Babassu mesocarp flour in diet of finishing lambs

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ABSTRACT
Twenty crossbred lambs (21.6 ± 3.5 kg BW) were used in a completely randomised design to determine the effects of babassu mesocarp flour (BMF) on performance and ingestive behaviour. The treatments were defined by the increase in concentrations (0, 10, 20 or 30%, in DM basis) of BMF in the diet. When significant treatments effects were found, orthogonal polynomials for treatment responses were determined by linear and quadratic responses (p < .05). To determine the in situ ruminal degradability of the diets used in performance trial, one rumen-fistulated Santa Ines male sheep (63 kg BW) was used in a completely randomised design in a split splot arrangement with three replications (three periods of incubation) in times 3, 6, 24 and 72 h. Data from potential degradability (PD), dry matter (DM) and crude protein (CP) degradability for diets and the incubation time were compared by t-test (p < .05). Negative quadratic effect was observed upon nutrients intake, except for neutral detergent fiber (NDF) intake. The average daily gain, body condition score, feeding efficiency of DM and time spent in feeding decreased linearly with BMF addition. The BMF decreased the soluble fraction (a) potentially degradable fraction (b) PD, effective degradability of DM and CP and the NDF degradability. The addition of BMF in diets of sheep had negative effects on performance, feed efficiency of DM and degradability of DM, CP and NDF. However, the BMF can be used in diets, during the conventional grains off-season, at concentration up to 10.5% as alternative feed.

HIGHLIGHTS
- The mesocarp produced from industrialization of the babassu coconut has a great content of fiber and lignin.
- The great content of fiber associated to decrease in degradation of fiber and potential degradability in DM and CP reduced the performance of lambs.
- Although the reduction of the performance, BMF can partially replace the corn in diets of lambs in periods that the price of this ingredient is great.

Introduction
Sheep meat production has increased in Brazil, mainly because of its great productive potential and shorter finishing period compared to other ruminant animals (Neta et al. 2017), which resulted in increased use of the feedlot system. Thus, the use of a larger quantity of concentrate to meet their nutritional requirements and reach the slaughter weight in a short period of time has been adopted, increasing the cost of production and the risks of metabolic disorders, caused in most of time, by improper feeding management (Ørskov 1986). Therefore, it is necessary to use dietary ingredients that reduce these risks.

Babassu (Attalea speciosa Mart ex) is a palm tree (up to 20m high), native to the northern and northeast states of Brazil, found between Cerrado and Amazon forest (Albiero et al. 2011). Normally, there are 15 to 25 bunches of fruits (coconut) per tree in natural habitat (Teixeira 2007). The coconut of the babassu comprises epicarp, mesocarp, endocarp and kernel each accounting for 11, 23, 59 and 7% of the total mass, respectively (Soler et al. 2007).
mesocarp produced from industrialization of the babassu coconut for edible oil production, besides the potential for the pharmaceutical industry (Nonato et al. 2013), has been used to produce the babassu mesocarp flour (BMF) with application in human food (Gaitan et al. 1994) and animal feed. (Silva et al. 2012; Santana et al. 2014; Sá et al. 2016).

The babassu mesocarp flour is available throughout the year, thus making it an important alternative for producers due the significant starch content of the mesocarp, can be used as an energy source for ruminants (Sá et al. 2015), during the conventional grains off-season, period that the price of them may be 10 to 30% greater. However, after mesocarp extraction, the flour may contain small amounts of epicarp and endocarp, resulting in a BMF with greater fiber content and low starch content. So, due to the great availability in the region, the marketing price is low, usually 50% of the corn grain. On the basis of these facts, the objectives of this study were to assess the performance, ingestive behaviour, and in situ degradability in lambs fed increasing concentration of BMF in the diet, dry matter (DM) basis.

**Material and methods**

**Ethics considerations**

This research protocol and animal care followed the guidelines recommended in the Guide for the Care and Use of Agricultural Research and Teaching (FASS 1999). The protocol was approved by the Committee on the Ethics of Animal Experimentation, Universidade Federal do Maranhão, Brazil (Number process: 23115. 005228/2015-99).

