

Grazing behavior, dietary value and performance of sheep, goats, cattle and camels co-grazing range with mixed species of grazing and browsing plants

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ABSTRACT

A study was conducted to assess grazing behavior (GB), dietary value and performance of co-grazing sheep, goats, cattle and camels with initial body weights (BW) of 20.6 ± 2.09 , 16.6 ± 0.97 , 96.8 ± 3.43 and 162.3 ± 21.28 kg, respectively. Grazing lasted 16 weeks, using 6 growing animals per animal species. Animals co-grazed 6 ha of range containing grass, forb and browse species. GB observations for position and activity were made during day light. In weeks 4, 8 and 14 hand-plucked forages similar to that being selected by animal species were sampled for laboratory evaluation. BW was measured initially and at 28-days interval. Time allotted for feed consumption (grazing plus browsing), ruminating and idle was similar among animal species. However, camels and goats spent lower time grazing and higher time browsing than sheep and cattle. The CP content of hand-plucked forages was highest for camels (16.8%), intermediate for sheep (9.3%) and goats (10.2%) and lowest for cattle (4.5%); while NDF values took opposite trend. The IVDMD contents of forages took the trend of CP contents and were 55.8, 51.0, 43.6 and 72.8% for sheep, goats, cattle and camels, respectively. Daily BW gain was 34, 31, 94 and 358 g/day and BW change as percentage of initial BW was 19, 22, 11 and 26% for sheep, goats, cattle and camels, respectively, the former was higher for camels and the latter was lower for cattle. These results indicated reduced dietary overlap among animal species and consequently greater animal yield through co-grazing than perhaps could have achieved through mono-species grazing.

1. Introduction

Proper management of rangelands is vital owing to its important economical, ecological and environmental roles at local, regional and global scales. Relatedly, rangeland management schemes that can maximize animal yield per unit area without jeopardizing range productivity is key to develop economical, efficient, and sustainable livestock production system from rangelands. Various grazing management and restoration strategies have been employed for ecosystem maintenance and sustainable utilization of rangelands for livestock production. Rotational grazing (Eshetu, Muluaem & Monge, 2017; Jacobo, Rodriguez, Bartoloni & Deregibus, 2006), use of enclosures (Haftay, Yayneshet, Animut & Treydte, 2013; Mureithi, Verdoodt, Njoka, Gachene & Ranst, 2015) or area enclosures (Eshetu et al., 2017; Yayneshet, Eik & Moe, 2009), seasonal grazing (Ash, Corfield, McIvor & Ksiksi, 2011; Zhang et al., 2017), and use of proper grazing intensities (Zhang et al.,

2017) are notable measures of rangeland management. Moreover, employing mixed animal species grazing in a range with diverse array of plant species is a means to achieve optimal utilization of range resources (Jerrentrup et al., 2020; Liu et al., 2015) and can be considered as a good rangeland management tool (Glimp, 1988).

Rangelands are generally endowed with diverse herbaceous and browse plant communities. Plant species diversity in rangelands provide opportunities for distinct dietary preferences for different co-grazing livestock species (Cuchillo, Wrage-Mönnig, & Isselstein, 2017a). On swards with heterogeneous plant communities, co-grazing management has been noted to have benefits over mono-species grazing. Efficient and uniform utilization of available forages was noted when cattle, sheep and goats (Benavides et al., 2009) or cattle and sheep (Cuchillo, Wrage-Mönnig, & Isselstein, 2017a) were co-grazing than mono-grazing. Consequently, co-grazing prevented severe defoliation of preferred plant species and increased overall production on rangelands. Another

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positive feature of co-grazing has been total greater animal yield per unit area, attributed to complementary pasture use. This has been observed with co-grazing sheep and goats (McGregor, 2010), sheep and cattle (Fraser, Moorby, Vale & Evans, 2014; Jerrentrup et al., 2020), goats and cattle (Dennis, Unruh-Snyder, Neary & Nennich, 2012), sheep, goats and cattle (Anderson, Fredrickson & Estell, 2012), and cattle and camels (Phillips, Heucke, Dorges & O'Reilly, 2001). Accordingly, co-grazing has long been proposed as a method of improving pasture carrying capacity (Merrill & Miller, 1961), leading to greater animal gains per unit land area with minimal impact on rangelands. The positive effects of co-grazing on total greater yield of animal productivity is mainly a result of variation in forage selectivity and plant species preference observed among different species of grazing animals (Animut & Goetsch, 2008; Ferreira et al., 2013; Schwartz & Schaft, 1988). Moreover, grazing behaviors of co-grazing animals differ by plant diversity and due to differences in dietary selectivity by animal species (Cuchillo, Wrage-Mönnig, & Isselstein, 2017b), justifying limited competition among animal species for similar grazing resources in lands containing a variety of vegetation types.

