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Research article

# Stover yield, morphological fractions and nutrient composition of five stay-green sorghum (*Sorghum biochar* L.) varieties at the physiological maturity stage

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ABSTRACT

Stay-green sorghum varieties are known for their drought resistance and ability to retain green biomass during grain filling, making them crucial for sustainable agriculture in arid regions. However, there is limited information on their stover yield (SY) and nutritional quality when both grain and forage are harvested. This study assessed five stay-green sorghum varieties at the Bako Agricultural Research Centre using a randomized complete block design with three replications in 2020, 2021, and 2022. The research evaluated SY, morphological traits, and nutrient composition. Results indicated that the Chemeda and Gemedi varieties produced the highest SY, digestible dry matter, and organic matter yield, with greater plant height and stem dry matter yield. These varieties are better suited for and could be targeted toward smallholder farmers who require large quantities of fodder for dry-season feeding when feed shortages are prevalent. In contrast, Asosa1 yielded the highest leaf biomass and leaf-to-stem ratio, followed by Adukara, suggesting that stover produced by such varieties would contribute to higher-quality forage that supports livestock productivity. SY varied significantly ($P < 0.001$) across seasons, with the highest in year 1, followed by year 3, and the lowest in year 2. Ash, neutral detergent fiber, acid detergent fiber, and cellulose concentrations showed no significant difference ($P > 0.05$) among varieties, though some quality traits differed ($P < 0.05$). Crude protein ranged from 5.44 % (Chemeda) to 3.18 % (Marara). These levels were below the threshold required for optimal rumen microbial activity, highlighting the need for supplementation with high-quality feed to support effective animal performance. Most traits, except for the leaf-to-stem ratio, showed strong positive correlations. Overall, Asosa1 and Adukara provided less stover with higher nutritional quality, while Chemeda and Gemedi offered greater quantities of lower-quality stover. The choice of variety should be based on the livestock production purpose of the end users. Future research should focus on assessing the performance of ruminant animals fed stover from the recommended varieties.

## 1. Introduction

Ruminant production in tropical semi-arid and arid countries, such as Ethiopia, is challenged by limited year-round access to nutritious pasture and the high cost of conventional feedstuffs [1]. On the other hand, climate change is exacerbating the challenges associated with cattle feed accessibility in most tropical and sub-tropical regions [2]. In many tropical countries, the pasture growing

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season is expected to shorten, accompanied by higher variability in rainfall patterns and more frequent droughts, already occurring in some regions of the country [3]. Therefore, feed sources capable of withstanding such environmental conditions and requiring less water are needed to ensure sustainable animal production in these areas [4].

Sorghum is one such potential feed source. Ethiopia is one of the largest sorghum-growing countries in Sub-Saharan Africa [5]. This crop thrives across a range of agro-ecologies, including areas with extended dry seasons or drought [5]. Sorghum is a naturally occurring tropical genus that provides food, feed, and fuel to millions of smallholder farmer households and their livestock [6]. Sorghum is anticipated to become even more critical in the context of global climate change due to its ability to withstand high temperatures, water scarcity, and saline environments [7]. Extensive evaluations of various sorghum genotypes have been conducted at the Bako Agricultural Research Centre and other research institutes in Ethiopia, resulting in the release and registration of several promising varieties. Some of these varieties are classified as forage type or stay green, which maintain green biomass during grain harvest. These varieties are potential sources of superior quality stover compared to other cereal crops, making them an excellent candidates for animal feed production.

Sorghum growth, however, is influenced by a complex interactions between genotype and environmental circumstances, with these factors significantly affecting variables such as plant height, leaf area, and stoevr yield. Different varieties exhibit varying levels of resistance to environmental challenges, including fluctuations in rainfall, temperature, and soil moisture, which directly affect plant growth and development [8]. For instance, higher biomass yields are often observed during wet seasons, while dry conditions typically limit growth and result in lower yields [9]. The genotype-environment interaction is thus important because certain genotypes perform better under specific environmental conditions. For example, drought-tolerant cultivars might thrive might during dry years, whereas other varieties might flourish under ideal growth conditions [10]. To choose the best-performing genotypes for a variety of settings and guarantee sustainable fodder production in a range of climates, it is crucial to comprehend these relationships [11].