**Performance and feed behaviour trial**

**Animals and housing**

This study was conducted in the Small Ruminant Sector of Universidade Federal do Maranhão, located in Chapadinha, Maranhão, Brazil (03°44’33” S, 43°21’21” W). For the performance trial, twenty Santa Inês × Dorper crossbred male lambs, with an initial average body weight (BW) of 21.6 ± 3.5 kg and 135 ± 12 days old, were used. The animals were housed in covered pens (one animal/pen) with concrete floor and dimensions of 1.3 m × 3.5 m for 50 days. All lambs were dewormed with 10 g/kg moxidectin (Cydectin, Fort Dodge Animal Health, Campinas, SP, Brazil) at a dose of 1 ml/50 kg of body weight before the start of the experiment.

| Ingredients | Babassu mesocarp flour (%) | 0 | 10 | 20 | 30 |
|-------------|---------------------------|---|----|----|----|
| Tifton-85 hay | 30.0 | 30.0 | 30.0 | 30.0 |
| Corn | 43.5 | 34.9 | 25.7 | 18.2 |
| Soybean Meal | 8.1 | 9.9 | 12.7 | 14.6 |
| Urea | 1.3 | 1.3 | 1.3 | 1.3 |
| Limestone | 0.8 | 0.8 | 0.8 | 0.8 |
| Mineral Premixb | 1.3 | 1.3 | 1.3 | 1.3 |
| Babassu mesocarp flour | 0.0 | 10.0 | 20.0 | 30.0 |
| Wheat bran | 14.9 | 11.8 | 7.9 | 3.5 |

**Experimental design and treatments**

All animals were assigned to a completely randomised design with four treatments and five animals per treatment.

The treatments were defined by the increasing concentrations of BMF (Florestas Brasileiras S.A., Itapecuru Mirim, Maranhão, Brazil), with basis in dry matter (DM) of the diet. The treatments were as follows: control diet, without BMF (CONT); inclusion of 10% BMF (10 BMF); 20% BMF (20 BMF) or 30% BMF (30 BMF), formulated according to the National Research Council (NRC 2007), for sheep with a daily average gain of 200 g (Tables 1).

**Feeding management and data collection**

The feedlot period lasted for 64 days. The first 10 days were to adapt to the animals to the experimental pens and diets. The feedlot for performance and behaviour trial consisted in 50 days. After this, lambs stayed more four days in the installations for ultrasound measurements. Experimental diets were fed as total mixed rations every other day at 0800 h, and animals were allowed ad libitum access to feed and fresh water.

Hay was coarsely chopped to reduce the animal diet selection and feed wastage. Corn also was coarsely grounded using a grinder (Nogueira® DPM – 4, Itapira, Brazil) and then, mixed with soybean meal, wheat bran,
urea, limestone, and mineral premix. The concentrate and Tifton 85 hay were separately weighed using an electronic scale (Marte®, LC 100, São Paulo, SP, Brazil), then mixed and offered to the animals.

Each day, the feed was weighed on a five gram precision electronic scale and offered ad libitum. Amounts of total mixed ration fed to animals were calculated according to previous day’s animal intake, and adjustments were made when needed so that refused feed did not exceed 10% of daily intake. Orts (10% of the total weighted) and feed were recorded every week and frozen at −20°C for later analysis. To determine the average daily gain (ADG) and feed efficiency (FE, g of BW gain/g of feed), the animals were weighed after a 14 h fast on days 0, 28 and 50 of the experimental period, and the calculations were made considering two subperiods, considering the interval between days 0 to 28 (subperiod 1) and 29 to 50 (subperiod 2).

Feeding behaviour
Feeding behaviour (eating, rumination or idle) of the lambs was monitored on the 46th day of the experiment, with visual observations made every 5 min for 24 h (Johnson and Combs 1991). Total time (in min) spent on each activity was quantified by multiplying the total number of observations for that activity by five. The feed and rumination efficiencies, expressed as g DM h⁻¹, were obtained by dividing the average daily intake of DM by the total time spent eating and ruminating in 24 h, respectively.

Ultrasound measurements
After the experimental period, on 54th day of the feedlot, body condition score, ribeye area, and subcutaneous fat thickness were evaluated. Two previously trained examiners evaluated the body condition score, performing a visual and tactile examination of the lower back and the lamb’s tail (scored between 1 and 5, graduated every 0.5 points). The measures of ribeye area and subcutaneous fat thickness were estimated with ultrasound assistance, according to the methodology described by Silva et al. (2006).

Chemical composition and calculations
After the end of the trial, samples of diets and orts were thawed and pooled by diet and sub-period. Then, two samples of each diet and orts were ground through a 1.0-mm Wiley Mill screen (Marconi, Piracicaba, Brazil) for subsequent laboratory analyses according to the method of the Association of Official Analytical Chemists (AOAC 2012) for dry matter (DM; Method 930.15), ash (Method 942.05), ether extract (EE; Method 954.05), and nitrogen (Method 968.06). Crude protein (CP) was obtained by multiplying the total N content by 6.25. Neutral detergent fiber corrected for ash and protein (apNDF) was determined according to Van Soest et al. (1991), using heat-stable alpha-amylase and sodium sulfite, and acid detergent fiber (apADF), corrected for ash and protein, determined according to the method 973.18 of AOAC (2012). Organic matter (OM) was determined by difference between DM and ash. Non-fibrous carbohydrates (NFC) were estimated according to the equation:

\[
NFC = 100 - (NDF + CP + EE + Ash)
\]

(1)

The total digestible nutrients (TDN) were calculated according to Weiss et al. (1992):

\[
TDN = CP_{digested} + (EE_{digested} \times 2.25)
\]

(2)

The data used to calculate dietary TDN were obtained from Gerude Neto et al. (2016) in a metabolism trial with the same diets and animals used in this performance trial. The ME values for each diet were based on the assumption that 1 kg of TDN is equal to 4.409 Mcal of digestible energy (DE) and 1 Mcal of DE is equal to 0.82 Mcal of ME (NRC 2007).