Another attribute of multi- versus mono-species grazing is product diversification from use of various animal species. This leads to greater biological efficiency, enhanced total income, improved risk management and enterprise sustainability (Anderson et al., 2012; Glimp, 1988).

Despite the aforementioned potential favorable outcomes of co-grazing, research in such area has been limited in number and to only integration of not more than two or three species of grazing livestock. There has been some studies regarding performance, forage selectivity and/or grazing behavior of co-grazing sheep and goats (Animut et al., 2005a,b; Bojkovski, Štuhlec, Kompan & Zupan, 2014), sheep and cattle (Cuchillo, Wrage-Mönnig, & Isselstein, 2017a,b), cattle and camels (Phillips et al., 2001); and sheep, goats and cattle (Ferreira et al., 2013). However, such information appears to be non-existent for co-grazing sheep, goats, cattle and camels. Moreover, co-grazing studies appears to be lacking under Ethiopian condition where ecological, forage species diversity and forage productivity differences might prevail compared to other countries where similar studies were conducted. Therefore, the objective of this study was to evaluate the grazing behavior, dietary value and performance of sheep, goats, cattle and camels when co-grazing range containing mixed species of herbaceous and browse plants.

2. Materials and methods

2.1. Study location

The study was conducted at Fafen Livestock and Forage Research Station of the Somali Region Pastoral and Agro-pastoral Research Institute (SoRPARI), Fafen, Ethiopia, located at a longitude of 42.52°45 E and latitude of 9.20°16 N and at an altitude of 1600 m above sea level. The mean annual rainfall is 660 mm, and average annual minimum and maximum temperatures of the area are 21 and 38 °C, respectively (SoRPARI, 2005). The area is characterized by black clay fertile soil, and two rainy seasons, small rains March to June and heavier rains July to September.

2.2. Experimental procedure and treatments

Black head Ogaden sheep, Somali goats, Ogaden cattle and Dromedary camels with average initial body weights of 20.6 ± 2.09, 16.6 ± 0.97, 96.8 ± 3.43 and 162.3 ± 21.28 kg, respectively were used for the experiment. Six male growing animals from each of the animal species were purchased from local livestock market in Dhaqaxle town found near Jiggiga and used for the study. However, one sheep fell prey to a hyena in the 10th week of the study and data from the sheep was not considered. Sheep and goats were about a year of age, cattle were about one and half years of age, whereas camels were about two years of age.

Age was determined by dentition and information obtained from the owners. Up on arrival, animals were quarantined for 21 days. During this period, animals were treated for internal (ivermectin, albendazole, tetrazimole) and external parasites (diazinone). All animals were vaccinated for anthrax. Additional vaccinations were camel pox for camels; LSD and CBPP for cattle; sheep and goat pox and PPR for sheep; and sheep and goat pox, PPR, and CCPP for goats. The grazing experiment lasted 16 weeks during the dry season from November 2019 to February 2020. The animals grazed together a 6 ha of land selected to be representative of the general grazing range of the area and fenced to prevent access of non-experimental animals. Hence, treatments were comparisons of the four co-grazing animal species. The grazing area contained various species of grasses predominantly of *Chloris radiata*, *Eragrostis ciliaris*, and *Panicum atrosanguineum*; complex mixtures of forbs primarily of *Asystasia schimperii*, *Acanthospermum hispidum* and *Solanum somalensis*; and several species of browses dominantly of *Lantana camara* and *Acacia spp.* Grazing by the animals was done from 0730 to 1830 h. The animals spent the night confined in a barn of the research site facility to prevent attack by predators. No additional feed was provided to the animals while in the barn.

