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REGULAR ARTICLES

# Nutritional evaluation and productivity of supplemented sheep grazing in semiarid rangeland of northeastern Brazil

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## Abstract

Sheep production systems in Brazilian caatinga rangelands require supplementation adapted to changes in floristic and chemical composition as dry seasons progress. Meeting sheep nutritional needs in extensive semiarid systems is challenging because of sheep dietary preferences and habits. The objective of this trial was to evaluate the substitutive effect of concentrate supplementation on grazing sheep in the Brazilian caatinga rangeland and its consequences on performance in different seasons. The trial was conducted from March to August 2013 at Embrapa Goat and Sheep in Sobral, Ceará State, Brazil. Thirty-two Brazilian Somali multiparous ewes were submitted to estrus synchronization and controlled breeding. At the start of the trial, ewes averaged 30.45 + 2.60 kg body weight (BW). Ewes were divided into four groups and individually offered 0, 200, 350, or 500 g supplement head$^{-1}$ day$^{-1}$. Intake prediction and digestibility trials were evaluated at three periods: rainy season (April), transition rainy-dry (June), and dry season (August). Sheep weights were taken every 14 days to measure their performance from late gestation until weaning. Ewe BW and body condition score changes were determined too. Lamb BW changes were also measured every 14 days from birth through weaning. A completely randomized design with split plot arrangement using eight replications was used for intake and digestibility measurements. The differences between supplement offered (0, 200, 350, and 500 g sheep-1) and season (rainy, transition rainy-dry, and dry) were submitted to analyses of variance and multiple means were separated, where differences were detected, using the Tukey's test. During lactation up through weaning, ewes supplemented at 500 g day$^{-1}$ had greater BW than ewes without supplement. Ewes supplemented with 200 g concentrate head$^{-1}$ day$^{-1}$ had 9.1% greater ($P \leq 0.05$) BW at weaning and their lambs had 19.7% greater birth and 16.6% heavier wean BW despite lower dry matter intake compared to unsupplemented animals. Supplementation with 200 g concentrate increased carrying capacity by 28.8% during the dry season and by 20.5% during the rainy season. This study confirmed that in the dry season, when quality of rangeland forages decreases, supplementation contributes to greater DMI, improves postpartum and lactation BW recovery of ewes, and contributes to greater lamb birth and wean weights. Moreover, supplementation leads to feed substitution effects that may increase rangeland resilience by mitigating overgrazing. Supplementation with 200 g concentrate can also prevent negative energy balance for grazing animals, improving longer postnatal recovery, longer intervals between parturitions, fewer double and is necessary to ensure a better BW at birth to lambs.

**Keywords** LIPE · Nutrition · Pasture · Semiarid · Sheep · Supplementation

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**Abbreviations**

| | |
|---|---|
| ADF | Acid detergent fiber |
| ADFAD | Acid detergent fiber apparent digestibility |
| ADFI | Acid detergent fiber intake |
| ADIN | Acid detergent insoluble nitrogen |
| ADL | Acid detergent lignin |
| aNDF | Amylase neutral detergent fiber |
| BCS | Body condition scoring |
| BW | Body weight |
| CP | Crude protein |
| CPAD | Crude protein apparent digestibility |
| CPI | Crude protein intake |
| DM | Dry matter |
| DMAD | Dry matter apparent digestibility |
| DMI | Dry matter intake |
| EE | Ether extract |
| IVDMD | In vitro dry matter digestibility |
| LIPE® | External marker consisting of pure and enriched lignin |
| NDIN | Neutral detergent insoluble nitrogen |
| NFC | Nonfiber carbohydrates |
| OM | Organic matter |
| TC | Total carbohydrates |

## Introduction

It is essential to improve sheep husbandry in the rural economy of semiarid regions, where it is one of the few alternatives of livelihood. According to the FAO (2016), Brazil holds the 17th largest sheep herd of the world (17.8 million approximately), of which 57.88% are raised in the northeastern semiarid region. Despite environmental adversity found in similar arid and semiarid regions around the world, sheep husbandry has increased because it is associated with the economic and social development of these areas (Askar et al., 2014). Because vegetation in semiarid ecosystems is more susceptible to degradation, the appropriate management of native vegetation to achieve sustainable animal production becomes indispensable (Araújo Filho, 2013).

During the rainy season, caatinga vegetation growth increases and some herbaceous ephemerals complete their growth cycle in less than a month (Pfister et al., 1983). After the rains, shrub and tree litter becomes the primary sheep diet component (Maciel et al., 2014). As a result of these seasonal changes, forage consumed by sheep may oscillate (Santos et al., 2009) such that nutritive intake will vary throughout the year. In addition, voluntary consumption is influenced by the forage chemical composition as well as changes in sheep nutritional needs (Formiga et al., 2011). Understanding the selective capacity of sheep in caatinga rangeland is essential to adjust supplement offered during strategic periods because the nutritive value of available forage differs from what they actually consume (Araújo Filho, 2013).