For better characterization of BMF and due to the great variability in its composition, the contents of starch, lignin, total tannins and condensed tannins were determined. The Starch content of BMF was measured using the glucogenic assay, as described by Herrera-Saldana and Huber (1989) and Van Soest et al. (1963). The lignin fraction was extract with 72% sulfuric acid (Van Soest and Wine 1967). The total tannin were determined by the Folin–Ciocalteu method (Xu and Chang 2009), and the condensed tannin was determined by the method of Broadhurst and Jones (1978), adapted by Agostini–Costa et al. (1999).

Ruminal degradation parameters
For in situ degradation, one castrated male sheep of 63 kg BW, with ruminal cannula, was used in completely randomised design in a split-plot arrangement with three replications. The same treatments of performance trial were evaluated, representing the plots (diets with 0, 10, 20 or 30% of BMF) in the ruminal incubation times 3, 6, 24 and 72 h. The replications consisted in three times of incubation in the same animal (representing three experimental periods).
A nylon bag method (AFRC 1993) was used to determine the DM, CP, and NDF degradability of the experimental diets by suspending the bags in the rumen (Tomich and Sampaio, 2004). The sheep was fed a diet formulated according to NRC (2007), containing BMF in the ratio of 30:70 of forage:concentrate (DM basis) at 8:00 and 16:00 h, and had free access to water. Sheep were adapted to the diet for 10 days.

After the adaptation period, samples of experimental diets were ground through a 2.0 mm diameter and pre-loaded into nylon bags of 8 x 12 cm, with pore size of 50-μm, containing 4 g DM, according to the methodology adopted by Alves et al. (2007), incubated in the rumen for 3, 6, 24, and 72 h, according to Sampaio (1988), for three periods of incubation. For the various incubation times, bags were inserted progressively, and all were removed at the same time. After withdrawing the bags from the rumen, they were washed using cold water to stop the fermentative process. The readily water-soluble fraction (time 0) was determined by immersing the bags containing equivalent samples to those used in the rumen incubation, into a hot-water bath at 39 °C for 1 h (Makkar 1999) and then, together with the bags from the remaining incubation times, they were washed in a washing machine until the water turned clear. The bags were then pre-dried in a forced-air oven at 55 °C for 48 h for subsequent analysis of the DM (AOAC 19968.06), and NDF (Van Soest et al.1991).

The in situ degradation parameters (a, b and c) and the potential degradability (PD) of DM and CP were calculated following the interactive method of Gauss–Newton, employing the NLIN procedure of SAS (Statistical Analysis System, version 9.2.), using the model proposed by Ørskov and McDonald (1979):

$$PD = A + B \times (1 - e^{-c})$$

(3)

where, PD = actual percentage of degraded nutrient after t hours of incubation in the rumen; A = soluble fraction (%), B = potentially degradable insoluble fraction (%), c = degradation rate constant of fraction “B”, and t = incubation time in h.

The effective degradability (ED) of the DM and CP in the rumen was estimated using the equation proposed by Ørskov and McDonald (1979):

$$ED = a + \left[ (a.b)/(c + k) \right]$$

(4)

where, ED = effective degradation; a = rapidly degraded soluble fraction; b = slowly degraded insoluble fraction; c = fractional rate of degradation of b; k = rate of passage of solids 5 and 8% per hour, as suggested by AFRC (1993).

The NDF degradability was estimated using the model of Mertens and Loften (1980):

$$Rt = B.e^{-k(t-L)} + I$$

(5)

where, R = residue at time t; B = digestible fraction; k = digestion rate constant; L = lag time; and I = indigestible fraction.

After adjusting the NDF degradation equation, we proceeded to the standardization of fractions, as proposed by Waldo et al. (1972), using the equations:

$$BP = B/(B + I) \times 100$$

$$I = I/(1+B) \times 100$$

(6) (7)

where, BP = standardised potentially degradable fraction (%); I = standardised undegradable fraction (%), and B and I = as previously defined.