2.3. Measurements

Grazing behavior observations were made on all animals. Making observations on all animals in a single day was difficult. Hence, one animal from each species were color marked on the body and followed for behavioral observation. Thus, there were a total of six days of behavioral observation, which was made in the middle of weeks 2, 4, 6, 8, 12 and 14. Behavioral observations were made every 30 min during daylight for position (i.e., standing versus lying) and activity (i.e., grazing, browsing, ruminating, and idle or not grazing or ruminating). Behavioral observations were made from a distance of about 15 m so as not to influence behavior. One person was assigned for each animal species to follow the animal and make observations. Behavioral observations were made from 0800 to 1800 h of daylight. Observations were averaged over time to determine percentage of total daylight for each position or activity.

In weeks 4, 8 and 14 simulated forage samples were collected for each animal species separately. The three weeks were selected to represent the early, middle and end of the grazing period. With utmost care not to influence animal behavior, and after close visual observation of animals grazing for 15–20 min in regard to types of plants and plant parts being consumed, hand-plucked samples of forages similar to that being selected and from the same area were collected around 0930 hour. The clipped plant material were later dried at 55 °C for 48 h in a forced-air oven, ground to pass a 1-mm screen for chemical analysis and in vitro dry matter (DM) digestibility or 2- mm screen for *in sacco* degradability of DM.

Unshrunk body weight (BW) was measured at the beginning of the grazing period immediately before the animals were placed into the grazing range, and at 28-days interval using weighing balance. Average daily BW gain (ADG) were calculated for each 4 weeks period and for the entire experimental period as a difference of final and initial BW divided by the number of grazing days.

2.4. Chemical analysis

Hand-plucked forage samples were analyzed for DM, total ash and Kjeldahl nitrogen (N) (AOAC, 1990); neutral detergent fiber (NDF), acid detergent fiber (ADF) and saturated potassium permanganate lignin (Van Soest & Robertson, 1985). Crude protein (CP) content was calculated as N*6.25. Organic matter (OM) content was calculated as 100 – ash. Tilley and Terry (1963) two stage technique was employed to analyze in vitro DM digestibility (IVDMD) of forage samples. Rumen fluid for IVDMD was obtained from rumen fistulated Boran x Holstein Friesian steers kept on a maintenance diet of hay fed ad libitum

supplemented with 4 kg of concentrate containing 74, 25 and 1% wheat bran, noug seed cake and salt, respectively.

In sacco DM degradability parameters were determined following the procedure of Ørskov & McDonald (1979). Forage samples weighing 3 g were incubated in duplicates in a nylon bag (41 µm pore size and 6.5 × 14 cm dimension) in three rumen fistulated steers kept in individual pens and fed similarly as noted for IVDMD. Samples were sequentially added and incubated in the rumen for 0, 6, 12, 24, 48, 72 and 96 h. Then, bags were rinsed and washed immediately using tap water to remove the debris and stop fermentation. Zero-hour solubility was estimated by hand washing samples contained in nylon bags in the same way as the incubated samples. The bags with the residues were dried at 55 °C for 72 h and weighed. Data on ruminal DM degradability characteristics were obtained as the difference of the DM in the residues and original samples.

The DM degradability data was fitted to the exponential equation $P = a + b(1 - e^{-ct})$ as described by Orskov and McDonald (1979), using Neway Excel program (Chen, 1997), where P is DM degradation (%) at time t. Since washing losses (A) were higher than the estimated rapidly soluble fraction (a), the lag time was estimated according to McDonald (1981) by fitting the model $P = A$ for $t < t_0$; $P = a + b(1 - e^{-ct})$ for $t > t_0$. The degradation characteristics of forage samples were defined as A = washing loss (readily soluble fraction); $B = (a + b) - A$, is the insoluble but fermentable material; c = the rate of degradation of B (/h); and the lag phase (L) = $(1/c) \log_e[b/(a + b - A)]$. Potential degradability (PD) was estimated as $PD = A + B$; while effective degradability (ED) was calculated by using the method of Orskov and McDonald (1979) and assuming the rumen outflow rate (k) of 3% / h: $ED = a + [bc / (k + c)]$.

2.5. Statistical analysis

Data on grazing behavior, nutritive value of hand-plucked forage samples and animal performance were analyzed using the general linear model (GLM) procedure of statistical analytical systems, SAS (SAS, 2008). The statistical model used for data analysis was $Y_{ij} = \mu + T_i + e_{ij}$; where: Y_{ij} = Individual observation; μ = Overall mean; T_i = Animal species effect; e_{ij} = Random error. Least significant difference (LSD) was used to locate differences between means when F-test was significant ($P < 0.05$).