Fluctuations in forage nutritive value will influence not only sheep supplement needs but also how that feed changes ingested forage digestibility (El-Shaer, 2010). This interaction between supplement and ingested forage may be even more important during the dry season when the nutritive value of pasture is low (Araújo Filho, 2013). With this work, the objective was to evaluate intake and digestibility of diets, and performance during late gestation to weaning by Brazilian Somali ewes on caatinga rangeland as affected by feed supplement, as well as the subsequent effect on their lambs.

## Material and methods

The trial was conducted from March to August 2013 at the Centro de Convivência com o Semiárido, Fazenda Crioula do Meio, at Embrapa Goat and Sheep in Sobral, Ceará State, Brazil (3° 45′ S, 40° 20′ W, 110 m altitude). The climate according to the Köppen classification is a BSh type, with a January to June rainy period and a July to December dry season. During the trial year, the accumulated precipitation was 693.4 mm and mean annual temperature was 28 °C (22.5 °C min and 34.9 °C max) according to INMET (2014). The vegetation available to sheep in the trial area consisted of a hyperxerophilic caatinga rangeland, with the arboreal canopy thinned to maintain an average 206 trees ha$^{-1}$. To increase the herbaceous mass availability, the rangeland was overseeded with *Panicum maximum* cv. Massai. This management model has been maintained in these areas for about 20 years, as recommended by Araújo Filho (2013), and it was designed to maintain a stable botanical and nutritional composition. The experimental area was divided into paddocks maintained with a minimum 40% ungrazed herbaceous and litter cover. This preserved the botanical biodiversity and ensured optimum carrying capacity by avoiding overgrazing and maintaining herbage allowances as suggested by Araújo Filho (2013). Although the areas have had the same management throughout the year, biomass availability changed with seasons: 3664 kg DM ha$^{-1}$ in the rains, 6348 during the transition, and 1937 for the dry season. Prior to the trial, paddocks were rested from June 2012 until their use in 2013.

Thirty-two Brazilian Somali multiparous ewes were submitted to estrus synchronization and controlled breeding. These were pregnant with single lambs as confirmed by ultrasound at 90 days post-breeding. At the start of the trial, ewes averaged 30.45 ± 2.60 kg BW. Body weight and BCS were recorded fortnightly for all animals, and BCS was always tested by the same handler. The sheep were kept in caatinga paddocks where they had ad libitum access to water and minerals.

Ewes were divided into four groups and individually offered 0, 200, 350, or 500 g supplement head$^{-1}$ day$^{-1}$. Tested supplementation levels were initially defined as control (without supplementation) and maximum amount of concentrate supplement provided in different systems of sheep rearing in the Brazilian semiarid (500 g supplement head$^{-1}$ day$^{-1}$). To define the intervals, considering an average natural matter dietary intake of 3.6% BW (1080 g head$^{-1}$ day$^{-1}$) according to Barbosa et al. (2003), thus 500 g supplement head$^{-1}$ day$^{-1}$ correspond to 46.3% of expected consumption, 350 g supplement head$^{-1}$ day$^{-1}$ correspond to 32.4% of expected consumption, and 200 g supplement head$^{-1}$ day$^{-1}$ correspond to 18.5% of expected consumption (increasing intervals from 13.9% of concentrate inclusion until maximum level of 46.3% of expected total consumption or 500 g supplement head$^{-1}$ day$^{-1}$). Supplement consisted of ground maize (72.4%), soybean meal (6.7%), cotton meal (17.8%), limestone (1.8%) and base minerals (1.3%) on a DM basis. The nutritive value of the supplement and the herbaceous material or litter available in the paddocks is summarized in Table 1.

To avoid excessively rapid ingestion by ewes, supplement was split into two meals: before entering into the rangeland at 7:30 and after returning to the stalls at 16:00. All animals, regardless of supplement, were grazed in the same paddock to avoid variations in caatinga botanical composition but separated into individual stalls during supplementation. The sheep were adapted to this schedule and their respective diets for 21 days prior to data collection.

## Intake and digestibility trials

Intake prediction and digestibility trials were evaluated at three periods: rainy season (April) (61 days), transition rainy-dry (June) (61 days), and dry season (August) (62 days), lasting 184 days of experimental duration. Rangeland dry matter (DM), crude protein (CP), amylase neutral detergent fiber (aNDF), and acid detergent fiber (ADF) were measured during these periods. An external marker of purified and enriched lignin (Saliba et al., 2002) was used to estimate fecal output by feeding 0.25 g LIPE® capsules twice daily to each animal during 5 days for adaptation and 5 days during collection. LIPE® concentrations were determined via infrared proximal spectrophotometry. Fecal output was calculated by the difference in logarithmic spectral bands between $\lambda 1$ (1050 nm) and $\lambda 2$ (1650 nm) (Saliba et al., 2002) according to the formula cited by Prigge et al. (1981):

$$\text{Fecal output} = \frac{\text{g indicator ingested}}{\text{indicator concentration in feces}} \times \text{fecal DM\%at } 105^{\circ}\text{C} \quad (1)$$

Thus, the intake was measured indirectly through fecal output in relation to the inverse of in vitro dry matter digestibility (IVDMD) of the pasture and supplement according to the formula cited by Penning and Jonhson (1983):

$$\text{Intake (kg DM/d)} = \frac{\text{Fecal output}}{1{-}\text{IVDMD}/100} \quad (2)$$

During the collection period, fecal samples were retrieved directly from rectums, stored in plastic bags, identified by animal and date, and frozen. Pasture and supplement samples were also collected. When collection was complete, feces and food samples were thawed, pooled by animal, and pre-dried in a forced-air oven set at 55 °C for 72 h. Samples were then ground through a Wiley mill (Thomas Scientific, Swedesboro, NJ, USA) equipped with a 1-mm screen.