**Statistical analysis**

The intake of nutrients, ADG and FE were analysed as a repeat measures using the MIXED procedure of the SAS (Statistical Analysis System, version 9.2.), considering the fixed effect of diets (D), subperiod (P) and the interaction (D × P), and the random effect of lambs and residual error. The covariance matrix that best fit the data set was “autoregressive” (AR 1) and was selected using both Akaike corrected and Bayesian information fit criteria after adjusting models with the Autoregressive (1) (AR 1), Heterogeneous AR (1) (ARH 1), Ante-Dependence (ANTE), Compound Symmetry (CS), Heterogeneous CS (CSH), and Unstructured (UN) covariance. The ultrasound measurements and feeding behaviour data were analysed, considering the fixed effect of diets and random effects of lambs and residual error. The means were obtained using the LSMEANS command. The Shapiro–Wilk normality test was used to check the homogeneity of variances. When significant treatments effects were found, orthogonal polynomials for treatment were determined by linear and quadratic responses to increasing concentrations of BMF addition. Significance was considered at p ≤ .05.

Data from PD of DM and CP for diets and the incubation time were analysed as a repeat measures using the MIXED procedure of the SAS (Statistical Analysis System, version 9.2.), considering the fixed effect of diets (D), times of incubation (T) and the interaction (D × T), and the random effect of period of incubation (replications) and residual error. The covariance matrix that best fit the data set were “compound symmetry” (CS) and “autoregressive” (AR 1) for PD of DM and CP, respectively and also were selected using both Akaike corrected and Bayesian information fit criteria. When significant treatments effects were found, orthogonal
polynomials for treatment were determined by linear and quadratic responses to increase the concentrations of BMF addition. Significance was considered at $p \leq 0.05$.

**Results**

**Performance, ultrasound measurements and ingestive behaviour**

The great content of NDF, ADF and lignin in BMF (Table 2) resulted in a negative quadratic effect ($p < 0.05$) on intake of dry matter, organic matter, crude protein, ether extract, total carbohydrates and non-fiber carbohydrate (Table 3). However, the NDF intake did not differ ($p > 0.05$) with BMF addition. There was a time of-observation effect ($p < 0.05$) for all nutrient intake, with greater intakes recorded at second period (days 29 to 50 of the trial) likely because of the greater BW of lambs in the second period compared with first period (days 0 to 28 of the trial; $24.0 \pm 3.8$ kg vs. $27.8 \pm 4.6$ kg, respectively). However, a diet $\times$ period interaction was not observed.

The increasing concentration of BMF in the diet decreased linearly ($p < 0.05$) the final body weight (BW), average gain daily (ADG) and body condition score (BCS) (Table 4), decreasing in 0.156 kg, 2.760 g.d$^{-1}$ and 0.03, respectively, of each 1.0% of increase BMF in the diet. The addition of BMF at concentration up to 10.5% to effectively enhance dry matter intake (1172.5 g.d$^{-1}$) with lower effects on average daily gain (163.3 g.d$^{-1}$). The gain:feed (G:F) ratio, fat thickness and ribeye area were not affected ($p > 0.05$) by experimental diets. Therefore, there was not effect ($p > 0.05$) of period and a diet $\times$ time interaction on ADG and G:F ratio.

The BMF addition did not change ($p > 0.05$) the time spent in rumination and the time spent in idle with mean value of 545.45 min d$^{-1}$ and 666 min d$^{-1}$, respectively. However, the time spent in feeding increased linearly ($p < 0.05$), with increasing BMF in the diet (Table 5).

There was a linear decreased ($p < 0.05$) in feeding efficiency of DM. However, the feeding efficiency of NDF and rumination efficiency of DM and NDF were not affected ($p > 0.05$) by experimental diets.

**Ruminal degradation parameters**

The soluble fraction ($a$ fraction) and potentially degradable fraction ($b$ fraction) of DM and CP reduced ($p < 0.05$) with BMF addition, consequently there was observed a linear and quadratic effects for PD of DM and CP, respectively. Already the rate of degradation of the

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**Table 2. Chemical composition of babassu mesocarp flour (% DM).**

| Chemical composition       | Babassu mesocarp flour |
|----------------------------|------------------------|
| Dry matter                 | 89.9                   |
| Organic matter             | 92.7                   |
| Crude protein              | 4.0                    |
| Ether extract              | 0.9                    |
| Neutral detergent fibre, corrected for ash and protein | 52.7 |
| Acid detergent fibre, corrected for ash and protein | 45.0 |
| Non fibrous carbohydrate, | 35.1                   |
| Total carbohydrate         | 87.8                   |
| Starch                     | 30.4                   |
| Total tanin (equivalent grams of tannic acid kg$^{-1}$ of dry matter) | 12.5 |
| Condensed tanin (equivalent grams of leucocyanidin kg$^{-1}$ of dry matter) | 6.5 |