The influence of environmental variability is further highlighted by significant changes in the nutritional composition of sorghum stover [11]. A wide variability in the nutritional variability of sorghum stover have been reported in literatures. Chakravarthi et al. [12] reported crude protein content ranging from 5.29 % to 21.24 % across 50 sorghum genotypes. Singh et al. [8] found that crude protein and in-vitro dry matter digestibility values ranged from 3.7% to 6.7 % and 40.3%–55.7 %, respectively, among 11 varieties. This presents opportunities for collaboration between animal nutritionists and sorghum breeders to enhance sorghum not only for grain yield but also for stover yield and nutritional value.

However, most of the sorghum research conducted to date in Ethiopia has focused on grain yield, with little attention given to fodder yield and quality features. Between 1970 and 2015, 49 sorghum varieties were released for food purposes in Ethiopia [13], while only one variety was released in 2021 for forage purposes [14]. Grain-oriented varieties have primarily been selected based on grain yield, and plant height and total biomass, often neglecting their feeding value. Evaluating varieties for their stover quality aspects can help identify dual-purpose types that serve both human food and livestock feed requirements, thus enhancing food and feed security in mixed crop-livestock systems. As a result, the current study was conducted to assess the stover production, nutrient composition, and morphological components of stay-green sorghum varieties at the physiological maturity stage under the agro-ecology of Bako, western Ethiopia.

## 2. Material and methods

### 2.1. Description of the study area

The research was conducted at the Bako Agricultural Research Centre, Ethiopia, over three consecutive cropping seasons: 2020, 2021, and 2022. The center is located at 1650 m above sea level, with latitude and longitude coordinates of 9° 06′ N and 37° 09′ E. The map of the study area is shown in Fig. 1. The study area has predominantly Nitosol soil type with 2.5 % organic carbon, 10 ppm

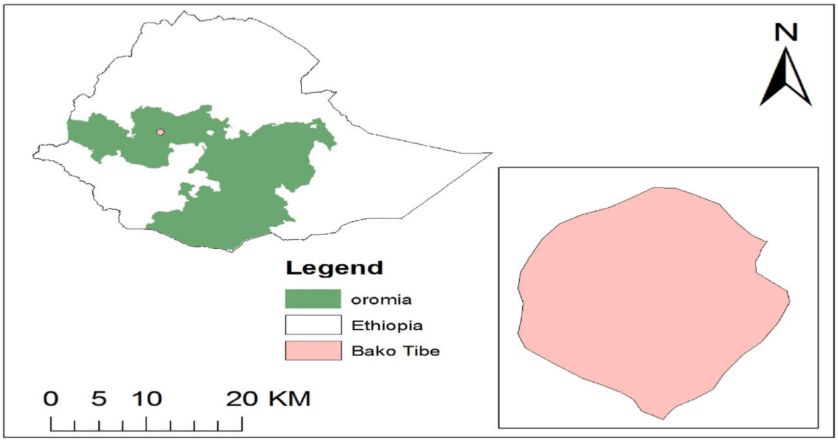


**Fig. 1.** Map of the study area (Bako-Tibe District).

available P, 0.22 % total nitrogen, and a pH of 5.18. Mean monthly rainfall and maximum and minimum temperatures for the experimental periods are shown in Fig. 2.

### 2.2. Sowing and data collection

Planting occurred in early May at the Bako Agricultural Research Centre fodder growing area during the experimental years 2020, 2021, and 2022. A total of 15 plots, each measuring 4.5 × 4 m, were established to plant the varieties. Sowing was done by hand, with the seeds drilled in rows 75 cm apart and spaced 15 cm apart in the rows. A consistent planting rate of 10 kg/ha, as recommended for the varieties, was applied. Each plot received NPS fertilizer, containing nitrogen (19 %), phosphate (38 % P2O5), and sulfur (7 % S), at a rate of 100 kg/ha at planting. Additionally, 50 kg/ha of urea was applied in two stages: the first half at planting and the second half 35 days later.

