

Protein supplement potential of *Dodonaea angustifolia* leaves by replacing *atella* on nutrient utilization and performance of Farta sheep fed natural pasture hay basal diet

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Abstract

Background: Protein feed resources for ruminant animal productions are deficit in Ethiopia.

Objectives: To evaluate the supplementation effects of dried *Dodonaea angustifolia* leaves (DDL), dried traditional brewery by-product locally called *atella* and their mixtures on nutrient utilization and growth performance of Farta sheep fed natural pasture hay (NPH) as basal diet.

Methods: Twenty-five yearling intact male Farta sheep with average initial body weight of 14.53 ± 1.35 kg (mean \pm SD) were used for the study. The experimental sheep were allocated into five blocks of five animals based on their initial body weight. The experiment lasted for 90 days of feeding trial followed by 7 days of digestibility trial. The experimental feeds were NPH ad libitum + 100% DDL + 100 g wheat bran (WB; T1), NPH ad libitum + 75% DDL + 25% dried *atella* + 100 g WB (T2), NPH ad libitum + 50% DDL + 50% dried *atella* + 100 g WB (T3), NPH ad libitum + 25% DDL + 75% dried *atella* + 100 g WB (T4) and NPH ad libitum + 100% dried *atella* + 100 g WB (T5).

Results: NPH, DDL and dried *atella* contained 7.42, 15.39, 21.13% crude protein (CP) and 66, 36, 34% neutral detergent fiber, respectively. Sheep supplemented with increasing level of *atella* had more dry matter intake (DMI) and crude protein intake (CPI) and the highest of these DMI and CPI were in T5 (868 g/d for dry matter and 113 g/d for CP). This progressive increased CPI from T1 up to T5 was reflected in a significant ($p < 0.001$) fibers and estimated metabolizable energy intake in the order of $T5 > T4 > T3 > T2 > T1$. Significant difference ($p < 0.001$) was recorded on nutrient utilization and the highest was for T5 and lowest for T1. Average daily gain (ADG) and feed conversion efficiency (FCE) were significantly ($p < 0.001$) increased as the *atella* inclusion level increased. Sheep in T4 and T5 had the highest ADG and FCE with the order of $T5 = T4 > T3 > T2 > T1$. ADG was correlated positively and highly significant with nutrients intake and digestibility.

Conclusion: *Atella* supplementation better than DDL and then their mixture (T2–T4) supplementation could be recommended in sheep fattening in the study area.

KEYWORDS

atella, *Dodonaea* dried leaves, Farta sheep, nutrient, performance

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1 | INTRODUCTION

Agriculture is the main economic activity, and more than 80% of Ethiopian population is dependent on agriculture of which livestock are an important and integral component (NBE, 2018). The contribution of live animals and their products to the agricultural economy accounts for 40% (excluding the values of draught power, manure and their use for transport services) and it can reach about 47% of agricultural GDP when these services are considering monetary value (International Livestock Research Institute [ILRI], 2019). This agricultural sub-sector does not only provide valuable sources of animal protein for the ever-growing human population, but also contributes to the gross domestic product of the country by providing several export commodities, such as live animals, meat, hides and skins. Livestock production is a year-round activity and therefore serves as security against the risk of crop failure and also, provides year-round employment to a huge workforce (ILRI, 2019). It contributes to the household incomes, varying from 37% in the livelihoods of smallholder farmers in the mixed farming system to 87% in pastoralist communities.

Ethiopia possesses about 42 million sheep including those in sedentary and pastoral areas of Ethiopia (CSA, 2020). Despite the huge numbers in possession, the current contribution of livestock to the producers and to the national economy is insignificant in comparison to its size or to the expected potential. Simultaneously it has increasingly been unable to meet the animal source food demand in the country for the rapidly growing population (Eshetie et al., 2018). Accordingly, the per capita meat consumption has been recorded as low compared to even neighbouring African countries such as Kenya. Inadequate quantity and poor quality of feed supply throughout the year is the major limiting factor hindering sheep farming in Ethiopia (Yadessa et al., 2016).

The major feed resources in Ethiopia are natural pasture (55.96%) and crop residues (30.12%), and other feed resources such as agro-industrial by-products, hay, improved forage and others also contribute to 1.61, 6.55, 1.67 and 4%, respectively. Natural pasture and crop residues are two major feed resources (more than 85%), but they cannot satisfy the maintenance requirement of ruminant animals (CSA, 2020). Unless they are supplemented with agro-industrial by-products, traditional brewer by-products, and improved forage, animals will lose weight in the long dry season (Hailecherkos et al., 2021). The tragedy is that the majority of farmers do not have access to or can afford the supplemental feed resources, which are available mainly in towns and cities of the country (Tsfay et al., 2016). Moreover, even after almost five decades of improved forage research and development interventions in Ethiopia with governmental and non-governmental agencies, its livestock feed contribution at national level is below 2% (CSA, 2020). The traditional brewery by-product, *atella*, is a homemade protein source livestock feed in Ethiopia. However, the price of brewery by-product (*atella*) has increased as the price of the raw materials increased. Therefore, looking for locally available protein source feed is critical for sustainable livestock production. Among from indigenous browse species, a shrub *Dodonaea angustifolia* (locally called *kitkita*) is

a promising feed ingredient from the protein nutrition point of view especially in the dry season.