The coefficients of DM, CP, aNDF, and ADF total tract apparent digestibilities (CTTAD) were determined according to the formula cited by Salman et al. (2010):

$$\text{Coefficient of digestibility} = \frac{\text{Nutrient intake}\left(\frac{g}{kg}\text{DM}\right) - \text{Nutrient excreted}\left(\frac{g}{kg}\text{DM}\right)}{\text{Nutrient intake}\left(\frac{g}{kg}\text{DM}\right)} \quad (3)$$

where Nutrient = dry matter (DM), crude protein (CP), amylase neutral detergent fiber (aNDF), and acid detergent fiber (ADF).

Determination of DM (AOAC 934.01), ash (AOAC 942.05), CP obtained by determining total N, using the

**Table 1** Chemical composition (DM expressed as g/kg wet and others nutrients expressed as g/kg DM) and in vitro dry matter disappearance (IVDMD) of supplement and caatinga forage offered to ewes

| Feed | DM | Ash | CP | EE | NDIN | ADIN | aNDF | ADF | ADL | TC | NFC | IVDMD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Supplement | 874 | 60 | 14 | 37 | 1.6 | 0.3 | 220 | 69 | 7 | 763 | 543 | 834 |
| Rainy season[a] | 467 | 92 | 97 | 28 | 2.2 | 1.1 | 607 | 440 | 108 | 783 | 176 | 519 |
| Transition[a] | 293 | 90 | 81 | 26 | 2.9 | 1.7 | 616 | 403 | 73 | 803 | 188 | 540 |
| Dry season[a] | 306 | 74 | 68 | 25 | 3.2 | 2.0 | 711 | 558 | 75 | 833 | 123 | 426 |

[a] Rainy season refers to forage in April, transition to June, and dry season to August, 2013

micro-Kjeldahl technique (AOAC 920.87) and EE (AOAC 920.85), according to AOAC (1990). Heat stable α-amylase was used in the aNDF procedure without the use of sodium sulfite (Van Soest et al., 1991). Acid detergent fiber (ADF) was determined according to AOAC (1990) (AOAC 973.18) and both fiber fractions were expressed inclusive of residual ash (i.e., aNDF, ADF). Lignin was determined by solubilization of cellulose with sulfuric acid as described by Robertson and Van Soest (1981), while total tannin concentrations were determined according to Makkar (2003). In vitro DM disappearances were determined as described by Tilley and Terry (1963). Neutral detergent insoluble nitrogen (NDIN) and acid detergent insoluble nitrogen (ADIN) were determined according to Licitra et al. (1996). Total carbohydrates and nonfiber carbohydrates were determined according Sniffel et al. (1992) and Weiss (1999), respectively.

### Animal performance

Sheep weights were taken every 14 days to measure their performance from late gestation (100 days) until weaning (100 days after the birth of the first lamb). From April to August 2013, ewe body weight (BW) and body condition score changes were determined. Lamb BW changes were also measured every 14 days from birth through weaning. Lambs had access to ewes from 4:30 PM to 7:30 AM of the next day. Starting the second week after birth, lambs had access to caatinga rangeland and supplement feed (38.95% soybean cake, 59.93% milled maize, and 1.12% mineral salt with monensin, DM basis). This supplement consisted of 882 g DM/kg as fed, 245 g CP/kg DM, 141 g aNDF/kg DM, and 891 g IVDMD/kg DM.

### Statistical analyses

A completely randomized design with split plot arrangement using eight replications was used for intake and digestibility measurements. The differences between supplement offered (0, 200, 350, and 500 g sheep$^{-1}$) and seasons (rainy, transition rainy-dry, and dry) were submitted to analyses of variance and multiple means were separated, where differences were detected, using the Tukey's test ($P \leq 0.05$). The following statistical model was used: $Y_{ijk} = \mu + t_i + e_{(i)k} + s_j + ts_{ij} + E_{ijk}$, where $Y_{ijk}$ is the observation of the subplot that received the levels of supplement $i$ ($i = 0, 200, 350$, and 500 g sheep$^{-1}$) of the factor $t$ (levels of supplement) and seasons $j$ ($j$ = rainy, transition rainy-dry, and dry) of the factor $s$ (seasons) in the repetition $r$, $\mu$ the overall mean, $t_i$ the fixed effect of levels of supplement $i$, $e_{(i)k}$ the error associated with the plots, $s_j$ the fixed effect of seasons $j$, $ts_{ij}$ interaction between levels of supplement and seasons, and $E_{ijk}$ the experimental error associated with the subplots. A completely randomized design with four treatments and eight replications was used for ewe and lamb performance. The following statistical model was used for these dependent variables: $Y_{ij} = \mu + t_i + E_{ij}$, where $Y_{ij}$ is the dependent variable, $\mu$ the overall mean, $t_i$ the fixed effect of levels of supplement $i$, and $E_{ij}$ the residual error term. Regression equations were also determined and, those with significant differences ($P \leq 0.05$) and coefficients of determination with $R^2 > 0.50$, discussed. Analyses were undertaken using the ExpDes.pt package of R *Software* (Ferreira et al., 2014). Probability limits for significance were set at $P \leq 0.05$ so no further specification of individual probabilities were included in the "Results" and "Discussion" sections.