3. Result

3.1. Grazing behavior

The time spent standing and lying did not differ ($P > 0.05$) among the co-grazing animal species (Table 1). All animal species spent their time predominantly standing accounting for more than 83% of the day light. The total time spent eating (i.e., grazing plus browsing) was 79, 78, 84 and 85% (SEM = 2.8) for sheep, goats, cattle and camels, respectively

Table 1

Grazing behavior of sheep, goats, cattle and camels co-grazing range with mixed species of herbaceous and browse plants based on visual observation during 10.0 h of daylight.

Item	Treatments				SEM
	Sheep	Goat	Cattle	Camel	
Position (% day light hours)					
Standing	86.0	83.3	86.7	91.7	2.66
Lying	14.0	16.7	13.3	8.3	2.66
Activity (% day light hours)					
Grazing	72.0 ^a	32.5 ^b	83.3 ^a	27.5 ^b	3.94
Browsing	7.0 ^c	45.0 ^b	0.8 ^c	57.5 ^a	3.44
Ruminating	8.0	11.7	4.2	7.5	3.14
Idle	13.0	10.8	11.7	7.5	3.06

^{a-c}Means within a row without a common superscripts differ ($P < 0.05$); SEM = Standard error of the mean.

and values were similar ($P > 0.05$) among the animal species. However, camels followed by goats spent more time on browsing than sheep and cattle ($P < 0.05$), whereas time spent for grazing was higher ($P < 0.05$) for cattle and sheep compared to goats and camels. The time spent for ruminating and idle did not differ significantly ($P > 0.05$) among the co-grazing livestock species.

3.2. Nutrient composition and in sacco degradability of simulated forage samples

The OM content in simulated forage samples was lower ($P < 0.005$) for camels compared with other animal species (Table 2). The CP concentrations in hand-plucked forages were the highest for camels, intermediate for sheep and goats and lowest for cattle ($P < 0.05$). Conversely, the NDF and ADF concentration in simulated grazed forage samples were in the order of Cattle > Sheep = Goats > Camels. The lignin content of hand-plucked forages was higher for cattle ($P < 0.05$) compared with the values for goats and camels, while the value for sheep significantly differed only with that of camels ($P < 0.05$). The IVDMD content of the hand-plucked forage samples took a similar trend to that of the CP content and was the highest for camels, lowest for cattle and intermediate for sheep and goats ($P < 0.05$).

The *in sacco* DM degradability parameters except for c, and DM disappearance values at different hours vary significantly ($P < 0.05$) among the co-grazing animal species (Table 3; Fig. 1). The A fraction and ED were highest for camel, intermediate for goats and lowest for sheep and cattle (Table 3). The B fraction was higher ($P < 0.05$) for camels and goats compared to the values for sheep and cattle. The PD values were in the order of Camel = Goats > Sheep > Cattle ($P < 0.05$). The DM disappearance values at different hours generally followed the trend of camel being the highest followed by goats and then sheep and lowest for cattle (Fig. 1).

3.3. Body weight and average daily gain

The co-grazing animal species used in this study except for sheep and goats are expectedly of not similar age and body weight (BW). Hence, initial and final BW obviously differ among co-grazing animal species, being in the order of Camels > Cattle > Sheep = Goats (Table 4). Body weight change for the 16-weeks grazing period was higher for camels ($P < 0.05$), while values for other animal species were not statistically different ($P > 0.05$). ADG differed among co-grazing livestock species in all except the third 28-days segment of grazing (Table 4). Means of the overall ADG and ADG in 28-days segments with significant treatment effect ($P < 0.05$) were higher for camels compared with other animal species. Overall ADG and ADG in all segments were similar ($P > 0.05$) among sheep, goats and cattle. Conversely, BW change as well as overall ADG as a percentage of initial BW was statistically similar ($P = 0.104$) among the co-grazing animal species. However, relatively lower values for cattle as compared to camels and small ruminates was observed.

Table 2

Hand-plucked grazed forage nutrient composition of sheep, goats, cattle and camels co-grazing range with mixed species of herbaceous and browse plants.