The indigenous browse species have significant potential in mixed crop-livestock production systems to supplement low-quality feeds, improve soil fertility and provide fuel, shelter and to help in soil and water conservation (Asmare & Mekuriaw, 2019). Indigenous browse species are well known to farmers and better adapt to the environments and produce higher biomass than exotic species under circumstances such as in dry areas. Consequently, they are in common use in many parts of the country, though not on a scientific basis (Haile & Tolemariam, 2008). Animals under semi-intensive and free-range systems have been observed feeding on browse species (Isah et al., 2012). The nutrient contents of the browse foliage change slowly throughout the year across the season, and this might reduce the animal's performance loss mostly seen in the dry season in Ethiopia. The protein content of the browse foliage is sufficient even at the mature stage to the extent that it can be used fairly as a quality supplement feed for ruminants with other low-quality feeds (Ouédraogo-Koné et al., 2008).

Dodonaea angustifolia is an evergreen shrub or small tree up to 5 m high. In tropical Africa, *D. angustifolia* is browsed by livestock and camels and used as an emergency fodder during the dry season. A study reported the chemical composition of *D. angustifolia* for crude protein (CP), neutral detergent fiber (NDF) and acid neutral detergent fiber (ADF) 108, 298 and 216 g/kg dry matter (DM), respectively. Better in vitro organic matter digestibility (51%) and metabolizable energy (ME; 11 MJ/kg DM) were reported for *D. angustifolia* (Mengistu et al., 2017). Although there is limited information on the animal performance, particularly to *D. angustifolia* feeding practice, there is plenty of information for other shrubs (Abraham et al., 2015). The availability of shrubs in general and *D. angustifolia* in particular is increasing because of forestation, area enclosure and land rehabilitation programs in the country as part of Ethiopia's green legacy initiative. Hence, knowledge of the nutritional value of nonconventional feed types will aid in the acceptance for use of these feed types in the diets of high producing animals. Therefore, this study was designed with the aim to evaluate the effect of different levels of *D. angustifolia* dried leaves supplement by replacing *atella* on nutrient utilization and body weight change of Farta sheep fed natural pasture hay as a basal diet.

2 | MATERIALS AND METHODS

2.1 | Experimental sheep and their management

Twenty-five yearling intact male Farta sheep with similar initial body weight 14.53 ± 1.35 kg (mean \pm SD) were purchased from local market of TachGayint district based on their dentition, body weight and information obtained from the owners. The animal was quarantined for 21 days in order to observe their health condition and get them adapted to the new environment. During this period, all animals were sprayed against external parasite (tick, mites, mange) using diazinon and dewormed against common internal parasites using albendazol

TABLE 1 Experimental dietary treatments

Treatment 1 (sole DDL). NPH ad libitum + 300 g DDL + 100 g WB
Treatment 2. NPH ad libitum + 75 g dried <i>atella</i> + 225 g DDL+100 g WB
Treatment 3. NPH ad libitum + 150 g dried <i>atella</i> + 150 g DDL+100 g WB
Treatment 4. NPH ad libitum + 225 g dried <i>atella</i> + 75 g DDL+100 g WB
Treatment 5 (sole <i>atella</i>). NPH ad libitum + 300 g dried <i>atella</i> + 100 g WB

Abbreviations: DDL, *D. angustifolia* dried leaves; NPH, natural pasture hay; WB, wheat bran.

based on the recommendation of veterinarian and vaccinated against common sheep diseases of the area. The animals were tagged on their collar for identification purpose and thereafter, all sheep were transferred to individual well ventilated pens for feed and pen adaptation. During the 15 days of adaption period, the experimental animals were allowed to acclimate the experimental feeds provided based on the treatment allocation. All experimental sheep were offered natural pasture hay ad libitum, but the nonconventional diet was introduced gradually over the 2 weeks of acclimation period in such a way that the total daily offer was reached at the end of the acclimation period. Hay, supplements and water were offered in separate containers. Water and mineral salt block were freely accessible to the experimental animals. This experiment had strictly followed the established experimental procedures.

2.2 | Experimental feed preparation

The natural pasture hay was purchased from the local farmers and it was chopped in to 3–5 cm to encourage intake and stored under shed to maintain its quality. *Atella* was collected from the local brewery producers. The wet *atella* was dried on a canvas that was stretched out on a sloppy area (about 5% slope) under shed. All the estimated quantity of *atella* required for the experimental period was collected and stored in sacks. *Dodonaea angustifolia* leaves were harvested from the established plant (watershed areas) and available in a definite proportion in the treatment diet. The leaves were collected by hand and transported and air dried and stored in a ventilated room during the experiment.