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**Table 3. Nutrients intake of lambs fed increasing concentrations of babassu mesocarp flour.**

| Intake, g.d$^{-1}$ | Babassu mesocarp flour (%) | SEM$^b$ | $p$-value$^c$ |
|--------------------|-----------------------------|---------|--------------|
|                    | 0 | 10 | 20 | 30 | D | P | D $\times$ P | L | Q |
| Dry matter$^a$     | 1057.6 | 1172.6 | 1068.4 | 746.2 | 38.30 | 0.01 | <0.01 | 0.18 | 0.01 | 0.01 |
| Organic matter$^a$ | 1074.5 | 1182.3 | 1100.7 | 778.9 | 37.91 | 0.01 | <0.01 | 0.15 | 0.02 | 0.02 |
| Crude protein$^a$  | 204.9 | 233.1 | 216.2 | 154.0 | 7.28 | 0.01 | <0.01 | 0.09 | 0.02 | 0.01 |
| Ether extract$^a$  | 14.7 | 19.6 | 16.3 | 10.9 | 0.67 | <0.01 | <0.01 | 0.06 | <0.01 | <0.01 |
| NDF$^a$            | 326.0 | 425.3 | 434.5 | 337.6 | 14.52 | 0.01 | <0.01 | 0.06 | 0.77 | 0.01 |
| TC$^a$             | 918.6 | 1000.2 | 917.9 | 654.2 | 32.54 | 0.01 | <0.01 | 0.20 | 0.01 | 0.02 |
| NFC$^a$            | 592.6 | 580.9 | 483.0 | 316.8 | 21.82 | <0.01 | <0.01 | 0.06 | <0.01 | 0.04 |
| Intake, % of BW.d$^{-1}$ | 4.0 | 4.4 | 4.1 | 3.1 | 0.10 | <0.01 | 0.25 | 0.56 | <0.01 | <0.01 |
| NDF$^a$            | 1.2 | 1.6 | 1.7 | 1.4 | 0.03 | <0.01 | 0.69 | 0.92 | 0.09 | 0.02 |

$^a$NDF: Neutral detergent fibre; TC: Total carbohydrate; NFC: Non-fibrous carbohydrate; SEM: Standard error mean.

$^b$D: effect of diet; P: effect of sub-period in feedlot; D $\times$ P: interaction of Diet $\times$ Sub-period; L: Linear effect; Q: Quadratic effect.

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Polynomials for treatment were determined by linear and quadratic responses to increase the concentrations of BMF addition. Significance was considered at $p \leq 0.05$. The great content of NDF, ADF and lignin in BMF (Table 2) resulted in a negative quadratic effect ($p < 0.05$) on intake of dry matter, organic matter, crude protein, ether extract, total carbohydrates and non-fiber carbohydrate (Table 3). However, the NDF intake did not differ ($p > 0.05$) with BMF addition. There was a time of-observation effect ($p < 0.05$) for all nutrient intake, with greater intakes recorded at second period (days 29 to 50 of the trial) likely because of the greater BW of lambs in the second period compared with first period (days 0 to 28 of the trial; $24.0 \pm 3.8$ kg vs. $27.8 \pm 4.6$ kg, respectively). However, a diet $\times$ period interaction was not observed.

The increasing concentration of BMF in the diet decreased linearly ($p < 0.05$) the final body weight (BW), average gain daily (ADG) and body condition score (BCS) (Table 4), decreasing in 0.156 kg, 2.760 g.d$^{-1}$ and 0.03, respectively, of each 1.0% of increase BMF in the diet. The addition of BMF at concentration up to 10.5% to effectively enhance dry matter intake (1172.5 g.d$^{-1}$) with lower effects on average daily gain (163.3 g.d$^{-1}$). The gain:feed (G:F) ratio, fat thickness and ribeye area were not affected ($p > 0.05$) by experimental diets. Therefore, there was not effect ($p > 0.05$) of period and a diet $\times$ time interaction on ADG and G:F ratio.

The BMF addition did not change ($p > 0.05$) the time spent in rumination and the time spent in idle with mean value of 545.45 min d$^{-1}$ and 666 min d$^{-1}$, respectively. However, the time spent in feeding increased linearly ($p < 0.05$), with increasing BMF in the diet (Table 5).

There was a linear decreased ($p < 0.05$) in feeding efficiency of DM. However, the feeding efficiency of NDF and rumination efficiency of DM and NDF were not affected ($p > 0.05$) by experimental diets.

The soluble fraction ($a$ fraction) and potentially degradable fraction ($b$ fraction) of DM and CP reduced ($p < 0.05$) with BMF addition, consequently there was observed a linear and quadratic effects for PD of DM and CP, respectively. Already the rate of degradation of the
fraction b (c fraction) increased (p < .05) as the BMF was added (Table 6). The effective degradation (ED) of DM and CP for passage rates of 5 and 8% decreased (p < .05) with increasing concentrations of BMF.

There was no interaction (p > .05) between diet and incubation time for potential degradation (PD) of DM and CP (Table 7).