Item	Treatments				SEM
	Sheep	Goat	Cattle	Camel	
Organic matter (% DM)	89.6 ^a	88.6 ^a	91.0 ^a	84.3 ^b	0.84
Crude protein (% DM)	9.3 ^b	10.2 ^b	4.5 ^c	16.8 ^a	1.17
Neutral detergent fiber (% DM)	64.6 ^b	61.6 ^b	74.3 ^a	45.7 ^c	2.89
Acid detergent fiber (% DM)	39.5 ^b	37.1 ^b	49.2 ^a	21.1 ^c	2.32
Lignin (% DM)	6.2 ^{ab}	5.8 ^{bc}	7.6 ^a	4.5 ^c	0.49
IVDMD (%)	55.8 ^b	51.0 ^b	43.6 ^c	72.8 ^a	1.63

^{a-c}Means within a row without a common superscript differ ($P < 0.05$); DM = Dry matter; IVDMD = In vitro DM digestibility; SEM = Standard error of the mean.

Table 3

In sacco dry matter degradability parameters for hand-plucked grazed forage samples of sheep, goats, cattle and camels co-grazing range with mixed species of herbaceous and browse plants.

Item	Treatments				SEM
	Sheep	Goat	Cattle	Camel	
Readily soluble fraction (A,%)	6.1 ^c	9.6 ^b	5.1 ^c	13.1 ^a	0.80
B (%)	55.8 ^b	67.1 ^a	50.9 ^b	68.2 ^a	1.50
c (% h ⁻¹)	0.031	0.028	0.024	0.038	0.0029
Effective degradability (ED,%)	33.7 ^c	41.3 ^b	27.7 ^c	50.8 ^a	1.93
Potential degradability (PD,%)	61.9 ^b	76.7 ^a	56.0 ^c	81.3 ^a	1.29

^{a,c}Means within a row without a common superscript differ ($P < 0.05$); B= Slowly but potentially degradable fraction; c = Rate of degradation of B fraction; SEM = Standard error of the mean.

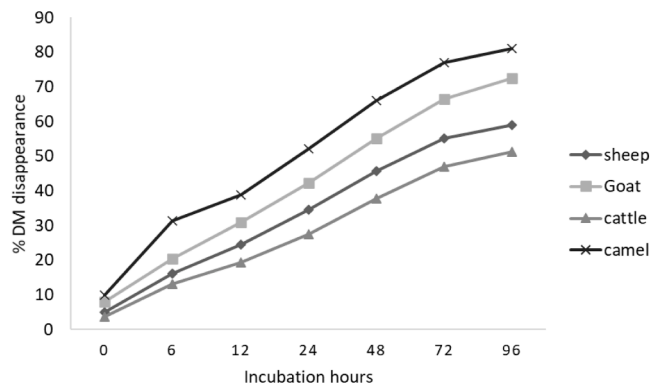


Fig. 1. *In sacco* dry matter (DM) disappearance of hand-plucked grazed forage of sheep, goats, cattle and camels co-grazing range with mixed species of herbaceous and browse plants.

Table 4

Initial and final BW and ADG of sheep, goats, cattle and camels co-grazing range with mixed species of herbaceous and browse plants.

Item	Treatments				SEM
	Sheep	Goat	Cattle	Camel	
Initial BW (kg)	20.6 ^c	16.6 ^c	96.8 ^b	162.3 ^a	4.64
Final BW (kg)	24.5 ^c	20.2 ^c	107.3 ^b	202.3 ^a	4.08
BW change (kg)	3.8 ^b	3.5 ^b	10.5 ^b	40.1 ^a	3.39
BW change (% Initial BW)	18.5	21.5	11.0	25.7	4.15
ADG (g/day)					
0–28 days	48 ^b	63 ^b	166 ^{ab}	307 ^a	53.7
29–56 days	–16 ^b	–9 ^b	–11 ^b	590 ^a	130.9
57–84 days	55	84	123	34	135.9
85–112 days	49 ^b	–14 ^b	99 ^b	499 ^a	69.8
Overall	34 ^b	31 ^b	94 ^b	358 ^a	30.3
ADG (% Initial BW)	0.17	0.19	0.10	0.23	0.037

^{a,c}Means within a row without a common superscript differ ($P < 0.05$); ADG = Average daily body weight gain; BW = Body weight; SEM = Standard error of the mean.

