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RESEARCH ARTICLE

Production and chemical composition of sesame forage at three harvest ages

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ABSTRACT

The phenological stage of plants affects forage production and nutritional quality. The objective of this study was to compare the production and chemical composition of sesame forage (*Sesamum indicum* L.) at three harvest ages in the dry tropics of Mexico. Dry forage yields (DFY) and chemical composition of sesame forage harvested at 58 (A58), 65 (A65), and 72 (A72) days of age were determined. A completely randomized design was used. Data was analyzed using ANOVA, and means were compared with Duncan's test ($p < 0.05$). Forage harvested at A72 showed the highest DFY, DM, organic matter, ether extract, Ca and P (4940.00, 198.81, 928.64, 112.81, 13.58 and 2.53 *vs*. 4075.86 kg ha^{-1}, 171.41, 918.57, 52.88, 12.28 and 1.9 g kg^{-1} respectively; $p < 0.05$), similar total digestible nutrients and neutral detergent fiber (623.23 and 485.11 g kg^{-1} *vs*. 610.34 and 501.97 g kg^{-1}; $p > 0.05$), and lowest ash, acid detergent fiber and cellulose (71.36, 377.28 and 226.21 g kg^{-1} *vs*. 81.43, 407.53 and 258.50 g kg^{-1} respectively; $p < 0.05$) compared with forage A58 which was the lowest except for Ca, it was intermediate. Crude protein content in forage A72 was 102.17 g kg^{-1}, only 5.4 g kg^{-1} lower than in forage A58 ($p < 0.05$). Therefore, under the conditions of this study, harvesting sesame forage at 72 d maximizes forage production and nutrient yield, suggesting its potential as an alternative feed resource for ruminants.

Key words: Dry tropics, feed, nutrient yield, ruminants, *Sesamum indicum*.

INTRODUCTION

Most small livestock (cattle, sheep, and goats) farmers in the Mexican dry tropics depend on extensive grazing of native grasslands to feed their animals, due to the low cost (Mireles et al., 2022; Rojas et al., 2024). However, these forage resources are strictly seasonal, and their availability and quality depend on the season of the year, being abundant and of good quality during the rainy season but limited and deficient during the dry season. This situation causes many animals in these herds to remain in poor body condition due to severe nutrient deficiencies; some even die from malnutrition (Castro-Hernández et al., 2017; García-Fuerte et al., 2025). In an effort to find solutions to this problem, some research has recently been conducted on sesame (*Sesamum indicum* L.) forage silage, showing promising nutritional qualities for ruminant feeding (Amorim et al., 2020; Pereira et al., 2021; Alonso et al., 2023). This crop is traditionally grown in some warm regions of the country to produce seed for human consumption (Toledo-Aguilar et al., 2023). This is due to the plant's attributes, such as its ability to adapt to high temperatures and tolerate prolonged periods of drought, as well as its lower nutrient requirements and agronomic management needs (Wei et al., 2022), which could represent an advantage over other conventional forage crops in these types of climates. Although information is limited, some research has reported the productive and chemical characteristics of this forage, focusing on ruminant nutrition, indicating that it provides similar or higher levels of protein and energy than some conventional forages such as corn, alfalfa, oats, sunflower, and millet (Amorim et al., 2019; Tîței et al., 2024). Despite the similarities among these studies, there are variations in some evaluated indicators, such as DM and crude protein (CP) content. These variations can be attributed to environmental conditions and the cutting age of the crop since, according to Capstaff and Miller (2018), the cultivated variety, phenological stage, soil fertilization, agronomic management, and climatic conditions can affect production and nutritional value of most forages. This creates uncertainty regarding the changes that may occur in the productive and nutritional qualities of this forage depending on the phenological stage. According to some research on other forage crops, cutting age affects forage yield, protein concentration, soluble carbohydrates, and fibrous compounds, due to morphological changes in the plants and the presence of seeds or grains (Lyons et al., 2019; Coblentz et al., 2022; Sainz-Ramírez et al., 2020). In the case of sesame, seeds contain a high concentration of oil (Zeinalzadeh-Tabrizi et al., 2025), which can influence the chemical composition of the forage depending on the plant's stage of maturity. This creates the need to define the optimal harvest stage to maximize forage's nutrient yield for inclusion in ruminant rations. Therefore, the objective of this study was to compare the production, chemical composition, and nutritional yield of sesame forage at three harvest ages in the dry tropics of Mexico.

MATERIALS AND METHODS

Description and location of the experiment

The study was carried out under the rainy season, from August to October 2023, in an experimental area of the Faculty of Veterinary Medicine and Zootechnics No. 1 of the Autonomous University of Guerrero (18°20'30" N, 100°39'18" W; 250 m a.s.l.), Mexico. Soil type was sandy loam (sand 77.32%, clay 12.68%, silt 10%), apparent density 1.12 g cm^3, slightly acidic pH 6.2, electrical conductivity 0.05 dS m^{-1} (very low salinity), and moderate organic matter 1.4%. Temperature and rainfall recorded by the Ciudad Altamirano Meteorological Station of the National Meteorological Service during the growing period are shown in Figure 1.