Stover yield data was collected at the physiological maturity stage. After manually cutting the center two rows of each plot to a stubble height of 15 cm, the fresh weight of the harvested biomass was measured immediately using a field balance. To determine stover dry matter yield, a 300 g subsample from each plot was dried in an oven at 65 °C for 72 h until a constant weight was achieved. Five plants were randomly selected and divided into leaf and stem fractions. Sub-samples of 300 g were taken from each fraction to estimate their dry matter yield, following the same procedure used for stover dry matter yield. The dry matter yields of the leaf and stem fractions were then used to calculate the leaf-to-stem ratio. Digestible stover dry matter and organic matter yields were estimated by multiplying the total stover dry matter yield by their respective dry matter and organic matter digestibility values, divided by 100.

### 2.3. Experimental design and cultivation management

Five stay green sorghum varieties were evaluated using a randomized complete block design with three replications giving a total of fifteen observations per experimental year. During each experimental year, the number of treatments (varieties), planting time, seeding and fertilization rates, as well as plot size and arrangements, were all kept uniform. The five stay green experimental varieties were: Chemeda, Gemedi, Marara, Asosa1, and Adukara. Asosa1 and Adukara are late-maturing varieties released in 2015 by the Asosa Agricultural Research Centre [15]. Chemeda and Gemedi, tall and late-maturing varieties, were released by the Bako Agricultural Research Centre in 2013 [16]. Marara, a medium-mature, intermediate-height variety, was released in 2019 [17] by the Bako Agricultural Research Centre. These varieties were selected for their stay-green trait and wider adaptability to the agroecology of the study area.

### 2.4. Chemical analysis

Dry matter, N (CP=N x 6.25), and ash value were analyzed using AOAC [18] procedure. The neutral detergent fiber was analyzed using the Van Soest et al. [19] method, whilst acid detergent fiber and acid detergent lignin were analyzed using the Van Soest and Robertson [20] method. Hemicellulose and cellulose content were calculated as a difference between NDF-ADF and ADF-ADL, respectively. In-vitro dry matter and organic matter digestibility were assessed using an earlier Tilley and Terry [21] as modified by Van Soest and Robertson [20].

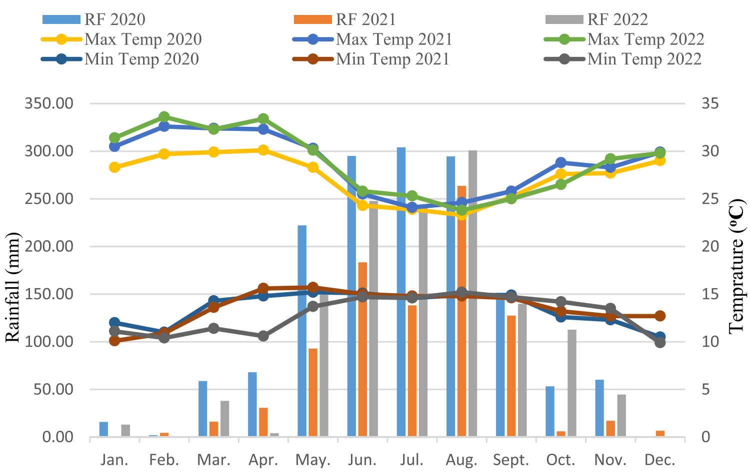


**Fig. 2.** Mean monthly rainfall and minimum and maximum temperatures at Bako.

### 2.5. Data analysis

Stover yield and morphological fraction data were collected over three years; however, quality attribute data were only gathered in the final year of the trial due to budget constraints for analyzing feed samples from each experimental year. As a result, the model for analyzing stover yield and yield attributes only took into account the effects of variety, experimental year, and their interaction. However, only varietal influence was taken into account as an independent variable in the model for quality parameters. The analysis of variance using the GLM procedure of SAS [22] version 9.0 was used for data analysis. The least significant difference test was used to differentiate significantly different means with a 5 % level of significance. The models used were:

For stover yield and related traits (Model 1): $Yijk = \mu + Vi + Yj + (V \times Y)ij + Bk + eijk$, where; $Yijk$ = response variable; $\mu$ = overall mean; $Vi$ = varietal effects; $Yj$ = year effect; $Vi \times Yj$ = interaction effects of variety and year; $Bk$ = block effects, and $Eijk$ is random error. For stover nutritional quality traits (Model 2): $Yij = \mu + Vi + Bj + eij$, where; $Yij$ = response variable; $\mu$ = overall mean; $Vi$ = varietal effects; $Bk$ = block effects, and $Eij$ is random error. Pearson correlation coefficient was also calculated among the stover yield and related parameters using a Microsoft Excel sheet.

## 3. Results

### 3.1. Stover yield and yield traits

The detailed results for stover yield and yield traits across varieties and years are presented in Table 1. There were significant effects of variety and experimental year ($P < 0.001$, for both effects) for the response variables, however, there was no interaction effect ($P > 0.05$). The Chemeda variety had the highest values for all measured characteristics (stover yield, digestible dry matter, and organic matter yield), followed by Gemedi, while Marara recorded the lowest values, and the remaining varieties showed intermediate values. Yield and yield-related traits were highest in year 1, followed by year 3, with year 2 showing intermediate values.

### 3.2. Plant height and morphological fractions

The findings of the analysis of variance for plant height and morphological fraction of stay-green sorghum varieties are shown in Table 2. Except for the leaf-to-stem ratio ($P > 0.05$) and leaf dry matter yield ($P > 0.05$), which showed no significant differences between cropping seasons, the remaining morphological fractions were significantly affected by the main effects of variety ($P < 0.01$) and growing seasons ($P < 0.01$), rather than their interaction ($P > 0.05$).

Chemeda exhibited the highest mean plant height, followed by Gemedi, while Adukara and Asosa1 showed lower and equivalent values. Similarly, Chemeda, followed by Gemedi, produced more stem dry matter (DM) yield than the other varieties, but also the least leaf DM, which was higher in Asosa1 and Adukara varieties. The leaf-to-stem ratio mirrored the pattern observed in leaf DM yield, with Asosa1 having the highest value, followed by Adukara, while Chemeda and Gemedi had lower values, and Marara had an intermediate value. Plant height and stem DM yield were higher in the first and last growing seasons compared to the second year, although the differences were statistically equivalent.

**Table 1**
Mean stover yield (t/ha), digestible DM yield (t/ha) and digestible OM yield (t/ha) of the five stay-green sorghum varieties at the physiological maturity stage.

| Sources of variations | Stover yield and related traits | | |
|---|---|---|---|
| | Stover yield | Digestible DM yield | Digestible OM yield |
| **Varieties** | | | |
| Chemeda | 20.39$^{a}$ | 11.86$^{a}$ | 10.05$^{a}$ |
| Gemedi | 15.98$^{b}$ | 9.11$^{b}$ | 7.68$^{b}$ |
| Asosa1 | 13.11$^{c}$ | 7.82$^{bc}$ | 6.67$^{b}$ |
| Adukara | 13.25$^{c}$ | 7.81$^{c}$ | 6.64$^{b}$ |
| Marara | 9.45$^{d}$ | 5.59$^{d}$ | 4.76$^{c}$ |
| Mean | 14.44 | 8.44 | 7.16 |
| SEM | 0.76 | 0.45 | 0.38 |
| **Year (Y)** | | | |
| Y1 | 17.93$^{a}$ | 10.48$^{a}$ | 8.89$^{a}$ |
| Y2 | 9.61$^{c}$ | 5.62$^{c}$ | 4.77$^{c}$ |
| Y3 | 15.77$^{b}$ | 9.21$^{b}$ | 7.81$^{b}$ |
| SEM | 0.59 | 0.35 | 0.29 |
| P-values | | | |
| Year | <0.0001 | <0.0001 | <0.0001 |
| Variety | <0.0001 | <0.0001 | <0.0001 |
| Interaction | 0.4122 | 0.4359 | 0.4416 |