## Results

There were no interactions among DM intake and seasons (Table 2) ($P < 0.05$). A linear increase for both was apparent as a result of supplementation during the rainy season and a quadratic behavior during the dry season, indicating that forage quality in the dry season may result in a DMI decrease even with high supplementation.

The substitutive effect of concentrate supplementation on forage intake may allow for an increase in stocking rate in the areas of caatinga to be used, which may avoid undergrazing and overgrazing. Converting consumption values from g per kg$^{0.75}$ animal$^{-1}$ day$^{-1}$ in Table 2 to kg animal$^{-1}$ day$^{-1}$, the following values are obtained: 3.02 kg DM animal$^{-1}$ day$^{-1}$ in the dry season and 3.35 kg during the rainy season for the control animals. For the 200-g animals, the results are 2.35 kg DM animal$^{-1}$ day$^{-1}$ during the dry season and 2.79 for the rainy season. In the rainy season, forage availability was 3664 kg DM ha$^{-1}$ while during the dry season, this decreased by 47% to 1937 kg (adjusted for a minimum 40% ungrazed herbaceous forage and litter). Therefore, the DM intake per animal in the 150-day period (trial period) was 454 kg (dry season) and 503 kg (rainy season) in the control treatment and 352 kg (dry season) and 419 kg (rainy season) for ewes supplemented with 200 g concentrate.

Supplement level did not influence ewe performance up to lambing (Table 3). During lactation up through weaning, ewes supplemented at 500 g day$^{-1}$ had greater BW than ewes without supplement. The supplementation improve lamb BW from birth to weaning, but no differences were observed in lamb BW gain and average daily gain. Regression equations were not valid for any performance parameter.

There were interactions among supplement levels and seasons for DMAD, CP intake, CPAD, aNDF, and ADF intakes, in vivo aNDF disappearance and ADFAD ($P < 0.05$) (Tables 2, 4, and 5). In the case of ewes given 200- and 350-g supplements, CPAD was greater in the rainy compared to the transition season (Table 4).

Ewes without supplement consumed the greatest aNDF during the dry season while those consuming the most

**Table 2** Means and regression equations for DM intake (DMI; grams per metabolic unit; g $kg^{0.75}$) and coefficients of dry matter apparent digestibility (DMAD) of feed consumed by grazing ewes supplemented at four levels during three climatic seasons

| Variables | Supplement (g $head^{-1}$ $day^{-1}$) | | | | Seasons | | | SEM | Supplement × seasons |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | 200 | 350 | 500 | Rainy | Transition | Dry | | *P* values |
| DMI (g $kg^{0.75}$) | 43.5$^{c}$ | 50.7$^{b}$ | 55.8$^{ab}$ | 57.4$^{a}$ | 52.5$^{\beta}$ | 55.2$^{\alpha}$ | 47.9$^{\gamma}$ | 0.8 | ns |

| DMAD | Seasons | Supplement (g $head^{-1}$ $day^{-1}$) SEM = 0.0069 | | | | Supplement × seasons *P* values |
|---|---|---|---|---|---|---|
| | | 0 | 200 | 350 | 500 | < 0.05 |
| | Rainy | 0.55$^{Ad}$ | 0.63$^{Ac}$ | 0.66$^{Ab}$ | 0.69$^{Aa}$ | |
| | Transition | 0.52$^{Bd}$ | 0.61$^{Bc}$ | 0.65$^{Bb}$ | 0.68$^{Ba}$ | |
| | Dry | 0.45$^{Cd}$ | 0.57$^{Cc}$ | 0.63$^{Cb}$ | 0.65$^{Ca}$ | |

| Regression equations[‡] | | | | |
|---|---|---|---|---|
| Variables | Seasons | | $R^2$ | *P* values |
| DMI (g $kg^{0.75}$) | Rainy | $y = 43.68 + 0.033 \times x$ | 0.77 | < 0.001 |
| | Transition | $y = 55.24$ | – | ns |
| | Dry | $y = 38.51 + 0.06 \times x - 0.0001 \times x^2$ | 0.66 | < 0.05 |
| DMAD | Rainy | $y = 0.5052 + 0.00046 \times x - 0.0000004 \times x^2$ | 0.99 | < 0.001 |
| | Transition | $y = 0.5223 + 0.00051 \times x - 0.0000004 \times x^2$ | 0.99 | < 0.001 |
| | Dry | $y = 0.454 + 0.0007 \times x - 0.0000006 \times x^2$ | 0.99 | < 0.001 |