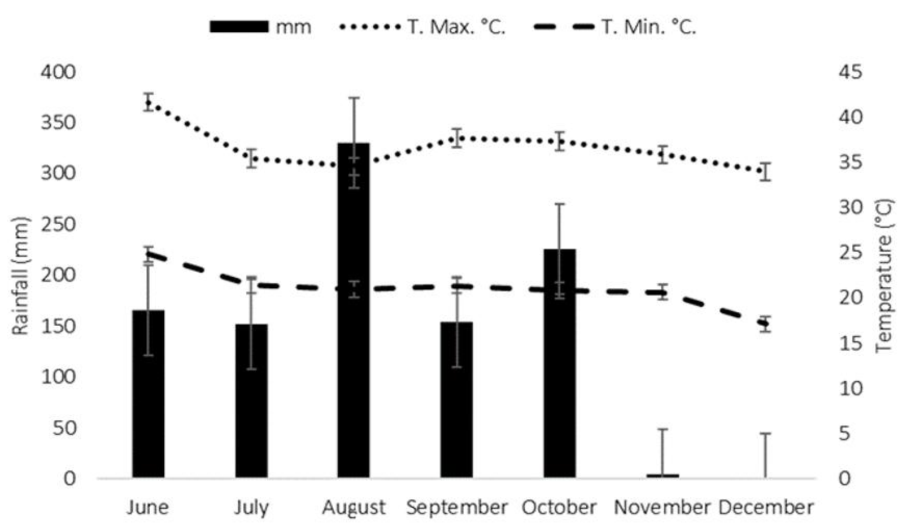

Figure 1. Rainfall, maximum temperature (T. Max.), and minimum temperature (T. Min.) during June to November, including the experimental period (August-October, 2023). Estación: 12019, Ciudad Altamirano, Guerrero, México. Source: CONAGUA (smn.conagua.gob.mx/tools/RESOURCES/Normales_Climatologicas/Mensuales/gro/mes12019.txt).

Crop planting

The cultivation was carried out on an experimental area previously prepared with agricultural machinery by applying a harrow and furrow cycle. Each experimental plot consisted of five 12 m long rows, with 0.75 m between rows. Sesame (*Sesamum indicum* L.) seeds were manually planted using the hill-seeding method with 0.50 m spacing between hills. Seeds were placed in each ridge of the furrow at a depth of 2.0 cm. The cultivar used for this evaluation was Cremoso, commercially known as 'Felicidad TC'. Seeds were previously treated with thiodicarb to prevent damage from ants and soil mites at a dose of 1 L 45 kg^{-1} seed. After sowing, two fertilizer applications were made, the first at 10 d of age with 25 kg ha^{-1} 18-46-00 and 25 kg ha^{-1} 46-00-00 (N-P_2O_5-K_2O), and the second was at 30 d of age with 50 kg ha^{-1} 18-46-00 and 50 kg ha^{-1} 46-00-00 (N-P_2O_5-K_2O), respectively. For post-emergence pest control, a single application of triflumuron was made with 1.25 L ha^{-1} doses, and as a corrective for nutritional deficiencies, a foliar fertilizer formulated with 20-30-10 (N-P_2O_5-K_2O) at a dose of 1 kg ha^{-1} was applied. Both products were applied 25 d after planting, using a 15 L manual sprayer pump. Weed control was achieved by weeding, which was carried out at 15 and 30 d, using a hoe.

Experimental design and treatments

A completely randomized experimental design with three treatments was used. The treatments consisted of forage harvested at 58 (A58), 65 (A65), and 72 (A72) d of age. For productive traits, including number of plants per hill (NP), green forage yield, dry forage yield, and DM, 20 independent samples were randomly collected and evaluated for each harvest age. From these 20 samples, 10 were randomly selected for chemical composition analyses, including organic matter, ash, crude protein, ether extract, neutral detergent fiber, acid detergent fiber, hemicellulose, cellulose, acid detergent lignin, total carbohydrates, non-fibrous carbohydrates, total digestible nutrients, Ca and P.

Forage harvest

The forage was harvested according to the pre-established date for each treatment. All plants belonging to the previously randomly selected clump were cut down. Sampling was made manually with a machete at a height of 10 cm above ground level to reduce contamination with inorganic material. The NP in the obtained sample was immediately counted and subsequently weighed on a digital scale with a precision of 0.01 g to estimate the green forage yield (GFY, kg ha^{-1}). Then, plants were cut to a size of approximately 3 to 5 cm, placed in aluminum trays, and put in a forced-air oven at 55 °C until constant weight was reached to determine the DM content (DM, %). The dry forage yield (DFY, kg ha^{-1}) was calculated as DFY = GFY × (DM/100), where DM is DM concentration (%).

Chemical analysis

To determine chemical composition of the forage, 10 samples per treatment of dry forage were randomly selected and sent to the Animal Nutrition and Biochemistry Laboratory of the Faculty of Veterinary Medicine and Zootechnics of the Universidad Nacional Autónoma de México (UNAM) for the following chemical analyses: DM, crude protein (CP), ether extract (EE), and ash were determined according to AOAC (2019). Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) were determined according to Van Soest et al. (1991). Organic matter (OM) was estimated using the equation OM = DM - ash, total carbohydrates (TC) were estimated using the formula TC = 100 - (CP + EE + ash), non-fiber carbohydrates (NFC) with the equation NFC = 100 - (CP + EE + ash + NDF) according to Sniffen et al. (1992), and total digestible nutrients (TDN) with the equation TDN = 99.39 - 0.7641 × NDF proposed by Capelle et al. (2001). Hemicellulose (HEM) was calculated using the equation HEM = NDF - ADF and cellulose (CEL) was calculated by equation CEL = ADF - ADL. All these chemical elements were expressed in g kg^{-1} DM. Calcium was determined by atomic absorption spectroscopy and P by visible spectrophotometry according to Delgadillo et al. (2015).

Nutrient yield

The yield of organic matter (OMY), crude protein (CPY), ether extract (EEY), neutral detergent fiber (NDFY), total carbohydrates (TCY), total digestible nutrients (TDNY), Ca (CaY), and P (PY) was estimated. Nutrient yield (kg ha^{-1}) was calculated by multiplying DFY (kg ha^{-1}) by the concentration of the corresponding nutrient in the forage (OM, CP, EE, NDF, TC, TDN, Ca, and P) for each harvest age.