[1]Means within columns followed by different letters differ significantly ($P < 0.05$); DM = dry matter; OM = organic matter; SEM = standard error of means.

**Table 2**
Mean plant height, leaf dry matter yield, stem dry matter yield, and leaf-stem ratio of the stay-green sorghum varieties at the physiological maturity stage.

| Sources of variation | Plant height and morphological fractions | | | |
|---|---|---|---|---|
| | Plant height (cm) | Stem DM yield (t/ha) | Leaf DM yield (t/ha) | Leaf:stem |
| **Varieties** | | | | |
| Chemeda | 326.67[a] | 17.87[a] | 3.01[abc] | 0.18[c] |
| Gemedi | 276.22[b] | 13.75[b] | 1.79[c] | 0.13[c] |
| Asosa1 | 165[d] | 10.12[c] | 3.47[a] | 0.36[a] |
| Adukara | 159[d] | 9.67[c] | 3.4[ab] | 0.35[ab] |
| Marara | 209.44[c] | 8.68[c] | 2.19[bc] | 0.23[bc] |
| Mean | 227.27 | 12.02 | 2.77 | 0.25 |
| SEM | 7.06 | 0.75 | 0.43 | 0.04 |
| **Year (Y)** | | | | |
| Y1 | 243.33[a] | 12.94[a] | 3.24 | 0.28 |
| Y2 | 204.07[b] | 9.99[b] | 2.56 | 0.24 |
| Y3 | 234.4[a] | 13.11[a] | 2.51 | 0.23 |
| SEM | 5.47 | 0.58 | 0.33 | 0.03 |
| P-values | | | | |
| Year | <0.0001 | 0.0009 | 0.2401 | 0.4815 |
| Variety | <0.0001 | <0.0001 | 0.0342 | 0.0009 |
| Interaction | 0.1180 | 0.1895 | 0.0866 | 0.0923 |

[1]Means within columns followed by different letters differ significantly ($P < 0.05$); SEM = standard error of mean.

### 3.3. *Pearson correlation coefficients among yield and yield-related parameters*

The correlation among the measured variables is shown in Table 3. The leaf-to-stem ratio only showed a significant and positive correlation with leaf DM yield. Stover DM yield, however, had a significant and positive correlation with all other traits. Leaf DM yield was negatively correlated with plant height but had a significant and positive association with the other traits. Stem DM yield showed a significant and positive correlation with plant height, digestible OM, and DM yield. Additionally, plant height demonstrated a significant and positive association with both digestible DM and OM yields.

### 3.4. *Chemical composition*

The nutritional composition of the five stay green sorghum varieties that were assessed at the physiological maturity stage was shown in Table 4. Except for ash, NDF, ADF, and cellulose concentrations, which showed no significant variation ($P > 0.05$), the remaining quality parameters exhibited significant differences ($P < 0.05$) among the varieties. Crude protein (CP) content had the narrowest range, with Chemeda having the highest value of 5.44 % and Marara the lowest at 3.18 %, yielding a mean value of 4.22 %. The DM concentration was higher in Asosa1 and Adukara varieties, both of which were statistically equal, while the other varieties had lower, equivalent values.