2.3 | Experimental design and treatments

Randomized complete block design (RCBD) was used for the experiment. The experimental animals were grouped into five blocks of five sheep each based on their initial body weight. Initial body weight was taken at the beginning of adaptation for blocking of animals and treatment allocation, and it also measured at the beginning of growth trial to start the actual experiment. An animal in a block was randomly assigned to one of the five experimental treatment diets putting five animals per treatment feed. The experimental feeds consisted of NPH ad libitum + 100% *Dodonaea angustifolia* dried leaves (DDL) + 100 g wheat bran(WB; T1), NPH ad libitum +75% DDL + 25% dried atella

+ 100 g WB(T2), NPH ad libitum + 50% DDL + 50% deried atella + 100 g WB (T3), NPH ad libitum + 25% DDL + 75% dried atella + 100 g WB (T4) and NPH ad libitum + 100% dried atella + 100 g WB (T5). *Atella* and *kitkita* leaves and their mixture were offered twice a day at 08:00 AM and 4:00 PM. NPH was provided to all treatment groups ad libitum by adding a 20% allowance. Note that 100 g of WB was added for each animal to meet the maintenance requirement of the non-*atella* supplemented group as dietary treatments shown in Table 1.

2.4 | Measurements

2.4.1 | Feed and nutrient intake

The feeding trial lasted for 90 days followed by 15 days of adaptation period. The amounts of feed offered and refused were weighed and recorded for each sheep daily. DM and nutrient intakes were determined as a difference between amount offered and amount refused. Spring weighing balance (Timbangan gantung 50 kg) was used for measurement. Representative samples of feed offered were collected per batch. Refusal samples for each sheep were collected and pooled per treatment. Sub-samples of the feed offered and refused were used for chemical analysis.

2.4.2 | Digestibility trial

Digestibility trial was conducted after the 90 days feeding trial period using all animals and treatments used for feeding trial. During this time, all the experimental animals were harnessed with faecal collection bags and left for 3 days, which was followed by seven consecutive days of total faecal collection.

During the faecal collection period, the daily faecal output per animal was weighed each morning before offering the morning meal. Representative faecal samples of 20% from each animal were taken daily and bulked over the experimental period and kept in refrigerator at –20°C. At the end of the collection period, the overall collected samples from each animal were thawed and thoroughly mixed, and 20% subsample from each animal was taken for chemical analysis. Representative faecal sample was partially dried in a forced draft oven at 55°C for 72 h. The dried faeces sample was ground to pass through 1 mm sieve screen and kept in airtight bag pending chemical analysis. The apparent dry matter digestibility (DMD) of experimental feeds was

determined using the following formula (McDonald et al., 2010):

$$\text{Apparent DMD (\%)} = \frac{\text{DMI Faecal} - \text{DM excreted}}{\text{DMI}} \times 100 \quad (1)$$

where, DMD is the dry matter digestibility and DMI is the dry matter intake.

Similarly, apparent digestibility of major nutrients was calculated as follows:

$$\text{AND\%} = \frac{\text{Total amount of nutrients in feed} - \text{Total amount of nutrients in feces}}{\text{Total amount of nutrients in feed}} \times 100 \quad (2)$$

where, AND is the apparent nutrient digestibility over DM base.

2.4.3 | Body weight change and feed conversion efficiency

The animals were weighed initially and every 10 days afterwards. Body weight was taken before the morning meal and after overnight fasting of the animals. The body weight of the sheep was measured using hanging balance (Timbangan gantung 50 kg). The average daily body weight gain (ADG) was calculated as the difference between the final body weight and initial body weight and divided by the number of feeding days. Feed conversion efficiency (FCE) of the experimental animal was calculated by dividing ADG by daily total DM intake.

2.4.4 | Chemical analysis

Representative samples of feeds offered, refused and faecal samples collected during the experimental period were dried in a forced draft oven (model: QW77) at 55°C for 72 h and milled to pass through a 1 mm sieve screen size. DM, organic matter (OM), nitrogen (N) and ash were determined according to the procedures of AOAC (1990). Furnace (model: FB1410M-33) used for OM determination. Kjeldhal (model: TURBOSOG) method was used for nitrogen determination. CP was calculated as $\text{CP} = \text{N} \times 6.25$. NDF, ADF and acid detergent lignin (ADL) were determined as per the procedure of Van Soest and Robertson (1985). The ME intake of experimental sheep was estimated from the digestible organic matter intake using the formula established by $\text{ME (MJ/kg)} = 0.0157 \times \text{DOMI g/kg}$ (AFRC, 1993), where DOMI = digestible organic matter intake per kg of DM.

2.5 | Statistical analysis

The data obtained on feed intake, digestibility and body weight was subjected to the analysis of variance (ANOVA) using SAS (2008) (version 9.1). Differences among treatment means were tested by Duncan's

multiple range test (DMRT) when $p < 0.05$. The model used for data analyses was as follows:

$$Y_{ij} = \mu + T_i + B_j + E_{ij} \quad (3)$$

where, Y_{ij} is the response variable, μ is the overall mean, T_i is the i th treatment effect and B_j is the j th block effect, and E_{ij} is the random error.

3 | RESULTS

3.1 | Chemical composition of treatment feeds

The chemical compositions of experimental feeds are presented in Table 2. As expected from the tropical forage, the CP of the grass hay used in this research is below the maintenance requirement for the rumen ecology (where the vital rumen microbes reside for the feed fermentation) of ruminant animals. Its fiber content is higher than the recommended level for better intake and digestibility. The CP content of *D. angustifolia* is comparable with wheat bran, one of the common agro-industrial by-product commonly used by the producers as supplement. Another advantage of the *D. angustifolia* is having relatively lower and almost in the recommended level of the fibers (NDF, ADF and ADL) in ruminant nutrition. The fiber content of the local brewery by-product (*atella*) is almost comparable with *D. angustifolia*, but higher in CP content.

