because of the transmission of polyphenolic compounds from the thyme to Segureño lambs. Similarly, Ayeb *et al*. (2022) reported that supplementing sheep diets with thyme leaves (*Thymus vulgaris*) at levels up to 100 g/day did not negatively affect the physical or chemical properties of the meat and improved sensory quality attributes such as tenderness and juiciness compared with those of control diets without thyme. In general, this study demonstrated that including dry thyme leaves in the concentrate diet of Hararghe Highland sheep, particularly at the 100 g level, significantly improved the tenderness, juiciness, and overall acceptability of the meat compared with those of the control.

4.5.4.3 Meat chemical composition (nutritional quality)

Table (11) shows the chemical quality of the meat of Hararghe Highland sheep subjected to dietary thyme additive treatments. The present study revealed that the inclusion of thymus leaves had no significant effect on the moisture, fat, protein, and ash contents of the meat. However, the meat of Hararghe Highland sheep fed a concentrated diet (T1) exhibited a relatively high fat percentage (13.4%), whereas the rams that received the thyme additive in their diet presented relatively low body fat accumulation or a relatively high leanness content attributed to the chemical ingredients in the thyme that helped to affect the lipid metabolism. However, the dietary treatments had no effect on the protein or ash content of the carcass. This finding is consistent with Ayeb *et al*. (2022) reported no significant differences in ash, lipid, and crude protein composition across groups after adding thyme ("*Thymus vulgaris")* leaves to lamb meat.

Table 11. Meat quality parameters evaluation for HHS.

Parameters	Dietary treatments			SEM	P values
	T1	T2	T3		
Physical meat quality parameters					
Meat Color evaluation					
*L (Lightness)	31.7	28.7	28.1	1.4	0.1935
*a (Redness)	11.5^{b}	13.5^{a}	13.3^{a}	0.4	0.0232
*b (Yellowness)	10.7	8.7	8.4	0.7	0.0780
Meat water holding parameters (%)					
Cooking loss	30.7^{a}	28.2^{ab}	23.7^{b}	1.5	0.0227
Drip Loss	3.27	2.7	1.9	0.8	0.9075
Thawing loss	6.5	6.08	5.9	1	0.8148
Meat Sensory Evaluation (%)					
Flavor	5.6^{b}	6.5^{a}	6.6^{a}	0.21	0.0109
Juiciness	5^{b}	6.6^{a}	6.6^{a}	0.17	<.0001
Tenderness	5.1^{b}	6.8^{a}	6.6^{a}	0.23	0.002
Over all acceptability	5.5^{b}	6.8^{a}	6.6^{a}	0.2	0.005
Chemical Meat quality analysis (%)					
Moisture	72.7	73.7	73.6	0.38	0.1584
Ether extract	13.4	8.3	6.3	1.7	0.1702
Crude Protein	19.3	22.5	23.3	1.5	0.1256
Ash	5.0	5.2	4.9	0.2	0.6894

[a-b] Means bearing different superscripts within factors across columns are significantly different at p > 0.05 =not significant; p < 0.05 =significant; p < 0.0001 =highly significant; SEM= Standard Error mean.

4.10 Demographic Information of Meta Woreda

Table 12. Shows a structured report on demographic information provided by respondents from Meta Woreda, East Hararghe zone. The survey findings revealed the gender distribution shows a greater number of males than females and primarily married population, with a significant proportion of adults, implying a stable family structure in the Woreda. In terms of age demographics, the majority of the population consisted of adults, with a sizable proportion being dependents, implying significant socioeconomic impact for family structures and resource allocation. Educational attainment is relatively low, with a large proportion of the population being illiterate or having only received primary education. This emphasizes issues in the Woreda's educational access and quality, which may have an influence on economic development and health consequences.

Table 12. Demographic Information of Meta Woreda of East Hararghe zone

Variables	**Categories**	**Frequency**	**Percentage**
Sex of the respondents	Male	75	62.5%
	Female	45	37.5%
Marital Status	Married	77	64.2%
	single	30	25%
	divorced	4	3.3%
	widowed	9	7.5%
Age of the respondents	Children (≤14 years)	14	11.7%
	Adult (≥15-64 years)	79	65.8%
	Dependents (>65 years)	27	22.5%
Educational status	Illiterate	13	10.8%
	Read and write only	26	21.2%
	Primary School	40	33.3%
	Secondary School	33	27.5%
	above Secondary School	8	6.7%