4. Discussion

Animals eat to satisfy their nutrient requirements, and that for grazing animals depend on adequate supply and quality of grazing herbage. Hence, the time spent for different activities by grazing herbivores is primarily a function of available forage mass and forage quality (Ferreira et al., 2013; Lyons & Machen, 2000). For instance, with decreasing forage mass grazing time increased to compensate for decreased bite size, and to search for sufficient bite (Burns & Soltenberger, 2002). In this study, all animal species spent more than 83% of the day light standing, which appeared to be predominantly used for feed consumption (i.e., grazing or browsing). Assuming feed consumption during day light was done while standing, about 92, 94, 97 and 93%

of the time standing was used for eating by sheep, goats, cattle and camels, respectively in this study. Kilgoura, Uetakeb, Ishiwatab and Melvillea (2012) comparably noted that activities other than eating such as ruminating and resting while standing to be quite low. As noted elsewhere in this text, animals in this study grazed only during day light, and thus a significantly greater proportion of the time spent standing versus lying during day time might be an attempt by the animals to allocate more time to harvest sufficient forages, while ruminating and resting be presumably the main nocturnal activities (Fierro & Bryant, 1990; Moges & Uden, 2005) when animals were staying in pens.

In the current study, the time spent for feed consumption (i.e., grazing and browsing) by the grazing animals ranged 78–85% of day light translating to 7.8 to 8.5 h a day. The current result agrees with the report of Lyons and Machen (2000) that mentioned livestock to spent 7 to 12 h a day grazing; with about 70–90% of grazing activity occurring during daylight hours (Viator, Scaglia, Wyatt & Soprano, 2013). Time spent for grazing by herbivores primarily depends on supply of feed from the grazing area (Viator et al., 2013). Less time is spent grazing when forage is plentiful and quality is good, and vice versa. Lyons and Machen (2000) noted that heifers increased grazing time by an average of 3.5 h per day as the amount of available forage decreased. Relatedly, with co-grazing sheep and goats time spent grazing increased with increasing stocking rate due to reduced forage availability associated with high grazing intensity (Animut et al., 2005a).

The time spent for forage consumption in the current study was divided into grazing and browsing activities. Accordingly, of the total time spent for forage harvesting by the animals 91, 42, 99 and 32% for sheep, goats, cattle and camels, respectively was spent on grazing, while the rest was spent for browsing. Camels and goats are known for their browsing choices (Kam, El-Meccawi & Degen, 2012; Moges & Uden, 2005). Camels and goats were seen browsing dominantly on *Acacia* spp. especially of *Acacia seyal* and on *Lantana camara* found in the range of the study area. Variable results on the contribution of browns in the diet of goats has been noted depending on variation in the availability of browse and herbaceous vegetation associated with season, and browse can account up to 90% of the diet of goats during seasons of scarce herbaceous vegetation (Animut & Goetsch, 2008). In Eastern Ethiopia, Moges and Udén (2005) reported that browsing/grazing of camels was the dominant daytime activity accounting for up to 68%, and on average 79 to 83% of the camels' diet comprised of browns. Conversely, cattle diets contain limited proportion of browse (Ferreira et al., 2013; Lechner-Doll, Rutagwenda, Schwartz, Schultka & Engelhardt, 1990) in part associated with the morphological structure of the mouth that make it more difficult for cattle to select leaves of woody plants (Putman, Pratt, Ekins & Edwards, 1987). The mobile tongue and large and flat muzzle of cattle makes them less efficient in short swards and browns. In the current study, herbaceous herbage DM mass was in the range of 1498 to 2352 kg/ha during the grazing period (unpublished data), which was greater than the 850 kg/ha a level suggested to restrict herbaceous forage DM intake (Lippke, Forbes & Ellis, 2000). Ferreira et al. (2013) also noted that cattle to be reluctant to modify diet preferences towards woody vegetation species if sward height is not below 4 cm. In this study, sward height was not measured, but available forage mass could presumably be a reason for cattle spending almost the entire time grazing. Time spent for grazing for sheep and cattle although did not differ significantly ($P > 0.05$), the value for sheep was about 14% lower than that for cattle ($P = 0.0617$), indicating the better incorporation of browse in the diets of sheep than cattle (Animut & Goetsch, 2008; Ferreira et al., 2013).