Statistical analysis

The ANOVA was performed on the yield and chemical composition variables according to a completely randomized design. The Duncan's test ($p < 0.05$) was used for mean comparisons where necessary. All data were processed using the InfoStat statistical package 2020 (Grupo InfoStat, Facultad de Ciencias Agropecuarias, Universidad Nacional de Córdoba, Argentina).

RESULTS

Forage yield

The green forage yield (GFY), dry forage yield (DFY), or number of plants per hill (NP) showed nonsignificant differences ($p > 0.05$) at the three harvest ages evaluated, unlike moisture and DM, which were significantly affected ($p < 0.0001$) by harvest age (Table 1). Although forage production was similar across the three harvest ages, numerically, harvest age A72 showed the highest GFY, with a difference of 1080 kg ha^{-1} compared to cutting age A58 ($p = 0.8699$). For the DFY, it was also higher in A72, with 864 kg ha^{-1} compared to A58, and 237.87 kg ha^{-1} compared to A65 ($p = 0.0921$). Although the NP per hill was similar ($p = 0.2581$) among the three harvest ages, a numerical difference of 3.39 plants was observed between the first (A58) and last (A72) cuts, indicating a loss of plants as the crop matured; however, this did not impact forage production. On the other hand, moisture content decreased significantly ($p < 0.0001$) with harvest age. The forage humidity from A58 showing 82.86%, and A72 showing 80.12%, indicating a slight loss with plant maturity. This reflects, conversely, an increase in DM depending on harvest age ($p < 0.0001$), with a difference of 2.74% between ages A58 and A72, which benefits forage and nutrient yield at the later cutting age.

Table 1. Sesame forage yield harvest at 58 (A58), 65 (A65), and 72 (A72) d of age. SEM: Standard error of the means. Means followed by different letters on the same line differ by Duncan's test ($p < 0.05$).

Variable	Harvest age			SEM	*P* valor
	A58	A65	A72		
Green forage yield, kg ha^{-1}	23 829.81	24 711.94	24 910.74	1539.22	0.8699
Dry forage yield, kg ha^{-1}	4075.86	4702.12	4939.99	283.01	0.0921
Humidity, %	82.86^a	80.86^b	80.12^c	0.21	< 0.0001
Dry matter, %	17.14^c	19.14^b	19.88^a	0.21	< 0.0001
Number of plants per hill	15.84	14.60	12.45	1.44	0.2581

Chemical composition of forage

The harvest age of the forage significantly affected ($p < 0.05$) several of the chemical compounds evaluated, as shown in Table 2. The DM, organic matter (OM), ether extract (EE), Ca, and P showed higher concentrations in the forage harvested at 72 d (A72), exceeding those of the forage harvested at 58 d (A58), with increases of 27.4, 10.07, 59.93, 1.3, and 0.63 g kg^{-1}, respectively ($p \leq 0.0001$). The Ca had an intermediate value in the A58 forage. The forage harvested at 65 d (A65) showed intermediate contents of these nutrients, except for Ca, which was lower at this harvest age. However, crude protein (CP), non-fiber carbohydrates (NFC), and ash were higher in forage A58 and lower in forage A72, with differences of 6.04, 26.96, and 10.07 g kg^{-1}, respectively ($p \leq 0.0463$). The forage A65 had similar CP to A72 but lower than A58; the NFC was lower than A72 but similar to A58, and ash was intermediate. Regarding the fibrous components, the forage harvested at 72 d showed a significant reduction in total carbohydrates (TC), acid detergent fiber (ADF), and cellulose (CEL) content, with lower levels by 43.83, 30.25, and 32.29 g kg^{-1}, respectively ($p \leq 0.0001$), compared to forage A58, which had the highest content of these compounds. The forage A65 showed intermediate levels for both compounds. The neutral detergent fiber (NDF), hemicellulose (HEM), and acid detergent lignin (ADL) were not affected by cutting age ($p \geq 0.1041$); however, NDF and ADL were numerically lower in A72 and higher in A58; in contrast, HEM was higher in A72 and lower in A58. Finally, TDN also showed nonsignificant differences by harvest age ($p = 0.1041$); however, the forage harvested at 72 d had the highest content, which was 623.33 g kg^{-1}.

Table 2. Chemical composition of sesame forage harvest at 58 (A58), 65 (A65), and 72 (A72) d of age. SEM: Standard error of the mean. Means followed by different letters on the same line differ by Duncan's test ($p < 0.05$).

Nutrients ($g\ kg^{-1}$)	Treatments			SEM	*P* valor
	A58	A65	A72		
DM	171.41^{c}	191.42^{b}	198.81^{a}	2.08	< 0.0001
Organic matter	918.57^{c}	922.18^{b}	928.64^{a}	0.71	< 0.0001
Ash	81.43^{a}	77.82^{b}	71.36^{c}	0.71	< 0.0001
Crude protein	108.21^{a}	102.26^{b}	102.17^{b}	1.92	0.0463
Ether extract	52.88^{c}	78.66^{b}	112.81^{a}	2.37	< 0.0001
Neutral detergent fiber	501.97	488.82	485.11	5.77	0.1041
Acid detergent fiber	407.53^{a}	393.73^{b}	377.28^{c}	4.61	0.0001
Hemicellulose	94.44	95.09	107.83	5.15	0.1261
Cellulose	258.50^{a}	243.84^{b}	226.21^{c}	3.73	< 0.0001
Acid detergent lignin	144.72	142.64	139.46	3.23	0.5156
Total carbohydrates	757.48^{a}	741.27^{b}	713.66^{c}	3.53	< 0.0001
Non-fiber carbohydrates	255.51^{a}	252.45^{a}	228.55^{b}	5.43	0.0014
Total digestible nutrients	610.34	620.40	623.23	4.41	0.1041
Ca	12.28^{b}	11.37^{c}	13.58^{a}	0.25	< 0.0001
P	1.90^{c}	2.22^{b}	2.53^{a}	0.09	0.0001