[abcd] Distinct letters in lines for supplement levels, considering DMI, indicate differences according to Tukey's test ($P \leq 0.05$). [αβγ] Distinct greek letters in lines for seasons, considering DMI, indicate differences according to Tukey's test ($P \leq 0.05$). [Aa] Distinct uppercase letters in lines and lowercase letters in columns, considering DMAD, indicate differences according to Tukey's test ($P \leq 0.05$). *SEM*, standard error of the means; *ns*, not significant ($P > 0.05$).
[‡] *y* corresponds to DMI (g $kg^{0.75}$ ) and DMAD, *x* corresponds to supplement level (g $day^{-1}$ )

supplement consumed the least aNDF (Table 5). The greatest ADFI occurred during the dry season for ewes supplemented at 0, 200, and 350 g $day^{-1}$ whereas there were no differences among seasons at the 500-g level. During the dry season, a shift occurred in which ewes in 0- and 200-g treatments digested aNDF to a greater extent than ewes on either 300- or 500-g supplement. During the rainy season, ewes without supplement had greater values of ADFAD compared to those offered 500 g $day^{-1}$ (Table 5). During the dry season, ewes in the 200-g treatment also exhibited greater values compared to those supplemented at greater levels, and a linear regression best explains this relationship.

On the other hand, large quantities of supplement during gestation (corresponding to rainy season) can compromise forage fiber intake, essential for adequate rumen function. In the last third of gestation, ewes can consume from 20 to 35% of their NDF as supplement without negatively affecting overall energy intake. The consumption of aNDF in our study

**Table 3** Ewe and lamb performance (kg) on caatinga rangeland at supplementation levels

| Variables according animals categories evaluated | Supplement (g $head^{-1}$ $day^{-1}$) | | | | SEM | *P* values |
|---|---|---|---|---|---|---|
| | 0 | 200 | 350 | 500 | | |
| Ewes | | | | | | |
| Initial BW | 30.45 | 30.42 | 30.40 | 30.52 | – | ns |
| Late gestation BW | 31.15 | 32.40 | 33.98 | 34.70 | 0.60 | ns |
| Postpartum BW | 28.08 | 29.06 | 30.34 | 31.98 | 0.59 | ns |
| Lactation BW | 25.05$^{b}$ | 27.45$^{ab}$ | 28.52$^{ab}$ | 30.85$^{a}$ | 1.57 | < 0.05 |
| Weaning BW | 24.94$^{b}$ | 27.72$^{ab}$ | 28.58$^{ab}$ | 31.65$^{a}$ | 0.69 | < 0.05 |
| Lambs | | | | | | |
| Birth BW | 2.03$^{b}$ | 2.43$^{a}$ | 2.50$^{a}$ | 2.63$^{a}$ | 0.06 | < 0.05 |
| Weaned BW | 12.78$^{b}$ | 14.90$^{ab}$ | 16.45$^{ab}$ | 16.74$^{a}$ | 0.53 | < 0.05 |
| Weaned lamb BW/ewe BW | 0.510 | 0.543 | 0.577 | 0.543 | 0.07 | ns |
| Lamb BW gain | 10.75 | 12.48 | 13.95 | 14.12 | 0.50 | ns |
| Average daily gain | 0.108 | 0.125 | 0.140 | 0.141 | 0.01 | ns |

[a] Distinct letters in lines indicate differences according to Tukey's test ($P \leq 0.05$). *ns*, not significant ($P > 0.05$); *SEM*, standard error of the means; *BW*, body weight

**Table 4** Crude protein intake (CPI; g day$^{-1}$) and coefficients of crude protein apparent total tract digestibility (CPAD) of feed consumed by ewes grazing caatinga while supplemented at different levels and different seasons

| Variables, SEM, and seasons | Supplement (g head$^{-1}$ day$^{-1}$) 0 | 200 | 350 | 500 | Supplement × seasons *P* values |
|---|---|---|---|---|---|
| CPI (g kg$^{0.75}$); SEM = 0.12 | | | | | |
| Rainy | 6.97$^{Ab}$ | 7.83$^{Aa}$ | 8.17$^{Aa}$ | 8.59$^{Aa}$ | < 0.05 |
| Transition | 6.40$^{Bc}$ | 7.24$^{Bb}$ | 8.04$^{Aab}$ | 8.16$^{Aa}$ | |
| Dry | 4.58$^{Cc}$ | 5.93$^{Cb}$ | 6.90$^{Ba}$ | 7.05$^{Ba}$ | |
| CPAD; SEM = 0.0065 | | | | | Supplement × seasons *P* values |
| Rainy | 0.58$^{Ab}$ | 0.59$^{Aab}$ | 0.61$^{Aab}$ | 0.62$^{Aa}$ | < 0.05 |
| Transition | 0.41$^{Cc}$ | 0.52$^{Bb}$ | 0.56$^{Bab}$ | 0.59$^{Aa}$ | |
| Dry | 0.54$^{Bc}$ | 0.58$^{Ab}$ | 0.62$^{Aa}$ | 0.55$^{Bbc}$ | |
| Regression equations$^{‡}$ | | | | | |
| Variables | Seasons | | | $R^2$ | *P* values |
| CPI (g kg$^{0.75}$) | Rainy | $y = 7.06 + 0.003 \times x$ | | 0.57 | < 0.001 |
| | Transition | $y = 7.46$ | | – | ns |
| | Dry | $y = 4.56 + 0.009 \times x - 0.00002 \times x^2$ | | 0.78 | < 0.05 |
| CPAD | Rainy | $y = 0.60$ | | – | ns |
| | Transition | $y = 0.4113 + 0.00064 \times x - 0.0000006 \times x^2$ | | 0.78 | < 0.05 |
| | Dry | $y = 0.57$ | | – | ns |