3.2 | DM and nutrient intake

The average daily DM and nutrient intake of Farta sheep are presented in Table 3. Significant difference ($p < 0.001$) was observed among treatments in total DM and nutrients intake. As the level of *D. angustifolia* leaves increased the sheep's total DM intake and other nutrients intake linearly declined, but the reverse was true for the progressively increased *atella* inclusion. It followed the trend of $T_5 > T_4 > T_3 > T_2 > T_1$ ($p < 0.001$). As the level of *atella* increased, the natural pasture hay consumption had also increased. The fibers and estimated ME intake also significantly increased for sheep assigned in the increased *atella* and sole *atella* supplemented diets.

3.3 | DM and nutrients digestibility

The mean apparent digestibility of DM and nutrients for Farta sheep in the current study are presented in Table 4. There was significant ($p < 0.001$) difference among treatments in DM, OM, CP and fiber's apparent digestibility. The apparent nutrient digestibility of the current study followed the same pattern as the DM and nutrient intake: $T_5 > T_4 > T_3 > T_2 > T_1$. Sheep fed increasing level of *atella* responded more to DM and other nutrients digestibility than *D. angustifolia*.

TABLE 2 Chemical compositions of experimental feeds as duplicated samples (% for DM and g/kg DM for others)

Feeds and treatments	Parameters					
	DM	CP	NDF	ADF	ADL	Ash
NPH	91.88	7.42	66.21	46.88	10.28	9.16
T1 (sole DDL)	94.60	15.39	36.10	18.25	4.98	6.56
T2	93.81	17.17	35.90	19.36	5.62	6.20
T3	93.18	18.18	35.40	20.42	6.14	5.80
T4	92.26	19.92	35.14	21.62	6.84	4.40
T5 (sole <i>atella</i>)	90.81	21.13	34.88	22.10	7.11	3.59
Wheat bran	90.88	15.38	44.48	13.72	3.55	6.88
NPH refusal						
T1	90.20	3.09	71.39	59.24	16.46	8.30
T2	90.46	4.98	69.23	56.73	15.57	7.90
T3	90.71	4.79	68.65	55.87	15.27	8.14
T4	90.97	5.04	68.82	53.14	14.79	8.40
T5	91.28	5.01	67.24	52.00	14.24	7.63

Note: T1 = natural pasture hay+ 300 g *D. angustifolia* dried leaves (Sole)+100 g WB; T2 = natural pasture hay+75% (225 g) *D. angustifolia* dried leaves+25% (75 g) dried *atella* + 100 g WB; T3 = natural pasture hay+ 150 g *D. angustifolia* dried leaves + 150 g dried *atella* + 100 g WB; T4 = natural pasture hay+ 75 g *D. angustifolia* dried leaves + 225 g dried *atella*+ 100 g WB; T5 = natural pasture hay+ 300 g dried *atella* (Sole) + 100 g WB; WB = wheat bran.

TABLE 3 Daily dry matter and nutrient intakes of Farta sheep (five replicates per treatment) fed natural pasture hay supplemented with different proportions of *Dodonaea angustifolia* dried leaves, dried *atella* and their mixtures

Dry matter intake	Treatments					SEM	p-Value
	T1	T2	T3	T4	T5		
Grass hay (g/d)	266.88 ^e	409.26 ^c	406.42 ^d	444.66 ^b	468.96 ^a	3.680	<0.001
Supplements (g/d)	400	400	400	400	400	3.640	NS
Total DMI (g/d)	666.88 ^e	809.26 ^c	806.42 ^d	844.66 ^b	868.96 ^a	3.620	<0.001
Total DMI (%BW)	4.28 ^d	4.50 ^a	4.34 ^b	4.32 ^c	4.08 ^e	0.060	<0.001
TDMI (g/kg BW ^{0.75})	80.25 ^a	81.71 ^a	80.23 ^a	74.08 ^b	76.54 ^b	1.150	<0.001
Nutrient intake							
Total OMI (g/d)	577.51 ^e	683.01 ^d	698.84 ^c	732.15 ^b	743.39 ^a	3.230	<0.001
Total CPI (g/d)	81.35 ^e	97.26 ^d	100.08 ^c	108.14 ^b	113.57 ^a	0.240	<0.001
Total NDFI (g/d)	329.48 ^e	423.08 ^c	419.77 ^d	444.30 ^b	459.61 ^a	2.270	<0.001
Total ADFI (g/d)	193.58 ^e	263.66 ^d	265.51 ^c	287.04 ^b	299.86 ^a	2.020	<0.001
Total ME (MJ/d)	6.38 ^e	6.78 ^d	7.29 ^c	7.87 ^b	8.26 ^a	0.060	<0.001

Note: T1 = natural pasture hay+ 300 g *D. angustifolia* dried leaves (Sole)+100 g WB; T2 = natural pasture hay+75% (225 g) *D. angustifolia* dried leaves+25% (75 g) dried *atella* + 100 g WB; T3 = natural pasture hay+ 150 g *D. angustifolia* dried leaves + 150 g dried *atella* + 100 g WB; T4 = natural pasture hay+ 75 g *D. angustifolia* dried leaves + 225 g dried *atella*+ 100 g WB; T5 = natural pasture hay+ 300 g dried *atella* (Sole) + 100 g WB; WB = wheat bran.