4.11 Consumer Perceptions of Sheep Meat Consumption in Meta Woreda

As the current study revealed, the majority of respondents (54.2%) consumed mutton once per holiday, with 33.3% consuming mutton at wedding ceremony and 10.8% consuming mutton once a month. This demonstrates that the majority of people in the Meta Woreda do not consume sheep meat on a daily or weekly basis. The study also revealed that chicken is the most preferred meat (58.3%), followed by goat (33.3%) and beef (5.8%). Sheep, however, make up only 2.5% of preferences. This low preference for sheep meat in Meta Woreda contrasts with other highland areas where sheep constitute a significant part of the diet, such as in the highlands of Tigray or certain regions of Oromia. The results of the present study are consistent with those of a previous study by Tsegay (2012), which reported that the majority of consumers in the eastern part of Ethiopia favor chicken, beef, and chevon meat as their first options, followed by mutton as their last preference, which may be due to the sensory value of sheep meat.

A critical issue raised in the survey was the negative perception of the smell of sheep meat. The respondents attributed this to several factors, including excess fat accumulation (50%), feed type (33.3%), and sheep breed (8.3%). This may be fat accumulation, and feed type can influence the flavor and odor of meat, particularly in sheep. Excess fat in sheep meat, especially from traditional breeds raised in extensive systems, can produce off-flavors and odors, which may lead to consumer aversion. This is compounded by the type of feed, as diets high in certain grasses or plants can cause undesirable odors in sheep meat due to specific volatile compounds produced in the digestive process. The survey highlights traditional methods of mitigating smell, such as live animal skin washing (40.8%), hot carcass spicing (30.0%), and special cooking methods (29.2%). These practices are reflective of the cultural knowledge used to improve the acceptability of sheep meat. Special cooking techniques are employed in many cultures to reduce strong odors in certain meats, often involving spicing or marination to mask or neutralize undesirable smells. This suggests that, despite the negative perception, there is a cultural awareness of methods to improve the sensory qualities of sheep meat.

Table 13. Sheep Meat Consumption in Meta Woreda, East Hararghe zone.

Variables	Categories	Frequency	Percentage
Frequency of Meat Consumption	Once a week	0	0.0%
	once a month	49	40.8%
	once per holiday	71	59.2%
Meat Preferences	Chicken	70	58.3%
	Goat	40	33.3%
	Beef	7	5.8%
	Sheep	3	2.5%
	Other	0	0.0%
Consumption times of Sheep Meat	Frequently	0	0.0%
	Rarely	120	100.0%
The frequency at which people rarely eat	Once a week	2	1.7%
	once a month	13	10.8%
	once per holiday	65	54.2%
	Wedding ceremony	40	33.3%
Reasons for rarely Consumption	due to preferences existing	0	0.0%
	Religious related	0	0.0%
	Bad smell	120	100.0%
Management of bad smell of sheep meat	Live animal's skin washing	49	40.8%
	Hot carcass spicing	36	30.0%
	Special cooking methods	35	29.2%
Perceived Causes of bad smell of sheep meat	Types of feed	40	33.3%
	Sheep breed	10	8.3%
	Excess fat accumulation	60	50%
	Environmental condition	10	8.3%

5. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary and Conclusion

This study was conducted at Haramaya University, Goat Farm, and Meta Woreda of the East Hararghe Zone to evaluate the effects of the inclusion of thyme (*Thymus schimperi*. R.) leaves as feed additives on growth performance, carcass characteristics, and meat qualities of Hararghe Highland Sheep (HHS) and assess consumers' perceptions of sheep mutton eating trends in Meta Woreda. A total of 18 finishing rams with an initial body weight of 23 ± 0.02 kg were purchased from local markets and used for a 60-day finishing trial. The experimental design was RCBD with six replications in which the animals were blocked on the basis of their initial body weight. The rams were grouped into six blocks and three dietary treatment groups. Each block had three rams, and rams within a block were randomly assigned to one of the three treatment diets. The three dietary treatment groups were T1, T2, and T3, in which dried thyme leaves were included in the ration and fed to the animals at rates of 0 g, 100 g, and 200 g, respectively.

The concentrate mixtures formulated from wheat bran, noug seed cake, and table salt, as well as ruminant vitamin and mineral premixes, were fed to the animals on a DM basis at a rate of 2.5% of their body weight with grass hay as a basal diet. Compared with those in the control group, the performance of Hararghe Highland sheep fed with dried thyme leaves, including body weight change, average daily gain, and carcass yield, feed conversion efficiency, apparent digestibility, and feed intake, improved. The inclusion of dried thyme leaves to the diet of Hararghe Highland rams increased some meat quality parameters, such as water-holding structure of the muscle in fattening animals and thereby retained more moisture in the meat from loss, color stability and reduce the fat content of the meat. In general, this study demonstrated that the inclusion of dry thyme leaves in the concentrate diet of Hararghe Highland rams, improved the tenderness, juiciness, and overall acceptability of the meat compared with a control diet without thyme leaf inclusion.