$^{Aa}$ Distinct lowercase letters in lines and uppercase in columns indicate differences according to Tukey's test ($P \leq 0.05$). *SEM*, standard error of the mean; *ns*, not significant ($P > 0.05$). ‡ *y* corresponds to CPI and to CPAD, *x* corresponds to supplement level

(Table 5) exceeded those recommendations, reaching almost 78%. The coefficients of digestibility are presented in Table 5.

## Discussion

These results indicate a likely substitutive effect by supplementation over caatinga intake. In general, as supplement level increased, dry matter intake and dry matter digestibility also increased. Crude protein intake decreased as seasons progressed from the rainy to the dry seasons, probably because of the lower quality of caatinga pasture after the herbaceous canopy diminished and probably because shrubs and trees contributed in greater proportion in the composition of the diet ingested by the animals. Besides that, the reduction in rumen space caused by fetal development in late gestation may probably have limited ewe DMI during the rainy season. Moreira et al. (2006) attributed digestibility reduction of ruminant diets selected from caatinga, vis-á-vis purely herbaceous pastures, to the contribution of woody species containing greater secondary metabolites.

Dividing forage availability values by the corresponding intake values (DM per animal in the period of 150 d) results in carrying capacities of 4.3 mature ewes ha$^{-1}$ for the control treatment and 5.5 for those supplemented with 200-g concentrate supplementation during the dry season. Supplementation increased carrying capacity by 28.8%. In the rainy season, the control treatment carrying capacity was 7.3 mature ewes ha$^{-1}$. For ewes supplemented with 200 g of concentrated, carrying capacity was 8.8 ewes ha$^{-1}$, a 20.5% increase. Araújo Filho (2013) reported that in thinned enriched caatinga, carrying capacity can reach 10 mature ewes ha$^{-1}$, a value that was not exceeded with the concentrate supplementation applied in our trial.

During the rainy season, diet selection favored herbaceous canopy compared to the other seasons. As a group, these species tend to have greater digestibility for ruminants compared to grasses or woody species due to lower fiber content, among other factors (Formiga et al., 2011). The general decline in forage nutritive value during the dry compared to the other seasons likely also influenced this selection. Formiga et al. (2011) attributed digestibility reduction of ruminant diets selected from caatinga, vis-á-vis purely herbaceous pastures, to the contribution of woody species containing greater secondary metabolites.

Pfister (1983), who assayed the digestibility of caatinga plants found near Sobral, Ceará Brazil, reported coefficient of digestibility from 0.606 during the rainy season (April) to 0.523 during the dry season (August). Leite et al. (2002) evaluated the effects of caatinga thinning: thinning and fertilization with 100 kg $P_2O_5$ ha$^{-1}$ year$^{-1}$; thinning and overseeding with *Cynodon dactylon*; and thinning, fertilization, and overseeding on protein and energy balances in sheep. They found that coefficient of digestibility changed from 0.57 during the rainy season to 0.38 during the dry season.

**Table 5** Mean neutral detergent fiber (aNDFI) and acid detergent fiber intakes (ADFI) and coefficients of neutral detergent fiber apparent total tract digestibility (aNDFAD) and acid detergent fiber apparent total tract digestibility (ADFAD) of diets selected by ewes grazing caatinga and supplemented at four rates during three seasons