Abbreviations: ADFI, acid detergent fiber intake; CPI, crude protein intake; DMI, dry matter intake; ME, metabolizable energy; NDFI, neutral detergent fiber intake; OMI, organic matter intake; SEM, standard error of mean; WB, wheat bran.

^aWithin a row not bearing common superscripts are significantly different at $p < 0.001$.

^bWithin a row not bearing common superscripts are significantly different at $p < 0.001$.

^cWithin a row not bearing common superscripts are significantly different at $p < 0.001$.

^dWithin a row not bearing common superscripts are significantly different at $p < 0.001$.

^eWithin a row not bearing common superscripts are significantly different at $p < 0.001$.

TABLE 4 Apparent digestibility percentage of dry matter and nutrients of Farta sheep (five replicates per treatment) fed natural pasture hay supplemented with different proportions of *Dodonaea angustifolia* dried *atella*, and their mixtures

Digestibility (%)	Treatments					SEM	p-Value
	T1	T2	T3	T4	T5		
DM	61.86 ^e	64.24 ^d	68.46 ^c	73.68 ^b	75.44 ^a	0.160	<0.001
OM	62.16 ^e	64.77 ^d	69.94 ^c	72.22 ^b	77.69 ^a	0.140	<0.001
CP	71.77 ^e	73.32 ^d	75.24 ^c	77.61 ^b	79.26 ^a	0.120	<0.001
NDF	60.56 ^e	61.48 ^d	62.72 ^c	65.65 ^b	67.46 ^a	0.200	<0.001
ADF	60.79 ^e	61.18 ^d	63.48 ^c	65.37 ^b	69.96 ^a	0.250	<0.001

Note: T1 = natural pasture hay+ 300 g *D. angustifolia* dried leaves (Sole)+100 g WB; T2 = natural pasture hay+75% (225 g) *D. angustifolia* dried leaves+25% (75 g) dried *atella* + 100 g WB; T3 = natural pasture hay+ 150 g *D. angustifolia* dried leaves + 150 g dried *atella* + 100 g WB; T4 = natural pasture hay+ 75 g *D. angustifolia* dried leaves + 225 g dried *atella*+ 100 g WB; T5 = natural pasture hay+ 300 g dried *atella* (Sole) + 100 g WB; WB = wheat bran.

Abbreviations: ADFI, acid detergent fiber intake; CPI, crude protein intake; DMI, dry matter intake; ME, metabolizable energy; NDFI, neutral detergent fiber intake; OMI, organic matter intake; SEM, standard error of mean; WB, wheat bran.

^aWithin a row not bearing common superscripts are significantly different at $p < 0.001$.

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^dWithin a row not bearing common superscripts are significantly different at $p < 0.001$.

^eWithin a row not bearing common superscripts are significantly different at $p < 0.001$.

TABLE 5 Body weight parameters and feed conversion efficiency of Farta sheep (five replicates per treatment) fed natural pasture hay supplemented with different levels of *Dodonaea angustifolia* dried leaves, dried *atella*, weight bran/WB/and their mixtures

Parameters	Treatments					SEM	p-Value
	T1	T2	T3	T4	T5		
Initial BW (kg)	14.28	14.38	14.31	14.48	14.59	0.210	0.48
Final BW (kg)	15.57 ^c	17.95 ^b	18.55 ^b	19.55 ^a	21.25 ^a	0.140	<0.001
BWC (kg)	1.29 ^c	3.57 ^b	4.24 ^b	5.07 ^a	6.66 ^a	0.160	<0.001
ADG (g/d)	14.33 ^c	39.66 ^b	47.12 ^b	56.33 ^b	74.00 ^a	1.710	<0.001
FCE	0.021 ^d	0.049 ^c	0.058 ^b	0.066 ^b	0.085 ^a	0.001	<0.001

Note: T1 = natural pasture hay+ 300 g *D. angustifolia* dried leaves (Sole)+100 g WB; T2 = natural pasture hay+75% (225 g) *D. angustifolia* dried leaves+25% (75 g) dried *atella* + 100 g WB; T3 = natural pasture hay+ 150 g *D. angustifolia* dried leaves + 150 g dried *atella* + 100 g WB; T4 = natural pasture hay+ 75 g *D. angustifolia* dried leaves + 225 g dried *atella*+ 100 g WB; T5 = natural pasture hay+ 300 g dried *atella* (Sole) + 100 g WB; WB, wheat bran.

Abbreviations: ADFI, acid detergent fiber intake; CPI, crude protein intake; DMI, dry matter intake; ME, metabolizable energy; NDFI, neutral detergent fiber intake; OMI, organic matter intake; SEM, standard error of mean.