Nutrient yield

The nutrient yield was significantly affected ($p < 0.05$) by harvest age, as shown in Table 3. Harvest age A72 had the highest yield of all nutrients (OMY, CPY, EEY, TCY, NDFY, TDNY, CaY, and PY) compared to A58 ($p < 0.05$) and was only superior for OMY, EEY, CaY, and PY ($p < 0.05$) compared to A65. Finally, A65 had higher OMY, EEY, TCY, NDFY, TDNY, and PY compared to A58 ($p < 0.05$). Therefore, the highest nutrient yield was observed in the forage harvested at 72 d.

Table 3. Nutrient yield of sesame forage harvested at 58 (A58), 65 (A65), and 72 (A72) days of age. SEM: Standard error of the mean. Means followed by different letters on the same line differ by Duncan's test ($p < 0.05$).

Nutrients ($kg\ ha^{-1}$)	Treatments			SEM	*P* valor
	A58	A65	A72		
Organic matter yield	3743.96^{c}	4278.42^{b}	4587.47^{a}	33.55	< 0.0001
Crude protein yield	441.05^{b}	473.93^{ab}	504.72^{a}	12.85	0.0063
Ether extract yield	215.53^{c}	364.70^{b}	557.28^{a}	16.00	< 0.0001
Total carbohydrates yield	3087.38^{b}	3439.79^{a}	3525.47^{a}	37.842	< 0.0001
Neutral detergent fiber yield	2045.96^{b}	2269.42^{a}	2396.44^{a}	44.67	< 0.0001
Total digestible nutrient yield	2487.68^{c}	2877.13^{b}	3078.74^{a}	33.47	< 0.0001
Ca yield	50.03^{b}	52.79^{b}	67.10^{a}	1.74	< 0.0001
P yield	7.74^{c}	10.28^{b}	12.50^{a}	0.57	< 0.0001

DISCUSSION

Forage yield

In the present study, harvest age did not affect green forage yield (GFY), dry forage yield (DFY), or number of plants per hill (NP) ($p > 0.05$); only moisture and DM were significantly affected ($p < 0.05$), as shown in Table 1. However, numerically, GFY and DFY were higher in the forage harvested at 72 d of age (A72), reaching yields of 24 911 and 4940 kg ha^{-1}, respectively, even though NP was lower than in the forage harvested at earlier ages. Increases in forage yield and DM have been observed in other forage species harvested at different cutting ages, which is consistent with the present research (Mandić et al., 2018; Sainz-Ramírez et al., 2020). However, some studies have demonstrated differences in forage production due to cultivars, plant density, fertilization rates, and environmental conditions present in each crop (Mandić et al., 2018; Coblentz et al., 2022). For example, Garay-Martínez et al. (2021) observed that lines and cutting age influence soybean forage production. Similarly, Zhang et al. (2023) observed differences in oat forage yield, attributed to the genotype and environmental conditions of the crops. In this regard, Lipi and Maniruzzaman (2023) observed that the planting method and plant density influence sesame plant height. Furthermore, Ihsanullah et al. (2023), when evaluating different N doses in sesame crops, observed that the dose affected plant height, number of branches, number of capsules, and seed yield. According to Capstaff and Miller (2018), these agronomic indicators affect forage production, as there is already a positive correlation between plant heights and forage yield in various forage crops. The forage yields in this study are lower than those obtained by Amorim et al. (2019) and Tîței et al. (2024), which is attributed to cultivar, agronomic management, and the specific environmental conditions of the crop. This provides evidence for the possibility of achieving higher sesame forage yields by improving techniques and agronomic management of the crop.

Chemical composition of forage

Most of the forage chemical compounds were affected by the harvest age (Table 2), which can be attributed to the physiological and structural changes present at the cutting stages, such as the leaf-to-stem ratio, flowering, capsules, and seeds. The structural changes are responsible for the chemical differences in other forage species (Coblentz et al., 2022). The lower DM content in forage of 58 d of age (A58) was attributed to the high moisture content of the different plant tissues (leaves, stems, capsules, and seeds), which were still green or immature. In contrast, A72 plants had mature tissues (yellowish) and seeds, exhibiting greater lignification and dehydration, which is consistent with the findings of Pereira et al. (2021), who observed increases of 143.7 to 244.5 g kg^{-1} DM in sesame forages aged 76 and 136 d. However, the cultivar in this study has a shorter cycle, making it impossible to maintain it beyond 85 d, the stage at which it would exhibit a higher DM content. Furthermore, Amorim et al. (2019) obtained 27.9% and 20.6% DM in the same type of forage at the mature stage in 2014 and 2016, respectively, attributing these differences to the climatic variations present in each growing cycle. However, Tîței et al. (2024) reported 22% DM in sesame forage at the flowering stage used for silage production, a content even higher than that of the A72 forage in the present study. These differences are attributed to the cultivar, agronomic management, and climatic conditions (Capstaff and Miller, 2018). The DM is the fundamental element for determining the nutritional quality of forages, especially when they are to be preserved as silage. For this purpose, the DM content of this forage can present problems for producing silage of good fermentative quality, leading to the development of undesirable proteolytic bacteria, which thrive in silages with high moisture content (Kung et al., 2018). However, some management techniques applied to the forage before ensiling, such as partial pre-drying, addition of molasses, and combining it with other forages with lower moisture content, favor the fermentation process and silage quality (Alonso et al., 2023). The organic matter (OM) increased with harvest age (Table 1); however, its estimation depended directly on ash concentration, which, conversely, decreased with plant maturity. This same behavior has been observed in other forage species, which is attributed to a dilution effect due to a higher concentration of fibrous compounds adhering to the stems of mature plants (Coblentz et al., 2022). This partially explains the lower ash concentration in mature plants (A72), although there is also a significant increase in essential ether extract (EE) at this age, due to the high oil concentration in mature seeds (Zeinalzadeh-Tabrizi et al., 2025), which could have contributed to the dilution effect. The OM and ash contents of the present study coincide with the results obtained by Pereira et al. (2021) (OM: 904.7 to 935.9 g kg^{-1}, ash: 95.3 to 64.1 g kg^{-1}) in sesame forage at the flowering and mature stages, respectively. On the other hand, Tîței et al. (2024) recorded slightly higher ash (114 g kg^{-1}) than those obtained in the present study, because the forage they analyzed was harvested at flowering stage, being younger than those evaluated in this research, which results in a lower OM content than that obtained in the present study.