| Variables, SEM, and seasons | | Supplement (g head$^{-1}$ day$^{-1}$) 0 | 200 | 350 | 500 | Supplement × seasons *P* values |
|---|---|---|---|---|---|---|
| aNDFI (g kg$^{0.75}$); SEM = 0.38 | | | | | | |
| Rainy | | 26.08$^{Ba}$ | 25.14$^{Aa}$ | 23.52$^{Aab}$ | 21.47$^{Ab}$ | < 0.05 |
| Transition | | 30.73$^{Aa}$ | 27.15$^{Ab}$ | 25.14$^{Ab}$ | 21.83$^{Ac}$ | |
| Dry | | 27.58$^{Ba}$ | 25.09$^{Aab}$ | 23.71$^{Ab}$ | 19.13$^{Bc}$ | |
| ADFI (g kg$^{0.75}$); SEM = 0.41 | | | | | | Supplement × seasons *P* values |
| Rainy | | 18.90$^{Ba}$ | 16.81$^{Ba}$ | 14.62$^{Bb}$ | 12.11$^{Ac}$ | < 0.05 |
| Transition | | 19.70$^{Ba}$ | 16.18$^{Bb}$ | 14.06$^{Bb}$ | 11.22$^{Ac}$ | |
| Dry | | 24.04$^{Aa}$ | 19.82$^{Ab}$ | 17.18$^{Ac}$ | 12.04$^{Ad}$ | |
| aNDFAD; SEM = 0.0084 | | | | | | Supplement × seasons *P* values |
| Rainy | | 0.58$^{A}$ | 0.59$^{A}$ | 0.56$^{A}$ | 0.56$^{A}$ | < 0.05 |
| Transition | | 0.50$^{Ba}$ | 0.49$^{Ba}$ | 0.51$^{Aa}$ | 0.41$^{Bb}$ | |
| Dry | | 0.49$^{Ba}$ | 0.52$^{Ba}$ | 0.41$^{Bb}$ | 0.40$^{Bb}$ | |
| ADFAD; SEM = 0.0136 | | | | | | Supplement × seasons *P* values |
| Rainy | | 0.59$^{Aa}$ | 0.57$^{Aab}$ | 0.52$^{Aab}$ | 0.50$^{Ab}$ | < 0.05 |
| Transition | | 0.41$^{B}$ | 0.38$^{B}$ | 0.39$^{B}$ | 0.37$^{B}$ | |
| Dry | | 0.56$^{Aa}$ | 0.57$^{Aa}$ | 0.42$^{Bb}$ | 0.34$^{Bb}$ | |
| Regression equations$^{‡}$ | | | | | | |
| Variables | Seasons | | | $R^2$ | | *P* values |
| aNDFI (g kg$^{0.75}$) | Rainy | $y = 24.05$ | | – | | ns |
| | Transition | $y = 26.21$ | | – | | ns |
| | Dry | $y = 28.07 – 0.02 \times x$ | | 0.62 | | < 0.001 |
| ADFI (g kg$^{0.75}$) | Rainy | $y = 19.17 – 0.014 \times x$ | | 0.82 | | < 0.001 |
| | Transition | $y = 19.68 – 0.017 \times x$ | | 0.75 | | < 0.0001 |
| | Dry | $y = 24.38 – 0.02 \times x$ | | 0.84 | | < 0.01 |
| aNDFAD | Rainy | $y = 0.57$ | | – | | ns |
| | Transition | $y = 0.48$ | | – | | ns |
| | Dry | $y = 0.46$ | | – | | ns |
| ADFAD | Rainy | $y = 0.54$ | | – | | ns |
| | Transition | $y = 0.39$ | | – | | ns |
| | Dry | $y = 0.5936 – 0.0005 \times x$ | | 0.53 | | < 0.001 |

[aA] Distinct lowercase letters in lines and uppercase letters in columns indicate differences according to Tukey's test ($P \leq 0.05$). *SEM*, standard error of the means; *ns*, not significant ($P > 0.05$); ‡ *y* corresponds to neutral detergent fiber (aNDF) and to acid detergent fiber intakes, to NDFAD and to ADFAD, *x* corresponds to supplement level

Likewise Askar et al. (2014) in arid regions of Egypt found that supplementation increased overall diet disappearance from 0.706 in the rainy to 0.538 in the dry season.

In paddocks grazed during the transition season, there were greater amounts of herbage biomass which allowed greater sheep diet selectivity (Araújo, 2015). At the beginning of the rainy season, herbage biomass was still developing after a previous water restriction period of at least 8 months. During the transition season, this availability of biomass reached its peak, although nutritional value declined. Dicotyledons and litter contributed more than grass to this increase in herbage biomass. Most of the herbaceous layer consisted of dicotyledonous species, a group with generally greater CP content than grasses, and lower fiber content than woody species (Boufennara et al., 2012). Even if there was less selection for dicotyledons during the transition season (Table 4), their greater availability at least offered greater selectivity for CP intake, especially the *Malvaceae* which can contain greater CP content (Araújo, 2015).

April (rainy season) mean CPI as a relative percentage of DMI (forage and supplement) was 15.03% while August (dry season) was 12.78%, greater than those reported in other trials.

Pimentel et al. (1992), for example, reported daily sheep CPI from thinned caatinga of 115.9 g in April and 68.2 g in October, equivalent to the rainy and dry seasons, respectively, in partially thinned caatinga of Morada Nova, Brazil. Santos et al. (2009), in a caatinga study in Pernambuco, Brazil, reported 17.19% and 10.64% forage CPI during May and November, respectively.

Depending on caatinga CP quantity ingested by sheep, a protein deficit likely occurred since digestibility values were low (Table 5). Quality of caatinga forage CP is limited by the digestibility of that forage despite the fact that CP contents exceeded 100 g kg$^{-1}$ during all seasons (Santos et al. 2009). Pfister (1983) corroborated this by stating that CP voluntary intake by sheep on caatinga is a more dependable predictor of production than CP content because of plant secondary compounds that inhibit CP availability in the rumen. Lignin is another limiting factor in caatinga forage nutritive value according to Araújo Filho (2013). These authors pointed out that not only does CP and acid detergent insoluble N concentration decline from the rainy to the dry season in caatinga but NDF, ADF, and ADL contents also increase.

It is not our intent to indicate a specific supplement quantity that should be given to ewes grazing caatinga. To measure the effect of concentrate supplementation on sheep under partially thinned caatinga overseeded with Massai Grass is the main innovation of this research. This grass is tolerant of water stress and has adapted to shading areas of thinned caatinga, contributing to the increase in biomass production available to livestock production.