The 20BMF diet had the shortest time of colonisation (lag time), with mean value of 2.07 h followed by control diet, with mean 2.42 h (Table 8). The control diet had the greatest proportion of potential fraction degraded in the rumen (Bp) and lowest non-degradable standardised fraction (I) (62.8% and 37.2%, respectively), while the 30 BMF diet had the lowest proportion of Bp and greatest I fraction (45.3% and 54.7%, respectively).

Discussion

Performance, ultrasound measurements and ingestive behaviour

The quadratic effect on DM intake observed when BMF was added in the diet is probably due to the greater NDF, ADF and lignin contents (52.7, 45.0 and 15.8%, respectively), which according Van Soest (1994), might affect the dry matter intake and, consequently, the intake of other nutrients.

According to Waldo (1986), DMI is negatively correlated with NDF diet concentration when rumen fills it limits voluntary feed intake. Concentration of NDF in the experimental diets increased as more BMF added (Table 1). Thus, the quadratic effect observed on DMI indicates that BMF limited feed intake that was facilitated by the smaller ruminal rate and extent of degradation of BMF (Tables 7 and 8). Others authors, when evaluating different by-products of babassu, with great concentration of NDF, such as endocarp meal (Sá et al. 2015, 2016) and babassu meal (Sousa Júnior et al. 2006; Xenofonte et al. 2008) also reported decreased in DM intake. Despite the quadratic effect on DMI, the NDF intake did not differ with BMF addition, because the greater NDF content in diets with greater concentrations of BMF, but NDFI as % of BW had a quadratic effect, because the linearly decreased of final BW.

As a result of the effect on DMI with BMF addition, final BW, ADG and ECC of lambs decreased linearly. In a metabolism trial published using the same experimental diets and lambs (Gerude Neto et al. 2016), ME
of experimental diets, expressed as a mcal/kg DM, was reduced as more BMF was added in the diet. Moreover, the response on growth is also related to the lower degradability of DM, CP and NDF of diets with increasing concentrations of BMF. Because the quadratic effect on DMI and linear decrease on ADG, the G:F ratio did not change with increasing BMF concentration in the diet.

The average daily gain (ADG) obtained in this experiment in Control diet (184 g.day
^{-1}) is close to the values of 191 g/day (Alves et al. 2003), 202 g.day
^{-1} (Santos et al., 2015) and 201 g.day
^{-1} (Silva et al. 2016), reported previously for Santa Ines crossbred lambs fed with diets containing similar proportion of roughage to the diets of this trial. This demonstrates that the ADG data recorded in this experiment for control diet were within the normal range.

Although the effects on final BW and ADG with increasing concentrations of BMF, the rib eye and fat thickness did not differ among treatments. In general, the overall fat thickness obtained in the current experiment was 0.20 cm and 6.89 cm², respectively, values that are similar to data reported previously for Santa Ines lambs [i.e. 0.23 cm (McManus et al. 2013) for fat thickness; and 7.02 cm² (Cartaxo and Sousa, 2008)] for rib eye area).

The time spent in eating, expressed as minutes per day, showed a quadratic response (p < .05) to increasing percentages of dietary BMF. Although, the mean value of DMI decreased from BMF 0 to BMF 30, we observed an increased on eating time (min.d
^{-1}), it is possible that these animals spent more time selecting their food at mealtime, which would explain this finding. When expressed as minutes per gram of DM, eating time decreased linearly, confirming the hypothesis of feed selection.

Rumination is a reflex performed by the animal trough mechanical stimuli that are related to the type of diet (fiber content) and the quantity ingested and it happens as a way to reduce the size of the feed

Table 6. Ruminal degradation parameters (a, b and c); potential degradability (PD) and effective degradation (ED) of dry matter and crude protein in lambs fed diets with increasing concentrations of babassu mesocarp flour (BMF).