The crude protein (CP) decreased with plant maturity (Table 2); however, the lowest content obtained in forage A72 was 102.81 g kg^{-1}, only 6.04 g kg^{-1} lower than that of forage A58. The values obtained in this study are similar to those observed by Amorim et al. (2020) in mature sesame forage (117.7 g kg^{-1}), but lower than those reported by Tîței et al. (2024) in crops at flowering stage (190 g kg^{-1}). This difference is attributed to the higher proportion of leaves at this stage, which have a higher protein content in young forages (Coblentz et al., 2022; Zhang et al., 2023). The CP in this study is slightly higher than that of forage from some varieties of corn and sorghum, widely used in ruminant feed, primarily in silage form (Lyons et al., 2019; Nazli et al., 2019; Guzmán-Ochoa et al., 2026). According to NASEM (2016), ruminants require 7% to 10% protein in their diet to ensure adequate growth of the microbial population and maintain balanced rumen function. From this perspective, the CP of this forage adequately meets this requirement, which can improve protein levels when integrated in the ruminant diet. The EE showed an increase of 59.93 g kg^{-1} at forage A72, representing a 113.3% increase compared to A58 (Table 2). This is attributed to the high concentration of oil in seeds of mature plant of this oilseed, which can contain 45% to 50% vegetable oil, depending on the variety and climatic conditions during the growing cycle (Wei et al., 2022; Zeinalzadeh-Tabrizi et al., 2025). The EE of forage A72 is similar to that obtained by Amorim et al. (2020) in mature plant forage used for silage (105.4 g kg^{-1}) and much higher than that reported by Pereira et al. (2021), who obtained 11.0 and 41.3 g kg^{-1} in forage harvested at 76 and 136 d of age, respectively. Considering this forage as an alternative in ruminant feed, its high oil content can ensure a high-density energy source, as fats provide 9.4 kcal g^{-1}, which is 2.25 times more than carbohydrates (NASEM, 2016). It can also reduce methane (CH_4) production in the rumen because fats coat fiber particles, limiting their fermentation by cellulolytic bacteria and causing direct toxicity to some methanogenic bacteria (Vargas et al., 2020; Roskam et al., 2025). However, high fat content in diets (> 7%) can have negative effects on ruminal fermentation, depending on the type and quality of fat (Vargas et al., 2020).

The fibrous compounds generally decreased as the plant matured. However, only acid detergent fiber (ADF) and cellulose (CEL) showed a significant reduction, although numerically, neutral detergent fiber (NDF) and acid detergent lignin (ADL) also decreased, while hemicellulose (HEM) increased (Table 2). Some studies conducted with grasses harvested at different phenological stages have also observed reductions or similar concentrations of fibrous compounds (NDF, ADF, HEM, and CEL) as the plant ages, attributing this to a dilution effect among the compounds present in the grains, primarily starch (Lyons et al., 2019; Nazli et al., 2019). This suggests that the fibrous compounds in sesame forage are reduced by a dilution effect, possibly due to the high concentration of oil present in the mature seed, which is reflected in high EE in the A72 forage. When comparing mature sesame forage with conventional forages, Amorim et al. (2019) reported values of 562.4, 369.9, 192.5, 338.5, and 31.4 g kg^{-1} for NDF, ADF, HEM, CEL, and ADL, respectively. The NDF, HEM, and CEL were slightly higher, ADF was similar, and ADL was lower compared to the results of the present study. On the other hand, Tîței et al. (2024) obtained values of 479, 296, 186, 224, and 72 g kg^{-1} for NDF, ADF, HEM, CEL, and ADL in sesame forage at the flowering stage. The NDF and CEL were similar, HEM was higher, and ADF and ADL were lower than the values in the present study. Finally, in another study, Pereira et al. (2021) indicate increases in NDF and ADF as plant age increases, with concentrations of 485.2 to 520 g kg^{-1} and 367.2 to 404.6 g kg^{-1} in forage from plants without capsules and plants with mature seeds, respectively. These differences can be attributed to the specific age of each forage and to the variability in the determination of fibrous compounds (Van Soest et al., 2020). The NDF, ADF, and HEM, particularly at the A72 forage in this research, are slightly lower than those observed in four corn varieties harvested at different stages (Nazli et al., 2019), some sorghum varieties (Guzmán-Ochoa et al., 2026), and mature triticale (Coblentz et al., 2022). According to Ferreira et al. (2022), high concentrations of NDF in diets negatively affect fermentation and passage rate, limiting voluntary feed intake. However, this fiber fraction contains HEM, which is essential for rumen function and the main energy substrate for rumen fermentative bacteria to produce volatile fatty acids (Weimer, 2022). On the other hand, high concentrations of ADF affect the digestibility and efficient energy utilization of forages, since they contain cellulose and lignin, compounds with very low or no digestibility by rumen fibrolytic enzymes. Therefore, high concentrations of CEL and ADL are negatively related to the degradation of fibrous carbohydrates and the efficient utilization of available energy (Ferreira et al., 2022). However, particularly for some legume forages, ADL content does not correlate well with fiber digestibility, suggesting different fermentation patterns in these forage species (Van Soest et al., 2020). This suggests further studies on the degradation of fibrous compounds in this forage for greater accuracy in determining its nutritional value for ruminant feed.