Although the vegetation in the experimental paddocks was thinned over 20 years ago, it was rested the year (2012) prior to the trial; despite this rest, supplementation allowed herbage biomass increases that expanded flock productivity potential. A supplement regimen adjusted to herbage biomass in enriched caatinga is an innovative strategy for ensuring ewe nutritional requirements without losing sight of the conservation and sustainability of caatinga rangelands.

Leite et al. (2002) found that despite improvement in available energy with caatinga vegetation manipulation, including fertilization and overseeding, digestible energy consumption is nearly always below that required by gestating or lactating ewes. Within this context, reproduction and health are important issues that can be correlated to nutrition. In the last weeks of pregnancy, sheep require increased supply of nutrients in less volume of food due to the reduction of abdominal space. Dietary adjustments, especially with the inclusion of higher energy density feed, can mitigate this limitation. Concentrate supplementation can also prevent metabolic disorders such as ketosis. Furthermore, malnourished ewes have longer postnatal recovery, longer intervals between parturitions, fewer double parturitions, among other problems. Ewes at the end of pregnancy suffering severe and abrupt nutritional restrictions have decreased fetal growth rate by up to 40% (Leite et al., 2002). If the restriction continues for more than 2 week at this stage, the losses can be even greater.

As rainfall decreases in semiarid rangeland, Santana et al. (2011) reported trends for decreased CPAD and DMAD as a result of decreasing forage CP content compounded by increasing NDF and ADL. We corroborated this trend although our apparent digestibility values were superior to those cited for other rangeland studies.

The decline in diet nutritive values as the dry season progresses can be attributed to changes in botanical composition as well as the nutritive value of those plants already present in the rainy and transition seasons (Santos et al., 2009). The latter can be a result of progressive herbage removal by animals as well as simple ontogeny and senescence of ephemeral species. Although supplementation should in most cases increase diet digestibility, some nutrient components such as fiber and, consequently overall digestibility, may decline along with intake, depending on level of supplement (Alves et al., 2011). In our trial, as supplement increased, it substituted more forage in the diet and decreased the forage:supplement ratio. Besides lowering fiber of forage origin in the diet, supplement can also affect passage rate in the rumen (Alves et al., 2011).

During early lactation, it is common for nutrient intake to be lower than ewe nutritional needs, which results in a negative energy balance for grazing animals. Supplementation can mitigate this deficit. When no supplement is offered, BW recovery is a challenge for grazing animals with potential negative effects on future performance. In our study, ewes supplemented with 500 g day$^{-1}$ recovered to their initial BW by weaning time. From this, we can deduce that supplement made up for any energy imbalance during lactation, improving their chances of initiating breeding season sooner. Even though ewes receiving no supplement did not lose BW during late gestation, a nutritional deficit was evident during lactation because those receiving 500-g supplement had greater BW than those receiving no supplement. Further evidence of inadequate nutrition during gestation was expressed in low lamb birth weight from ewes without supplement compared to those from ewes receiving 200 to 500 g of supplement. This may indicate that a minimum 200 g day$^{-1}$ of supplement to ewes is necessary to ensure a better body weight at birth to lambs.

Magalhães et al. (2010), in a review of Brazilian Somali lamb birth weight studies, reported a 2.35 kg mean, similar to what we recorded. The authors also pointed out that lamb production efficiency is strongly influenced by birth weight. Greater wean weights can result in precocious productivity, especially in females. Greater birth weights can reduce the negative effects of later nutritional deficits by as much as 30% in late gestation ewes (Gerassev et al., 2006; Reed et al., 2014). Despite an evident nutritional deficiency in ewes receiving no supplement in our study, they were able to wean lambs weighing over 50% of ewe BW.

In summary, caatinga pasture is the most important forage source used by farmers of semiarid lands in Brazil to feed their livestock, thus, has a socioeconomical importance to sheep breeders in this and similar regions throughout the globe. In dry season, when quality of these pastures decreases, supplementation is necessary to ensure better animal performance. Our study indicates that supplementation can contribute to greater DMI which in turn improved postpartum and lactation BW recovery of ewes and greater lamb birth and wean weights. Especially in relation to the greater lamb birth, supplementation of at least 200 g sheep$^{-1}$ day$^{-1}$ would be indicated. It is worth mentioning that this supplementation seems to be more necessary in the transition and dry periods. In contrast, they contribute to substitution effects that may increase rangeland resilience by avoiding overgrazing in these semiarid rangelands dominated by woody species. It is reiterated that it is not our intention to indicate a specific supplement quantity which should be given to ewes grazing caatinga. Economic feasibility studies are still needed to evaluate the supplementation of ewes in production created in the caatinga for long periods.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that there is no conflict of interest.

**Ethical approval** All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. The experimental protocol was approved by the Animal Ethics Committee at Embrapa Goats and Sheep, Sobral – CE, Brazil, registered with the number 01/2013.

**Informed consent** The authors declare to the proper purposes that the experiments comply with the current laws of Brazil, where they were performed. Informed consent was obtained from all individual participants included in the study.

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