The average amount of ADL was 4.99 %, with Gemedi having the highest value at 5.8 % and Adukara the lowest at 4.38 %. Hemicellulose concentration ranged from a higher value of 42.72 % for Asosa1 to a lower value of 37.53 % for Chemeda. Among the varieties, Asosa1, followed by Adukara and Marara, showed the highest digestibility levels in terms of both in-vitro dry matter (IVDMD) and organic matter (IVOMD) digestibility, as well as metabolizable energy (ME). However, these parameters were lower in Chemeda.

## 4. Discussion

The large varietal variation in stover yield observed in this study can be attributed to genetic differences among the examined

**Table 3**
Pearson correlation coefficients among stover yield and related features of five stay green sorghum varieties.

| | StDMY | LSR | LDMY | SDMY | Pht | DOMY | DDMY |
|---|---|---|---|---|---|---|---|
| StDMY | 1 | | | | | | |
| LSR | −0.15134 | 1 | | | | | |
| LDMY | 0.209364* | 0.839279*** | 1 | | | | |
| SDMY | 0.815641*** | −0.35965 | 0.10397* | 1 | | | |
| Pht | 0.686337** | −0.48567 | −0.10423 | 0.813443*** | 1 | | |
| DOMY | 0.997747*** | −0.11636 | 0.239523* | 0.804268*** | 0.657982** | 1 | |
| DDMY | 0.998569*** | −0.12351 | 0.233488* | 0.80688*** | 0.663993** | 0.999907*** | 1 |

StDMY = stover dry matter yield; LSR = leaf to stem ratio; LDMY = leaf dry matter yield; SDMY = stem dry matter yield; Pht = plant height; DOMY = digestible organic matter yield; DDMY = digestible dry matter yield.

**Table 4**
Mean nutrient composition of stay-green sorghum varieties at the physiological maturity stage. Values are average of three replicates.

| Quality traits | Sorghum varieties | | | | | Mean | SEM | P-value |
|---|---|---|---|---|---|---|---|---|
| | Chemeda | Gemedi | Asosa1 | Adukara | Marara | | | |
| DM | 92.51[b1] | 92.44[b] | 93.1[a] | 93.14[a] | 92.46[b] | 92.73 | 0.09 | 0.0010 |
| CP | 5.44[a] | 4.33[ab] | 3.53[bc] | 4.63[ab] | 3.18[c] | 4.22 | 0.39 | 0.0227 |
| Ash | 2.34 | 3.51 | 3.33 | 2.15 | 2.67 | 2.79 | 0.43 | 0.1993 |
| NDF | 68.79 | 70.25 | 75.79 | 71.89 | 72.17 | 71.78 | 1.47 | 0.0778 |
| ADF | 31.26 | 32.09 | 33.07 | 32.05 | 32.99 | 32.29 | 1.03 | 0.7138 |
| ADL | 4.6[bc] | 5.8[a] | 5.13[b] | 4.38[c] | 5.02[bc] | 4.99 | 0.19 | 0.0082 |
| H-cellu. | 37.53[c] | 38.16[bc] | 42.72[a] | 39.84[b] | 39.17[bc] | 39.49 | 0.69 | 0.0055 |
| Cellulose | 26.65 | 26.29 | 27.94 | 27.67 | 27.97 | 27.3 | 0.94 | 0.6217 |
| IVDMD | 58.09[b] | 56.8[c] | 59.64[a] | 58.99[ab] | 59.02[ab] | 58.51 | 0.31 | 0.0016 |
| IVOMD | 49.23[b] | 47.85[c] | 50.87[a] | 50.17[ab] | 50.21[ab] | 49.67 | 0.33 | 0.0016 |
| ME | 7.88[b] | 7.65[c] | 8.14[a] | 8.03[ab] | 8.04[ab] | 7.95 | 0.05 | 0.0016 |

[1]Means within columns followed by different letters differ significantly ($P < 0.05$); DM (%) = dry matter; CP (%DM) = crude protein; NDF (%DM) = neutral detergent fiber; ADF (%DM) = acid detergent fiber; ADL (%DM) = acid detergent lignin; H-cellu. (%DM) = hemicellulose; IVOMD (%DM) = in-vitro organic matter digestibility; IVDMD (%DM) = in-vitro dry matter digestibility, ME (MJ/kg DM) = metabolizable energy; SEM = standard error of means.