Total digestible nutrients (TDN) were similar at all three cutting ages, averaging 610 g kg^{-1} (Table 2). This value is similar to that estimated by Pereira et al. (2021) (588.4 g kg^{-1}) and slightly higher than that reported by Amorim et al. (2019) (564.1 g kg^{-1}) for mature sesame forage. This difference is attributed to the lower NDF of the forage in this study, which increases the TDN value. Similar values have been reported in corn forages (Nazli et al., 2019), but higher values in sunflower (Sainz-Ramírez et al., 2020).

Total carbohydrates (TC) and non-fiber carbohydrates (NFC) decreased with plant age, being lower in forage A72 (Table 2). This is attributed to the lower concentration of soluble and structural carbohydrates present at this age. These results differ from those of Pereira et al. (2021), who observed increases in TC with plant age (plant without capsules: 726.6 g kg^{-1} and plant with mature seeds: 742.2 g kg^{-1}) and reductions in NFC (plant without capsules: 236.8 g kg^{-1} and plant with mature seeds: 221.8 g kg^{-1}). However, Amorim et al. (2020) reported lower values of NFC in mature plant forage (153.5 g kg^{-1}), indicating a similarity in the content of these carbohydrates with corn forage, thus ensuring adequate lactic acid production to obtain a pH close to 4.0, an indicator of good quality silage (Kung et al., 2018).

The Ca and P increased with plant maturity, which may be associated with a greater accumulation of these minerals in the mature seed of forage A72 (Table 2), as it is rich in both minerals (Wei et al., 2022). Also, the increase in Ca in mature grasses is associated with the lignification process of the stems, where Ca forms part of the structural matrix of the cell wall (Castro-Hernández et al., 2017). The Ca concentrations in this forage are considered higher than those of most warm-climate grasses, which are classified as deficient. However, P concentration is similar to that of grasses (García-Fuerte et al., 2025). According to NASEM (2016), Ca and P requirements for grazing cattle are 0.30% to 0.50% and 0.20% to 0.35% DM, respectively; therefore, prolonged deficiencies of both minerals affect reproductive activity and metabolism in animals. Thus, this forage could reduce the need for supplementation of these minerals.

Nutrient yield

The nutrient yields were higher (p < 0.0001) in the forage harvested at 72 d (Table 3). Organic matter yield (OMY) increased by 850 kg ha^{-1}, due to the higher DM and OM levels in A72. Crude protein yield (CPY) increased by 63.67 kg ha^{-1} in A72, despite having the lowest CP, which is attributed to the higher DFY. Ether extract yield (EEY) was the nutrient that showed the greatest increase at A72, reaching 341.75 kg ha^{-1}, representing 158.56%. This increase is partly due to the influence of the DFY, but primarily to the high EE at this phenological stage, which is attributed to the oil concentration in mature seeds (Zeinalzadeh-Tabrizi et al., 2025). Total carbohydrates yield (TCY) increased by 438.09 kg ha^{-1} in A72, due to the influence of DFY. Neutral detergent fiber yield (NDFY) increased by 350.48 kg ha^{-1} at the last cutting age. For total digestible nutrient yield (TDNY), there was a considerable increase, reaching 591.06 kg ha^{-1} in forage A72 compared to forage A58, despite similar concentrations in the forage at all three cutting ages. The Ca yield (CaY) and P yield (PY) also increased at the last cutting age compared to the first, registering increases of 17.07 and 4.76 kg ha^{-1}, respectively. Nutrient yields across the three harvest ages indicate a significant benefit at cutting age A72, with an increase of approximately 1 t DM. According to CPY of 10 sorghum and one millet variety evaluated by Guzmán-Ochoa et al. (2026), it was lower than that observed at A72, while the NDFY was higher than in the present study. According to the DFY, CP, TDN, and NDF reported for brown midrib sorghums (Lyons et al., 2019) and hybrid maize (Mandić et al., 2018) are lower than those of the present work, except for the EEY, which, although they do not report EE, considering that these forages can have 2.5%, the EEY of sesame forage is considered higher than that of these forages, representing a significant energy production per cultivated area.

CONCLUSIONS

It is concluded that harvest age influences the production and chemical composition of sesame forage. A harvest age of 72 d resulted in the highest forage yield with the best nutritional profile, consequently providing the greatest nutrient yield per cultivated area. When considering this forage as an alternative in ruminant feed, it is necessary to evaluate animal performance to validate its appropriate inclusion in diets.

Author contribution

Conceptualization: J.A-G., E.J.M.M., L.C.G., A.G.P., R.R.H., R.C.H. Methodology design: J.A-G., E.J.M.M., L.C.G., R.R.H. Software: J.A-G., E.J.M.M., R.R.H., R.C.H. Validation: E.J.M.M., L.C.G., R.R.H. Formal analysis: E.J.M.M., L.C.G., R.R.H., R.C.H. Investigation: J.A-G., E.J.M.M., A.G.P., R.C.H., N.D-A., V.G.T. Data curation: J.A-G., A.G.P., N.D-A., V.G.T. Writing-original draft: J.A-G., N.D-A., V.G.T. Writing-review & editing: J.A-G., E.J.M.M., L.C.G., R.R.H., R.C.H. All co-authors reviewed the final version and approved the manuscript before submission.