Generally, the time spent during day light for feed consumption (grazing and browsing), ruminating and idle was not affected by the co-grazing animal species in this study. It appeared that animals were busy to harvest forages to meet nutritional requirements during the 11 h day light that they were allowed to stay in the grazing area. Accordingly, time spent for rumination and idle might have happened during night-time (Fierro & Bryant, 1990; Moges & Uden, 2005), with possible

differences among the co-grazing animal species. Although co-grazing animal species were exposed to the same pasture, differences in dietary selectivity were apparently observed. Hence, nocturnal rumination time might differ among the co-grazing animal species associated with the nutritional value of forage harvested during day light and could be more for the grazers than the browsers (Welch & Smith, 1970).

The OM content of hand-plucked forage samples were lower for camels, possibly due to selectivity for browse species, as browses are rich in most minerals and total ash content that can account up to 18% DM (Mahipala, P., Krebs, McCafferty & Gunaratne, 2009). Although values fail to differ significantly, numerical trend of high ash content for the diet selected by goats versus sheep and cattle has been also observed in this study probably associated with more browsing by goats. Relatedly, browse species are low in fiber (Mahipala et al., 2009) and rich in CP contents and have been suggested as protein supplement for ruminants (Skerman, Cameron & Riveros, 1988). This seemed to be the rationale for the observed high CP content of the hand-plucked forage samples for camels in the current study. Similar to the current result, Moges & Uden (2005) observed that camels were able to select a quality diet containing about 17% CP primarily from the available browse plants. The CP levels for the small ruminants in the current study was higher than the value for cattle, a sign of the better dietary selectivity of small ruminants versus cattle (Ferreira et al., 2013; Lechner-Doll et al., 1990). The CP content of the randomly clipped herbaceous vegetation from the grazing area at the start, middle and end of the grazing period of this study ranged 4.5 to 9% (unpublished data). Thus, the greater CP values of hand-plucked samples for camels and small ruminants suggests either preferential grazing of more nutritious plants and plant parts and/or due to browsing of species having better CP content. Conversely, the CP content of simulated forage samples for cattle was 4.5% less than most of the randomly clipped samples of the herbaceous herbage in the current study. Although the reason for this is not apparent, cattle among ruminant species is of generally least in selectivity and appeared to harvest relatively poor-quality forages (Lechner-Doll et al., 1990). Moreover, the animals were kept in pens during nighttime and hand-plucked sampling was done in the morning about two hours after the animals returned to the grazing area when the animals might have a high motivation to seek food (Ferreira et al., 2013; Gregorini, Tamminga & Gunter, 2006) with little selectivity. It was observed that grazing animals within species tend to stay closer. However, competition for grazing land among the co-grazing animals was unnoticed in this study. Thus, competition for grazing area appeared to be not a reason for differences in dietary value among the co-grazing animal species.

Associated with differences in CP and fiber content of hand-plucked forage samples, IVDMD values as expected were in the order of Camels > Small ruminants > Cattle. The trend of differences among animal species in the *in sacco* DM degradability parameters and DM disappearance at different incubation hours of hand-plucked forage samples is largely consistent with variations in the chemical composition values. Generally, based on concentration of CP and NDF, and IVDMD values, the diets of camels can be classified as good quality and that of cattle as low quality (Mugeriwa, Christianson & Ochetim, 1973; Norton, 1982; Van Soest, 1965), while that for small ruminants have a CP level more than the 7% required to satisfy maintenance requirement of ruminants (Paterson, Cohran & Klopfenstein, 1996).

Body weight gain during the 16-weeks grazing period for camels was about four times higher compared to cattle and more than ten-fold greater compared to small ruminants. The BW change as a percentage of initial BW did not differ among co-grazing animals in this study ($P = 0.104$). However, the value for cattle was lower by more than half compared to camels, by 68% compared to sheep, and by 95% compared to goats. Generally, it appeared that cattle were gaining relatively less as compared to their body size than other co-grazing animal species in this study. Such observation is apparently in line with differences in the nutritional values of the diets selectively harvested by the co-grazing animals in this study as evidenced by the concentration of CP, NDF

and IVDMD from hand-plucked forage samples. However, positive body weight gains for cattle on the basis of the nutritional value of hand-plucked forage samples appeared to be unwarranted (Mugeriwa et al., 1973; Norton, 1982; Van Soest, 1965). Thus, for conclusive results on the hand-plucked forage samples for some co-grazing species if not for all, a continuous monitoring of the diurnal pattern of dietary consumption and selectivity by the animals might be needed. In a review on the interaction of diurnal grazing patterns and nutrient supply, Gregorini, Gunter, Beck, Soder and Tamminga (2008) noted that ruminal conditions most likely dominates the short-term intake rate during grazing, whereas on a larger spatiotemporal scale, the animal may operate within a framework of daily level of energy demand. Therefore, selective ingestion of better diet by cattle in this study perhaps could have happened in times of the day and in days, other than those used to make behavioral observation and hand-plucked forage sampling.