^aWithin a row not bearing common superscripts are significantly different at $p < 0.001$.

^bWithin a row not bearing common superscripts are significantly different at $p < 0.001$.

^cWithin a row not bearing common superscripts are significantly different at $p < 0.001$.

^dWithin a row not bearing common superscripts are significantly different at $p < 0.001$.

3.4 | Body weight change and FCE

The average initial and final body weight, body weight change, average daily gain and FCE of Farta sheep are shown in Table 5. Significant difference ($p < 0.001$) was observed between treatments for final body weight, ADG, and FCE. Increased ADG of sheep was recorded the highest in sole *atella* (T5) but no significant difference observed in T2, T3 and T4. In similar trend, there was significant difference ($p < 0.001$) between treatments in FCE; the highest was recorded in sole *atella* supplementation (T5) followed by T4 = T3 > T2 > T1. Weight loss was not recorded in the experimental animals.

The trends of body weight change of experimental sheep across the experimental periods are shown in Figure 1. As indicated, all the supplemented groups showed an increasing trend of body weight change with more obvious improvement in dried *atella* supplemented groups

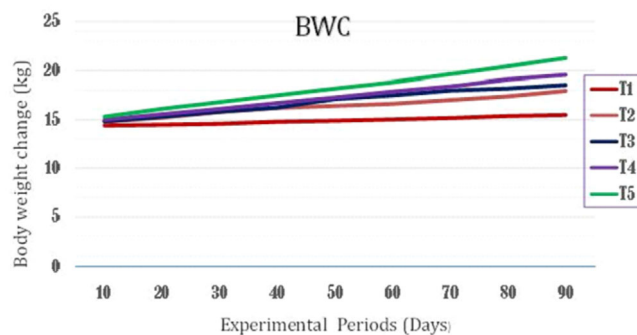
**FIGURE 1** Sheep fed *atella* perform better in body weight gain than *D. angustifolia* throughout the feeding trial. *D. angustifolia* leaves fed sheep also maintain their body weight in sustain manner in the feeding period.

TABLE 6 Correlation between average daily weight gain, dry matter and nutrient intake and digestibility of Farta sheep fed natural pasture hay supplemented with *Dodonaea angustifolia* dried leaves, dried *atella* and their mixtures

	DMI	OMI	CPI	NDFI	ADFI	DMD	OMD	CPD	NDFD	ADFD	ADG
DMI	1										
OMI	0.97**	1									
CPI	0.41*	0.23*	1								
NDFI	0.95**	0.93**	0.47*	1							
ADFI	0.70**	0.75**	0.78**	0.87**	1						
DMD	0.83**	0.81**	0.35*	0.35*	0.14	1					
OMD	0.85**	0.85**	0.90**	0.35*	0.14	0.27***	1				
CPD	0.76*	0.78*	0.99***	0.23	0.15	0.27**	0.46**	1			
NDFD	0.71	0.73	0.38*	0.80**	0.80**	0.85**	0.85**	0.98***	1		
ADFD	0.49	0.5	0.69*	0.71	0.78*	0.83	0.94	0.88*	0.76*	1	
ADG	0.83**	0.81**	0.48*	0.79**	0.73	0.78*	0.93**	0.88**	0.79*	0.93	1

Abbreviations: ADFD, acid detergent fiber digestibility; ADFI, acid detergent fiber intake; ADG, average daily gain; CPD, crude protein digestibility; CPI, crude protein intake; DMD, dry matter digestibility; DMI, dry matter intake; NDFD, neutral detergent fiber digestibility; NDFI, neutral detergent fiber intake; OMD, organic matter digestibility; OMI, organic matter intake.

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$.

when inclusion levels increased along with the experimental periods. But those in the *D. angustifolia* group (T1) showed a slight and constant weight change from start to end of experimental periods. The trend was $T5 = T4 > T3 > T2 > T1$.

3.5 | Correlation between nutrient intake, digestibility and average daily weight gain

The correlation between nutrient intake and digestibility of feeds is presented in Table 6. DM intake was correlated positively and highly significant ($p < 0.01$) with OM, CP, NDF and ADF intake and also with the respective nutrients' digestibility. As the total DM intake increased, the other nutrients' intake was also increased. DMD was correlated weakly but positively with ADFI. In this study, CP intake was positively correlated ($p < 0.01$) with intake of DM, ADF and NDF, and digestibility of ADF and NDF. Similarly, CP digestibility was significantly and positively correlated ($p < 0.01$) with DM and OM intake and digestibility.

4 | DISCUSSION

4.1 | Chemical composition of treatment feeds

The chemical analysis shows that the DM content of natural pasture hay used in this experiment (i.e., 91%) is comparable with the value reported by Moges et al. (2008), Mekuriaw et al. (2012) and Asmare and Mekuriaw (2019) who reported 91.59, 91.77 and 89%, respectively. Similarly, the organic matter (based on the reported ash content) of the natural pasture hay used in this study is in line with the report of the same authors like DM and Bishaw and Melaku (2008). Not neces-

sarily that high level of DM and OM content of the feed are better in quality because of high fibers in the DM.