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References
Alonso, G.J., Mireles, M.E.J., Gutiérrez, S.I., Valencia, A.M.T., Jáuregui, P.I., Cuicas, H.R., et al. 2023. Comparación del pH y la materia seca en tres procesos de ensilaje con forraje de ajonjolí (*Sesamum indicum*) en el trópico seco de México. Archivos Latinoamericanos de Producción Animal 31(1):281-285. doi:10.53588/alpa.310549.

Amorim, D.S., Edvan, R.L., Nascimento, R.R., Bezerra, L.R., Araújo, M.J., Silva, A.L., et al. 2019. Sesame production and composition compared with conventional forages. Chilean Journal of Agricultural Research 79:586-595. doi:10.4067/S0718-58392019000400586.

Amorim, D.S., Edvan, R.L., Nascimento, R.R., Bezerra, L.R., Araújo, M.J., Silva, A.L., et al. 2020. Fermentation profile and nutritional value of sesame silage compared to usual silages. Italian Journal of Animal Science 19(1):230-239. doi:10.1080/1828051X.2020.1724523.

AOAC. 2019. Official methods of analysis. 21th ed. Association of Official Analytical Chemistry (AOAC), Rockville, Maryland, USA.

Capelle, E.R., Valadares, F.S.C., Silva, J.F.C., Cecon, P.R. 2001. Estimativas do valor energetico a partir de caracterısticas quımicas e bromatologicas dos alimentos. Revista Brasileira de Zootecnia 30(6):1837-1856.

Capstaff, N.M., Miller, A.J. 2018. Improving the yield and nutritional quality of forage crops. Frontiers in Plant Science 9:535. doi:10.3389/fpls.2018.00535.

Castro-Hernández, H., Domínguez-Vera, I.A., Morales-Amaráz, E., Huerta-Bravo, M. 2017. Composición química, contenido mineral y digestibilidad *in vitro* de raigrás (*Lolium perenne*) según intervalo de corte y época de crecimiento. Revista Mexicana de Ciencias Pecuarias 8(2):201-210. doi:10.22319/rmcp.v8i2.4445.

Coblentz, W.K., Ottman, M.J., Kieke, B.A. 2022. Effects of harvest date and growth stage on triticale forages in the southwest United States: Agronomic characteristics, nutritive value, energy density, and in vitro disappearance of dry matter and fiber. Journal of Animal Science 100(3):skac021. doi:10.1093/jas/skac021.

Delgadillo, R.L., Bañuelos, V.R., Esparza, I.E.L., Gutiérrez, B.H., Cabral, A.F.J., Muro, R.A. 2015. Nutrient profile evaluation of agave bagasse as alternative feedstuffs for ruminants. Revista Mexicana de Ciencias Agrícolas 6(11):2099-2103. doi:10.29312/remexca.v0i11.778.

Ferreira, G., Galyon, H., Silva-Reis, A.I., Pereyra, A.A., Richardson, E.S., Teets, C.L., et al. 2022. Ruminal fiber degradation kinetics within and among warm-season annual grasses as affected by the brown midrib mutation. Animals 12:2536. doi:10.3390/ani12192536.

Garay-Martínez, J.R., Maldonado-Moreno, N., Ascencio-Luciano, G., Joaquín C.S., Bautista-Martínez, Y., Granados-Rivera, L.D. 2021. Potencial forrajero de líneas experimentales de soya (*Glycine max*). Ecosistemas y Recursos Agropecuarios 8(2):e2932. doi:10.19136/era.a8nII.2932.

García-Fuerte, R.M., Huerta, B.M., Álvares-Rodríguez, J.R., Cortés, D.E., Vallejo, H.L.A., Sosa, P.G. 2025. Mineral diagnosis of grazing beef cows. Revista Mexicana de Ciencias Pecuarias 16(2):236-249. doi:10.22319/rmcp.v16i2.6802.

Guzmán-Ochoa, G., Felipe-Victoriano, M., Lucio-Ruiz, F., Aranda-Lara, U., Joaquín-Cancino, S., Estrada-Drouaillet, B., et al. 2026. Forage yield, nutritional composition, and aerobic stability of silages from sorghum genotypes and pearl millet under warm-subhumid conditions. Chilean Journal of Agricultural Research 86:93-101. doi:10.4067/S0718-58392026000100092.

Ihsanullah, Manzoor, D., Ali, M.M., Ahmed, S.Z., Ali, K.A., Hussain, A.M., et al. 2023. Growth and yield response of sesame to different nitrogen levels. Journal of Arable Crops and Marketing 5(1):27-33. doi:10.33687/jacm.005.01.479.

Kung, J.L., Shaver, R.D., Grant, R.J., Schmidt, R.J. 2018. Silage review: Interpretation of chemical, microbial, and organoleptic components of silages. Journal of Dairy Science 101(5):4020-4033. doi:10.3168/jds.2017-13909.

Lipi, N.J., Maniruzzaman, M. 2023. Effect of planting methods and planting density on growth and yield of sesame in non-saline area of Patuakahali, Bangladesh. Journal of Agroforestry and Environment 16(2):14-18. doi:10.55706/jae.