varieties, as documented in the literature [23,24]. Among the varieties, Chemeda and Gemedi are expected to produce the highest stover yields. This is likely due to their taller plants and higher stem dry matter yields compared to the other varieties, which had shorter plants and lower stem dry matter yields (Table 2). As reported by Kebede et al. [25], cutting height correlates positively with fodder yield in Napier grass. Except for Marara, all varieties produced stover yields within the published range of 12.6–22.5 t/ha [26]. Similar yields for dual-purpose sorghum harvested between physiological grain maturity (18.01 t/ha) and one month after grain reap (13.05 t/ha) were reported by Mwangi et al. [27]. Chemeda and Gemedi achieved significantly higher stover yields in this study than the values reported by Miron et al. [28] for 14 sorghum varieties (10.5–14.9 t/ha). These yield differences may relate to the genetic makeup of the varieties and the stage of stover yield collection.

The higher digestible dry matter (DM) and organic matter (OM) yields of Chemeda, followed by Gemedi, result from their greater stover yields, as these yields depend on total stover production and the corresponding in-vitro DM and OM digestibility. Despite a lower stover output than Gemedi, Asosa1 and Adukara provided comparable digestible DM and OM yields. This is likely explained by their relatively higher in-vitro DM and OM digestibility values compared to Gemedi (Table 3). These findings highlight that livestock farmers in regions prone to feed shortages and fluctuating climatic conditions could prioritize Chemeda and Gemedi for their superior stover yield. Cultivation of these varieties would serve as a reliable forage sources, especially during dry periods when forage availability may be limited. In contrast, Asosa1 and Adukara, with their higher nutritional quality, could be selected by livestock farmers who aim to optimize feed quality, particularly when livestock production goals require efficient energy utilization for growth and/or milk production.

Asosa1, Adukara, and Marara were outgrown in height by the genetically taller Chemeda and Gemedi varieties. Dwarfism genes in Asosa1 and Adukara, as suggested by Harinarayana et al. [29], may increase leaf-to-stem ratios and shorten internodes—traits observed in this study. The mean plant height reported by Ayub et al. [26] for seven sorghum varieties (256.6–257.8 cm) was lower than that recorded for Chemeda, comparable to Gemedi, but higher than Asosa1, Adukara, and Marara in the present study. The plant height (70.7–136.7 cm) reported by Asma et al. [24] for sorghum cultivars in Gadarif state, Sudan, was much lower than the findings of this study, possibly due to varietal differences and/or agro-ecological factors where the studies were conducted.

The significant variation in stover biomass allocation between leaf and stem fractions observed in this study aligns with findings for selected tropical grasses indigenous to Africa [30]. Fekede et al. [31] reported consistent results with Asosa1 and Adukara, showing that shorter oat varieties yielded more leaves, had better leaf-to-stem ratios, but produced lower stem yields than taller varieties. Mganga et al. [30] noted that varieties producing more leaves than stems are more nutritious and easier for animals to digest. Shorter internodes and increased leaf proportions in shorter varieties might result from a higher number of leaf-producing nodes or shorter stem internodes, characteristics associated with continuous growth throughout the season [31]. Year 1 showed better growing conditions for sorghum, with increased stover production and improved morphological parameters compared to the second and third experimental years (Fig. 1).

The relationship between stover yield and associated varietal characteristics appears influenced by genetic and environmental factors. The negative correlation between the leaf-to-stem ratio and other variables suggests independence from other traits, except leaf DM yield. Leaf production also showed no relation to plant height, indicating that cutting height did not affect leaf production. Overall, traits lacking positive correlations likely reflect independence, with changes in one trait not impacting others.