| Item            | Babassu mesocarp flour (%) | Effect*       |
|-----------------|---------------------------|---------------|
|                 | 0  | 10  | 20  | 30  | Diet | Time | D x T | L    | Q    |
| Dry matter      |    |     |     |     |      |      |       |       |      |
| a               | 32.7 | 30.9 | 28.7 | 27.5 | 0.98 | 0.97 | 0.98  | 0.94 |
| b               | 46.5 | 43.5 | 44.1 | 38.9 |      |      |       |      |
| c               | 4.6  | 5.3  | 5.0  | 6.1  |      |      |       |      |
| R²              |    |     |     |     |      |      |       |       |      |
| ED              | 55.1 | 53.4 | 50.9 | 48.9 | 0.03 | 0.01 | 0.60 | 0.78 |
| 5%              | 49.3 | 48.3 | 45.8 | 44.3 |      |      |       |      |
| PD              | 77.5 | 73.2 | 71.5 | 65.6 |      |      |       |      |
| 8%              | 48.9 | 48.3 | 45.8 | 44.3 |      |      |       |      |
| Crude Protein   | 50.9 | 45.1 | 42.0 | 37.0 | 0.00 | 0.01 | 0.09 | 0.03 |
| a               | 42.5 | 48.1 | 48.8 | 44.5 |      |      |       |      |
| b               | 3.3  | 2.9  | 3.7  | 4.6  |      |      |       |      |
| c               | 0.95 | 0.95 | 0.94 | 0.90 |      |      |       |      |
| ED              | 67.9 | 62.9 | 62.7 | 58.4 |      |      |       |      |
| 5%              | 63.4 | 58.1 | 57.4 | 53.4 |      |      |       |      |
| PD              | 89.6 | 88.2 | 87.5 | 80.2 | 0.02 | 0.01 | 0.09 | 0.10 |
| a: soluble fraction in water | b: insoluble fraction in water, but potentially degradable | c: fractional rate of degradation of b; R²: determination coefficient, ED: effective degradation; PD: Degradation in 72 hours of incubation in the rumen.  
D: effect of diet; T: effect of time of incubation; P x T: interaction of Diet x time of incubation; L: Linear effect; Q: Quadratic effect.

Table 7. Ruminal degradation of dry matter (DM) and crude protein (CP) in lambs fed diets with increasing concentrations of babassu mesocarp flour in function of incubation time.

| Item | Incubation time (hour) | Effect |
|------|------------------------|--------|
|      | 3  | 6  | 24 | 72 | L | Q |
| PD of DM | 33.0 | 37.6 | 59.9 | 71.9 | 0.09 | <0.01 |
| PD of CP | 52.4 | 55.8 | 72.1 | 86.4 | 0.35 | <0.01 |
| BP: Potential degradation of dry matter (DM) and crude protein (CP) in the rumen in function of incubation time.  
R²=0.9515.  
Bp: standardised potentially degradable fraction; I: standardised undegradable fraction (%); k: passage rate; R²: coefficient of determination.  
0  | 2.4 | 62.8 | 37.2 | 0.4 | 0.95 |
| 10 | 4.8 | 57.5 | 42.4 | 0.3 | 0.94 |
| 20 | 2.1 | 57.7 | 42.2 | 0.3 | 0.93 |
| 30 | 4.3 | 45.3 | 54.7 | 0.3 | 0.94 |

Table 8. Degradation parameters of neutral detergent fibre in lambs fed diets with increasing concentrations of babassu mesocarp flour.

| Item | Babassu mesocarp flour | Lag time (hour) | Bp (%) | I (%) | K (% h⁻¹) | R² |
|------|------------------------|-----------------|--------|-------|-----------|-----|
| 0    | 2.4 | 62.8 | 37.2 | 0.4 | 0.95 |
| 10   | 4.8 | 57.5 | 42.4 | 0.3 | 0.94 |
| 20   | 2.1 | 57.7 | 42.2 | 0.3 | 0.93 |
| 30   | 4.3 | 45.3 | 54.7 | 0.3 | 0.94 |

Bp: standardised potentially degradable fraction; I: standardised undegradable fraction (%); k: passage rate; R²: coefficient of determination.
particle (Santana et al. 2014). Normally, the time spent in rumination is proportional to NDF content of the diet (Van Soest 1994) and the NDF intake. According to Cheeke (1999), animals fed diets with greater NDF content needs more time to digest the dietary fiber, so they spent more time in rumination. In our study, although the diets with BMF had greater NDF and ADF contents, the time spent in rumination was not affected, which is related to unchanged NDF intake. Similarly, rumination efficiencies of DM and NDF were not affected by diets (Table 5).

The few studies available with by-products (Cruz et al. 2012; Santana et al. 2014; Neta et al. 2017) on ingestive behaviour have a variable results due to the different species of ruminant used, variable composition of by-product and different concentrations of addition in the diet.

**Ruminal degradation parameters**

The effects of BMF on the soluble fraction (a fraction), potentially degradable fraction (b fraction), and insoluble fraction (c fraction) are attributed to the decrease in the non-fibrous carbohydrate (NFC) and the increase in NDF, ADF, and lignin contents of diets with increasing concentrations of BMF. In our study, the degradation rate (c fraction) remained between 2 to 6% h⁻¹, which Tomich and Sampaio (2004) is considered ideal for a ruminant feeds with great quality, except the 30BMF that was 6.1%.

The fiber content in BMF diets (≥10% of BMF) was also responsible for a decrease in effective degradation of DM and CP, which is considered a negative effect.

The fraction of NDF is mainly related to the reduction of feed intake (Sousa et al. 2014), as observed in performance trial, while the ADF and lignin components of fibre, are directly related to the digestibility of nutrients (Van Soest, 1994). So, the lower degradability of nutrients in experimental diets is related to greater ADF contents of diets as increased the concentrations of BMF, since the lignin content of ADF is responsible by low digestion of cell wall in the rumen (Van Soest, 1994).