Daily BW gain in the 28-days segments lacks a consistent trend for the co-grazing animal species. Negative ADG for sheep, goats and cattle was noted in the second 28-days segment of grazing, while the highest ADG was observed for camels during this period. Given greater forage mass and better nutritional values of herbaceous vegetation observed in this study during the first two versus the last two 28-days grazing segments (unpublished data), lower gains noted in the second 28-days grazing segment were unexpected (Animut et al., 2005b). Overall ADG of 34, 31, 94 and 358 g/day for sheep, goats, cattle and camels was noted in this study. Body weight gains are reflection of the nutritional status of the animals. In a relatively better feeding regime that used supplemental concentrate and for similar breed of animal species used in this study, ADG of 116 g/day for sheep (Kiflay, Animut & Urge, 2014), 73 g/day for goats (Tesfu, 2018), 355 g/day for cattle (Getnet, Ayalew & Hegde, 2009), and 840 g/day for camels (Moges, Urge, Animut & Mohammed, 2016) were reported. These reported values are 3.4, 2.4, 3.8, and 2.4 times higher than the ADG values noted in this study for sheep, goats, cattle and camels, respectively. This indicates the relatively lower performance of grazers (i.e., sheep and cattle) versus browsers (i.e., camels and goats), an attribute of the better feeding and/or supplemental value of browses than the herbaceous vegetation in this study. Unlike the current result, Animut et al. (2005b) noted that with decrease in forage supply and nutritive value associated with increased stocking rate in pasture with mixtures of grasses and forbs but no browse, co-grazing goats were more impacted than sheep to ingest sufficient forage and attain comparable level of growth. This also shows the likely significant role of browses found in the grazing area of the present study in supplying better quality feed to those animal species that preferentially defoliates them.

Considering final body weights of the experimental animals and a tropical livestock unit (TLU) of 250 kg, the current stock rate was 1.42 TLU/ha. Derege, Muhyadin and Dahir (2019) estimated the average carrying capacity of rangelands in Harshin District, Eastern Ethiopia to be 0.3 TLU/ha/year (range 0 to 1 TLU/ha/year), while the existing stocking rate in the same area was 5.4 TLU/ha/year. The range condition in the study of Derege et al. (2019) and the current study might differ. As such, the current stocking rate appeared to be of not high intensity. However, the grazing period in this study was during the dry spells when energy and protein supply from grazing herbage might have been limited. Relatedly, the quality of herbaceous vegetation might have not been a kind that induce good animal growth as apparent from the relatively low productivity of cattle in this study. Thus, for better animal gains, application of rangeland improvement measures to enhance the feeding value of available herbaceous herbage and/or other options such as supplementation strategies (Tesfu, 2007) might be needed.

5. Conclusion

Daily time budgeted for grazing and browsing differed among co-grazing animal species in this study justifying reduced dietary overlap among the animal species. This and perhaps the greater utilization of

browses by camels and goats might have led to greater animal yield than probably stocking the range by cattle or cattle and sheep only. Thus, under the range condition of the present study, co-grazing by the four animal species appeared beneficial in terms of efficient range resource utilization and improving secondary productivity. However, the herbaceous vegetation condition might have not maximized animal yield that could have been harvested from the area as apparent from the relatively lower productivity of cattle, which seemingly was almost entirely dependent on grazing in this study. This thus warrants implementation of range improvement options for better nutritious supply of herbaceous vegetation and consequently enhanced livestock productivity. Further study through continuous digital monitoring of the grazing behavior and spatiotemporal distribution of the co-grazing animals might be useful to have a better insight on the impact of co-grazing of the four livestock species on range and livestock productivity.

6. Ethical protocol

All ethical protocols have been followed in the conduct and preparation of this manuscript

Declaration of Competing Interest

There are no conflicts of interest.

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