The CP concentration of all varieties in this study ranged from 3.18 % to 5.44 %, below the critical threshold of 7 % [32] needed for optimal rumen microbial activity. Mwangi et al. [27] reported similar CP concentrations for sorghum harvested at physiological maturity (6.77 %) and one month after grain reap (6.72 %). Diriba et al. [33] observed mean CP concentrations of 3.4 % in cereal straw, also below the critical level. Animals fed stover from such sources require supplementary high-protein feed. The DM concentration observed here aligns with values reported by Osman et al. [34] for sorghum samples from various locations and years (89.5%–91.2 %). Diriba et al. [33] reported a similar mean DM concentration of 92.2 % for cereal straw. However, NDF, ADF, and ADL concentrations in this study were lower than those reported by Singh et al. [35] for sorghum stover (73.1%–77.1 %, 47.4%–51.2 %, and 7.85%–8.74 %, respectively).

The significant difference in IVDMD observed in this study aligns with previous reports and falls within the range presented by Mwangi et al. [27] for sorghum stover. The IVOMD observed in this study was similar to sole-planted sorghum, lower than sorghum planted with forage cowpea [36], and higher than the average 44.8 % reported for cereal straw [34]. This discrepancy could be attributed to differences in cropping systems and varietal differences examined. The relatively higher in-vitro DM and OM digestibility in Asosa1, followed by Adukara, may be partly due to their higher leaf yields relative to stems (Table 2) and lower lignin concentrations (Table 3). The higher DM and OM digestibility in Asosa1 and Adukara varieties suggests improved energy availability, which is important for intensive livestock production systems focused on maximizing growth rates, milk production, or fattening in cattle. Al-Arif et al. [37] compared various cattle feeding models and found that diets with higher DM and OM digestibility significantly increased total digestible nutrients, enhancing energy intake and utilization. According to Owen and Jayasuriya [38], feed with an IVOMD greater than 50 % is considered adequately digestible, and all the varieties studied except for Chemeda and Gemedi exceeded the minimum threshold level.

The mean ME concentration of the varieties evaluated in this study, ranging from 7.65 to 8.14 MJ/kg DM, was comparable to the range of 7.43–9.49 MJ/kg DM reported by Terler et al. [39]. Similarly, this conclusion aligns with the mean value of 7.9 MJ/kg DM for tropical grasses such as Napier grass [40] and the crucial threshold level of 7.5 MJ/kg DM for roughages and forage feed resources [38]. However, compared to the value of 6.72 MJ/kg DM reported for cereal straw [33], the mean ME in this study was slightly higher.

## 5. Conclusion

In general, cultivating the Chemeda and Gemedi varieties helps livestock producers harvest larger quantities of lower-quality stover, while the Asosa1 and Adukara varieties offer lower stover yields but higher-quality characteristics. The Chemeda and Gemedi varieties provide feed for farmers who can supplement their cattle's diet, allowing them to optimize livestock production with the higher fodder yield these varieties offer. In contrast, Asosa1 and Adukara varieties serve as more cost-effective options for livestock producers, particularly in systems with limited feed availability or high supplemental feed costs. These varieties deliver better nutritional value from the available forage alone. Therefore, the choice of variety should depend on the livestock producer's objective and potential for sorghum production in their specific context. An abundance of fodder or forage does not necessarily ensure optimal livestock performance, as quality and digestibility play critical roles. Inconsistent fodder/forage characteristics present challenges for farmers aiming to maximize livestock productivity. Future research should focus on identifying the optimal harvesting stage to maximize the nutritional content and digestibility of Asosa1 and Adukara varieties.

## CRediT authorship contribution statement

**Abuye Tulu:** Writing – original draft, Software, Project administration, Formal analysis, Conceptualization. **Mekonnen Diribsa:** Writing – review & editing, Validation, Methodology. **Birmeduma Gadisa:** Writing – review & editing, Validation, Project administration. **Worku Temesgen:** Validation, Supervision, Project administration, Data curation.

## Data availability statement

Data used in this study will be available from the corresponding author up on request.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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