The identified bottlenecks of sheep meat consumption in the Meta Woreda were the bad smell of the meat, which resulted from the presence of excess fat, consumed types of feed, sheep breed, and environmental factors. Addressing these constraints through proper feeding management, meat preservation and cooking methods, and consumers' perception-enhancing trainings may improve the acceptance and consumption of sheep meat in the area. Finally, based on the findings of the current study, feeding the dried thyme leave of more than 100 g/day for finishing Hararghe Highland sheep is not recommended in terms of growth performance and carcass yield-related parameters (feed intake, digestibility, body weight change, HCW, CCW, and dressing percentages). However, it could enhance meat eating quality parameters, meat color, and water holding capacity, and lean meat yield by reducing fat contents.

5.2 Recommendation

On the basis of the results of the present study, we recommend that T2 (100 g of DTL) inclusion in diets for the finishing of rams within 60 days of fattening is suggested for future intervention. In addition, studies on economic feasibility, the effects of this herbal plant on overall reproductive performance, blood hematology and biochemical parameters in the same sheep breed are highly important.

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7. APPENDIXS

Appendix 1. Summary of the ANOVA results for daily nutrient intake and apparent digestibility coefficient of HHS.

Parameters	Source	DF	Sum of Squares	F Ratio	Prob > F	SL
DDM%	Trt	2	485.61727	193.8152	<.0001	**
DOM%	Trt	2	564.27319	631.5826	<.0001	**
DCP%	Trt	2	511.44348	300.9546	<.0001	**
DNDF%	Trt	2	164.15659	12.7663	0.0006	*
DADF%	Trt	2	412.18671	800.5355	<.0001	**
DMI (g/day)	Trt	2	150794.68	7.9240	0.0045	*
OMI (g/day)	Trt	2	188496.99	11.4263	0.0010	*
CPI (g/day)	Trt	2	3548.3445	7.5326	0.0054	*
ADFI (g/day)	Trt	2	12207.444	10.9231	0.0012	*
NDFI (g/day)	Trt	2	69499.529	5.2685	0.0185	*
ADLI (g/day)	Trt	2	2744.8486	4.2342	0.0348	*

Appendix 2. Summary of ANOVA for Growth Performance and FCE of Hararghe Highland sheep.

Parameters	Source	DF	Sum of Squares	F Ratio	Prob > F	SL
IBW (kg)	Trt	2	0.00463333	0.0003	0.9997	ns
FBW(kg)	Trt	2	87.153678	6.4746	0.0094	*
SBW(kg)	Trt	2	93.219233	6.8530	0.0077	*
HCW(kg)	Trt	2	32.614744	15.8842	0.0002	*
CCW(kg)	Trt	2	23.625733	11.8453	0.0008	*
LHCC (kg)	Trt	2	2.8334222	85.6882	<.0001	**
RDP%	Trt	2	60.711769	4.2172	0.0352	*
ADG (g/day)	Trt	2	24563.670	21.7005	<.0001	**
EBW(kg)	Trt	2	86.037969	7.9574	0.0044	*
FCE	Trt	2	0.01847113	10.1089	0.0017	*
REA (cm^2)	Trt	2	16.060211	56.6875	<.0001	**
Fat Thickness (mm)	Trt	2	0.98555878	12.3883	0.0007	*
Lean meat (kg)	Trt	2	5.1804425	73.3492	<.0001	**
Bone (kg)	Trt	2	0.01094150	0.0981	0.9080	ns
Fat (kg)	Trt	2	0.09292939	0.6780	0.5427	ns
TBWG(kg)	Trt	2	75.453011	80.2779	<.0001	**
Gain rate (%)	Trt	2	87.243217	42.21890	0.0045	*
MEI (kg)	Trt	2	49.1298321	34.98686	0.0021	*

Appendix 3. Summary of ANOVA for Non-Edible and Edible Offal of HHS.