The CP content of natural pasture hay offered to the experimental animals in the current study was 7.42% comparable with values ranging from 7.02 to 7.9% (Ayele et al., 2017; Mekuriaw et al., 2012; Nega & Melaku, 2009). It has been stated that the ruminant animals require the CP value of 8% and above for better rumen function (Waghorn & Clark, 2004). Hence, the observed CP content of natural pasture hay in the current study was lower than the maintenance requirements of sheep. This might be attributed to the late harvesting stage and forage species composition (Malik et al., 2020). Natural pastures in Ethiopia are managed in free grazing and subsequently the forage harvested like this is low in biomass and quality (Agza et al., 2013).

As expected, the fiber content of the natural pasture hay in the present study reflects the nature of tropical forages having fiber content beyond the ruminant animal fiber recommendation (Van Soest, 1994). Comparable NDF content of natural pasture hay was reported by Mekuriaw and Asmare (2018). The ADF content of natural pasture hay used in this experiment is comparable with the report of different authors (Bishaw & Melaku, 2008; Moges et al., 2008; Nega & Melaku, 2009) who reported the values ranging from 48.33 to 52.04%.

Due to the higher CP content, *D. angustifolia* could be considered as potential protein supplement in ruminant nutrition. The CP content (15.39%) of *D. angustifolia* dried leaves in the current study is comparable to the CP content of 16.4% for indigenous browse species grown in nonprotected areas, although it is lower than 28.3% CP from browse species grown in protected areas (Gebremeskel et al., 2019). In the current study, CP in *D. angustifolia* dried leaves is higher than CP content (12%) of *Ficus thoningii* leaves hay grown in North-West Ethiopia (Mekuriaw & Asmare, 2018). This shows that there are alternative protein sources in the area. The CP content of *atella* recorded in

the current study is comparable to the values reported in earlier studies (Demeke, 2007; Mekasha et al., 2002; Tikabo & Shumuye, 2021). The fiber content in both *atella* and *D. angustifolia* is within the recommended level for the ruminant nutrition for better rumen function (Zebeli et al., 2012). The fiber contents of *atella* in this study are higher than the previous study (Demeke, 2007) and nearly equivalent to as reported by Gebremeskel et al. (2019); this might be attributed to the ingredients difference for the preparation.

4.2 | DM and nutrient intake

The natural pasture hay consumption increased as *atella* replaced *D. angustifolia*, which might be attributed positively by better rumen fermentation because of the higher CP intake (Obeidat et al., 2020) and also higher ME. Synchronized availability of CP and ME in the rumen encourages rumen microbes proliferation and then they degrade the fibers in the feed for nutrient utilization. The result of the current study substantiates the idea reported by Niderkorn and Baumont (2009), which declared availability of nitrogen in the rumen when protein supplementation increased thereby improving the rate of degradation and utilization of the feed. The total DM intake per unit of metabolic body weight of the current study ranged between 74.08 and 81.71 g/kg BW^{0.75}, which is higher than the value reported by Fikre et al. (2019) for Washera sheep fed effective microbes treated grass, and comparable to the values reported by Bonsi et al. (1996) for Menze sheep fed teff straw and supplemented with protein sources. This might be attributed to breed, dietary and other management practices difference.

According to ARC (1980), the maintenance and growth ME requirement of 50–200 g daily gain for a 20 kg lamb is 4.5–7.9 MJ/day. Thus, based on these assumptions, the estimated ME of the treatment diets (6.38–8.26 MJ/day) in the current study was above the energy requirement for maintenance and growth (12.04–102.36 g/day gain) of the sheep. This result was relatively within the range of 5.94–10.23 MJ/day/head for black head Ogaden sheep fed grass hay and supplemented with different levels of corn silage and linseed meal (Urgesa et al., 2015). It was somewhat higher than the values (5.75–7.18 MJ/day) reported by Tsega et al. (2019) for Menz sheep fed grass hay basal diet supplemented with different combinations of wheat bran and lentil screening.

4.3 | DM and nutrient digestibility

Atella supplementation improved better DM and nutrients digestibility as compared to *D. angustifolia* dried leaves. This difference could be attributed to the nature of feedstuff and from the recorded higher CP and ME in *atella*. This agreed with the report of Niderkorn and Baumont (2009), who noted that addition of dietary protein in the supplemented treatments increased protein availability to rumen microorganisms to speed up the digestion process. Since the DM and other nutrients' digestibility percentage of this study are higher than 60%, it is possible

to conclude that *D. angustifolia* could be listed as good feed for ruminant animals in the area and it is supported by Adams et al.'s (2002) study. The apparent DM digestibility recorded in this study was higher than the values reported by Hailecherkos et al. (2021) for same sheep fed on desho grass hay supplemented with tree lucern and concentrate mixture. The DM digestibility of supplemented treatments were nearly comparable with the range 72.88–81.16% reported by Urgesa et al. (2015) for black head Ogaden sheep fed grass hay and supplemented with different levels of corn silage and linseed meal. Mekuriaw and Asmare (2018) reported, however, higher DM digestibility of Washera sheep fed *Ficus thonningii* leaves.