Lyons, S.E., Ketterings, Q.M., Godwin, G.S., Cherney, D.J., Cherney, J.H., Van Amburgh, M.E., et al. 2019. Optimal harvest timing for brown midrib forage sorghum yield, nutritive value, and ration performance. Journal of Dairy Science 102(8):7134-7149. doi:10.3168/jds.2019-16516.

Mandić, V., Bijelić, Z., Krnjaja, V., Simić, A., Petričević, M., Mićić, N., et al. 2018. Effect of harvesting time on forage yield and quality of maize. Biotechnology in Animal Husbandry 34(3):345-353. doi:10.2298/BAH1803345M.

Mireles, M.E.J., Rodríguez, A.D., Vázquez, J.H., Gutiérrez, S.I., Catalán, R.A., Alonso, G.J., et al. 2022. Productive behavior MEVEZUG lambs in native grasslands during the rainy season, in Tierra Caliente Guerrero, Mexico. Journal Agricultural Science Research 2(2):1-11. doi:10.22533/at.ed.973222201038.

NASEM. 2016. Nutrient requirements of beef cattle. 8th revised edition. National Academies of Sciences, Engineering, and Medicine (NASEM). The National Academies Press, Washington, DC., USA. doi:10.17226/19014.

Nazli, M.H., Halim, R.A., Abdullah, A.M., Hussin, G., Samsudin, A.A. 2019. Potential of four corn varieties at different harvest stages for silage production in Malaysia. Asian-Australasian Journal of Animal Science 32(2):224-232. doi:10.5713/ajas.18.0175.

Pereira, S.R., Santos, N.K., Rodrigues, S.A., Tavares, M.O., Alves, M.M.F., Dias, S.T.P., et al. 2021. Influence of the phenological stage at harvest of sesame (*Sesamum indicum*) on silage quality. Animal Feed Science and Technology 281:115102. doi:10.1016/j.anifeedsci.2021.115102.

Rojas, S.L.A., Albarrán, P.B., Mondragon, A.J., Martínez, G.C.G., García, M.A. 2024. La ganadería doble propósito en el trópico seco: diversidad de unidades de producción y orientación productiva. Tropical and Subtropical Agroecosystems 27:037. doi:10.56369/tsaes.5459.

Roskam, E., Kenny, D.A., Kelly, A.K., Hayes, M., Palevch, N., Maclean, P.H., et al. 2025. Effects of dietary supplementation with linseed oil, *Ascophyllum nodosum* or treated *A. nodosum* on animal performance, gaseous emissions, ruminal fermentation and microbiota, and meat quality in growing dairy-beef Bulls. Journal of Animal Science 103:skaf032. doi:10.1093/jas/skaf032.

Sainz-Ramírez, A., Botana, A., Pereira-Crespo, S., González-González, L., Veiga, M., Resch, R., et al. 2020. Effect of the cutting date and the use of additives on the chemical composition and fermentative quality of sunflower silage. Revista Mexicana de Ciencias Pecuarias 11(3):620-637. doi:10.22319/rmcp.v11i3.5092.

Sniffen, C.J., O'Connor, J.D., Van Soest, P.J., 1992. A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. Journal of Animal Science 70(11):3562-3577. doi:10.2527/1992.70113562x.

Tîței, V., Ababii, A., Andreoiu, A., Blaj, V., Gadibadi, M., Doroftei, V., et al. 2024. The quality indices of fodders from *Sesamum indicum* L. growing under the conditions of Moldova. Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development 24(4):853-860.

Toledo-Aguilar, R., Vásquez-Ortiz, R., Grajales-Solís, M., Arispe-Vázquez, J.L., Noriega-Cantú, D.H. 2023. Manejo agronómico del cultivo de ajonjolí en Guerrero. Folleto Técnico Número 28. 22 p. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Campo Experimental Iguala, Iguala de la Independencia, Guerrero, México.

Van Soest, P.J., Robertson, J.B., Hall, M.B., Barry, M.C. 2020. Klason lignin is a nutritionally heterogeneous fraction unsuitable for the prediction of forage neutral-detergent fibre digestibility in ruminants. British Journal of Nutrition 124(7):693-700. doi:10.1017/S0007114520001713.

Van Soest, P.J., Robertson, J.B., Lewis, B.A. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. Journal of Dairy Science 74(10):3583-3597. doi:10.3168/jds.S0022-0302(91)78551-2.

Vargas, J.E., Andrés, S., López-Ferreras, L., Snelling, T.J., Yáñez-Ruíz, D.R., García-Estrada, C., et al. 2020. Dietary supplemental plant oils reduce methanogenesis from anaerobic microbial fermentation in the rumen. Scientific Reports 10:1613. doi:10.1038/s41598-020-58401-z.

Wei, P., Zhao, F., Wang, Z., Wang, Q., Chai, X., Hou, G., et al. 2022. Sesame (*Sesamum indicum* L.): A comprehensive review of nutritional value, phytochemical composition, health benefits, development of food, and industrial applications. Nutrients 14:4079. doi:10.3390/nu14194079.

Weimer, P.J. 2022. Degradation of cellulose and hemicellulose by ruminal microorganisms. Microorganisms 10:2345. doi:10.3390/microorganisms10122345.

Zeinalzadeh-Tabrizi, H., Pirzad, A., Samadzadeh, F. 2025. Optimizing planting arrangement and density for enhanced oil yield and fatty acid composition in a non-shattering sesame cultivar. Manas Journal of Agriculture Veterinary and Life Sciences 15(1):91-102. doi:10.53518/mjavl.1652581.

Zhang, Y., Yu, K., Yan, H., Ma, L., Zhou, P., Peng, Y. 2023. Effect of harvesting time on forage yield and quality of whole-crop oat in autumn-sown regions of China. Journal of Plant Biology and Crop Research 6(2):1082.