Parameters	Source	DF	Sum of Squares	F Ratio	Prob > F	SL
Blood (kg)	Trt	2	0.51257778	1.4292	0.2703	ns
Head (kg)	Trt	2	0.00247778	0.0129	0.9872	ns
Tongue (g)	Trt	2	191.86111	0.7889	0.4723	ns
Heart	Trt	2	771.75000	1.2461	0.3157	ns
Kidney	Trt	2	25.631878	0.0922	0.9125	ns
Empty Gut (kg)	Trt	2	6880.2803	0.2520	0.7805	ns
Tests	Trt	2	28178.583	2.5287	0.1131	ns
Liver with Bladder (g)	Trt	2	426.36111	0.0445	0.9566	ns
Skin (g)	Trt	2	0.08632408	0.1559	0.8570	ns
Pancreas (g)	Trt	2	3.5277778	0.0183	0.9819	ns
Penis (g)	Trt	2	574.77778	3.7744	0.0670	ns
Genital Fat	Trt	2	4364.1944	1.0730	0.3668	ns
Bladder (g)	Trt	2	119.69444	1.2508	0.3145	ns
Spleen (g)	Trt	2	75.250000	0.5589	0.5833	ns
Trachea (g)	Trt	2	768.36111	0.6242	0.5490	ns
Lungs (g)	Trt	2	154.08333	0.0307	0.9698	ns
Esophagus (g)	Trt	2	91.444444	0.6705	0.5261	ns
Gut Content (kg)	Trt	2	0.18171667	0.0545	0.9471	ns
Depot fat(g)	Trt	2	0.03757234	0.4508	0.6454	ns
Total non-Edible proportion (kg)	Trt	2	0.45038240	0.0928	0.9119	ns
Total Edible non-Carcass (kg)	Trt	2	2.3339661	0.9670	0.4027	ns

Appendix 4. Summary of ANOVA results for physical, eating and chemical quality of HHS

Parameters	Source	DF	Sum of squares	F ratio	Prob > F	SL
CL%	Trt	2	147.58030	4.9239	0.0227	*
DL%	Trt	2	1.1746104	0.0977	0.9075	ns
TL%	Trt	2	1.8652898	0.2077	0.8148	ns
Fasting loss %	Trt	2	1.4036929	1.6729	0.2209	ns
Chilling Loss %	Trt	2	1.7843469	12.0977	0.041	*
L(Lightness)	Trt	2	45.821498	1.8363	0.1935	ns
A (Redness)	Trt	2	1.4818827	11.6767	0.0232	*
B (Yellownes)	Trt	2	18.371638	3.0380	0.0780	ns
Meat flavor intensity	Trt	2	3.4444444	6.2000	0.0109	*
Meat tenderness	Trt	2	11.111111	31.2500	<.0001	**
Meat juiciness	Trt	2	10.111111	15.1667	0.0002	*
Over all acceptability	Trt	2	6.3333333	12.9545	0.0005	*
Moisture %	Trt	2	3.7479324	2.0889	0.1584	ns
Protein %	Trt	2	55.243681	1.9974	0.1702	ns
Fat %	Trt	2	53.414521	4.4808	0.1256	ns
Ash%	Trt	2	0.34205204	0.3814	0.6894	ns

7.1 Appendix Figures during Research Conducted

Figure 2. Captured photo during Research Conducted

7.2 Questionnaire

Questionnaire for the assessment of farmers' perceptions of sheep fattening and mutton consumption trends and quality enhancement in Meta Woreda.

- ❖ Demographic information such as sex, age, number of household members, and education status of respondents were collected.
- ❖ The consumer's responses to the questions were expected to reveal information about eating mutton choices, preferred protein sources, favored meat parts, and their ability to assess the quality of mutton visually.

I. General or Socio-economic information.

1. Name of the interviewer: -__________________________ Date: -_____________

II. Demographic Information or Household Characteristics.

1. **Sex of the respondents**:
   A) Male________________________
   B) Female________________________
2. **Marital Status:** a) Married, b) single, c) divorced, d) widowed
3. **Age of the respondents:**
   A) Children (≤14 years) ________________________
   B) Adult (≥15-64 years) ________________________
   C) Dependents (>65 years) ________________________
4. **Educational status:**
   A. Illiterate B. Read and write only C. Primary School.
   D. Junior Secondary School E. Secondary School F. Above Secondary School.

III. Meat consumption trends

1. How often do you eat meat?

a) Once a week

b) Once a month

c) Once per holy day

2. Which animal's meat do you like?

a) Chicken

b) Goat

c) Beef

d) Sheep

e) Other specify ____

3. How often do you consume sheep meat?

a) Frequently

b) Rarely

4. Under question no. 3, at what time do you rarely eat?

a) Once a week

b) Once a month

c) Once per Arafa holy day

d) Wedding ceremony

e) Other, specify ____

5. Under question no.3, if your answer is no, why do you not eat?

f) Due to many preferences existing

g) Religious related

h) Bad smell

i) Other specify ____

6. **If your answer is due to its bad smell, how do you manage it?**
   a. Live animal skin washing
   b. hot carcass spicing
   c. Special cooking methods
7. **What could be the possible cause for sheep meat the bad smell of sheep meat?**
   a. Types of feed
   b. Sheep breed
   c. Excess fat accumulation
   d. Environmental conditions