The OM and CP apparent digestibility values of the supplemented groups in the current study were lower than 73.6–79% OM and 69.6–76% CP digestibility reported by Moges et al. (2008) for Wogera sheep fed hay basal diet and supplemented with different proportions (100–300 g/day) of brewery dried grain. But this study's results are slightly comparable with the 64.38–85.49% OM and 83.79–90.55% CP digestibility reported by Fikre et al. (2019) for Washera sheep fed grass hay basal diet supplemented with effective microbes and molasses solution treated grass.

4.4 | Body weight change and FCE

The superior ADG and FCE recorded in this study as level of *atella* supplementation increased could be attributed to the higher CP and ME from *atella*. Feedstuff with higher protein and ME could support sheep performance (McDonald et al., 2010). However, the ADG of the sheep fed sole *D. angustifolia* was in general recorded mostly from sheep supplemented with concentrate feed. Therefore, *D. angustifolia* could be an alternative supplement source for ruminant animals especially in the dry season. This would increase the chance of utilization as the *D. angustifolia* is available and will be available in sustainable manner in response with the existing natural resource conservation practices. In similar trend, there was significant difference ($p < 0.001$) between treatments in FCE; the highest was recorded in sole *atella* supplementation (T5) followed by T4, T3, T2 and T1. Higher CP and ME availability in *atella* could be also attributed for this treatment difference.

The better sheep performance: FBW, BWC, ADG and FCE recorded in the current study for *atella* supplementation than *D. angustifolia* might be justified that because of their CP and ME composition difference. This was probably due to the beneficial effects of CP to facilitate fiber hydrolysis and feed utilization, which in turn improved digestion, absorption and microbial protein synthesis in the rumen. Almaz et al. (2012) reported better body weight gain and health of the animals recorded with an increased level of crude protein supplementation.

The trends of body weight change of experimental sheep across the experimental periods are shown in Figure 1. As indicated, all the supplemented groups showed an increasing trend of body weight change with superior improvement in dried *atella* supplemented groups when inclusion levels increased along with the experimental periods. Those in the *D. angustifolia* group (T1) showed a slight and constant weight change from starting to the end of experimental periods, suggesting

that it could be an alternative supplement in sheep fattening although lower than *atella* fed sheep performance.

The enhanced FCE of the supplemented groups (T4 and T5) in the current study could be due to the higher nutrient concentration of the supplement feeds. The highest FCE for T4 and T5 might be justified that dried *atella* created effective CP effect in the rumen resulting in an improvement of quantity, availability and digestibility of nutrients leading to an increased body weight gain. The FCE values of all treatments were found within the range of 0.013–0.161 reported by Dessie et al. (2010) for Farta sheep fed hay basal diet supplemented with different levels of lentil hull and noug seed cake mixtures.

4.5 | Correlation between nutrient intake, digestibility and average daily weight gain

The positive and significant DM intake correlation with OM, CP, NDF and ADF intake, and digestibility could be reflected by the improved fermentation and passage rate of nutrients in the digestive system. Previous studies indicated that sheep fed on higher protein diet (18.9% CP) consumed more DM than sheep kept on low CP (14%) diet (Almaz et al., 2012). In this study, CP intake was positively correlated ($p < 0.01$) with intake of DM, ADF and NDF, and digestibility of ADF and NDF. Similarly, CP digestibility was significantly and positively correlated ($p < 0.01$) with DM and OM intake and digestibility. CP digestibility was not correlated ($p > 0.05$) with ADF and NDF intake, which is not in accordance with the results reported by Bishaw and Melaku (2008) and Hailecherkos et al. (2021) who reported that CP digestibility was negatively correlated with NDF and ADF intake. In line with this, the correlation of total DM intake with CP intake, DM, OM and CP digestibility was reported by Awoke and Mekasha (2014) for Washera sheep fed natural pasture hay and supplemented with *Ficus sycamores* (Shola). The positive interrelationship of TDMI with nutrient intake and digestibility indicated the improved fermentation and passage rate, which could promote the TDMI. ADG was correlated positively and highly significant with nutrients intake and digestibility. ADG showed positive strong correlation with almost all nutrients intake and digestibility. This could be explained by considering that both *D. angustifolia* and *atella* supplementation improved the fiber utilization in sheep nutrition.

5 | CONCLUSION

Based on the better CP and lower level of fibers content as compared to the majority of roughage feedstuff in Ethiopia, DDL could be considered as an alternative supplement feed. Although *atella* supplementation is superior than DDL in terms of nutrient utilization and biological performance of Washera lambs in this experiment, but DDL could be used as a sole and replacement of *atella* (T2 to T4) as far as an animal shows positive and sustained growth, and it could be recommended in sheep fattening in the study area by considering its economic performance.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Conceptualization, writing-original draft, data collection, formal analysis, methodology, and software: Defaru Teshager. Conceptualization, methodology, supervision, and writing-review and editing: Yeshambel Mekuriaw, Netsanet Beyero.

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ETHICS STATEMENT

Bahir Dar University has established ethical clearance committee and yet no established experimental procedures. This experiment had strictly followed to the established experimental procedures. Directive 2010/63/EU of the European Union guidelines (2010) concerning the treatment and use of animals in research and development purposes were employed.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available upon request.

PEER REVIEW

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