Regarding the parameters of NDF degradation, the results obtained with lag time, Bp and I of the control diet are due to the greater degradation of the constituents in this diet, compared to BMF diets, including the lower fiber and lignin contents that has low degradability and passage rate (k), increasing the time of permanence in the rumen. However, the lag time of 20 BMF was lower, including when compared to the control diet, which was not waiting because since the lower lag time, the less time is necessary for the beginning of the substrate fermentation, which increasing the fermentation (Sousa et al. 2014). This fact resulted in the similar Bp and I fractions between 10 BMF and 20 BMF, even with the higher NDF content in 20 BMF compared to 10 BMF (41.0 and 37.8%, respectively).

Sousa et al. (2014), studying the kinetics of fermentation for BMF, reported smaller fermentation of this ingredient compared to corn grain, that explain the results found in this trial, since a great part of corn in the diet was replaced by BMF in treatments of increasing concentration of this by-product.

**Conclusions**

The addition of babassu mesocarp flour in diets of sheep had negative effects on performance, feed efficiency of DM and NDF and degradability of DM, CP and NDF. However, during the conventional grains off-season, as corn, and higher price of them, the babassu mesocarp flour can be added, like an alternative feed, at concentration up to 10.5% to effectively enhance dry matter intake (1172.5 g.d⁻¹) with lower effects on average daily gain (163.3 g.d⁻¹).

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References

AFRC. 1993. Energy and protein requirements of ruminants: an advisory manual prepared by AFRC Technical Committee on responses to nutrients. Wallingford, (UK): Common Wealth Agricultural Bureau International.

Agostini-Costa TS, Garruti DS, Lima L, Freire S, Abreu FAP, Feitosa T. 1999. Evaluation of methodologies for tannin determination in cashew juice. Boletim CEPPA 17:167–176.

Albiero D, Maciel AJS, Gamero CA. 2011. Development and design of a harvester babassu (Orbignya phalerata Mart.) for family farmers in the transitional forest regions for the Amazon. Acta Amazonica. 41:57–68.

Alves KS, Carvalho FFR, Véras ASC, Andrade MF, Costa RG, Batista AMV, Medeiros AN, Maior Junior RJS, Andrade DKB. 2003. Levels of Energy in Diets for Santa Inês Sheep: Performance. R Bras Zootec. 32(6):1937–1944.

Alves AA, Sales RO, Neiva JNM, Medeiros AN, Praga AP, Azevedo AR. 2007. Ruminal degradability in situ of favera pods (Parkia platycephala Benth.) in different particle size. Arq Bras Med Vet Zootec. 59:1045–1051.

AOAC International (AOAC). 2012. Official methods of analysis of AOAC international, 19th ed. Gaithersburg (MD): Association of Analytical Communities.

Broadhurst RB, Jones WT. 1978. Analysis of condensed tannin of babassu and mandioca: a staple food in goiter areas of Brazil. Eur J Endocrinol. 131:138–144.

Cartaxo FQ, Sousa WH. 2008. Correlations between traits obtained by real time ultrasound and those obtained in the carcass of feedlot finished lambs. R Bras Zootec. 37(8):1490–1495.

Cheeke PR. 1999. Applied animal nutrition: feeds and feeding. 2nd ed. New Jersey (USA): Prentice-Hall.

Cruz, RS, Alexandrino E, Missio RL, Neiva JNM, Restle J, Melo JC, Sousa Júnior A, Resende JM. 2012. Feeding behaviors of feedlot bulls fed concentrate levels and babassu mesocarp meal. Rev Bras Zootec. 41(7):1727–1736.

FASS. 1999. Guide for the care and use of Agricultural Animals in Agricultural research and teaching. 1st Rev Ed. Savoy (IL): Fed Anim Sci Soc.

Gaitan E, Cooksey RC, Legan J, Lindsay RH, Ingbar SH, Medeiros-Neto G. 1994. Antithyroid effects in vivo and in vitro of babassu and mandiocca: a staple food in goiter areas of Brazil. Eur J Endocrinol. 131:138–144.

Gallo SB, Merlin FA, Macedo CM, Silveira RDO. 2014. Whole grain diet for feedlot lambs. Small Rum Res. 120:185–188.

Gerude Neto OJA, Parente MOM, Parente HN, Alves AA, Santos PAC, Moreira Filho MA, Zanine AM, Jesus DF, Bezerra LR, Gomes RMS. 2016. Intake, nutrient apparent digestibility and ruminal constituents of crossbred Dorper × Santa Inês sheep fed diets with babassu mesocarp flour. The Scient World J. 83:1–8.

Herrera-Saldana R, Huber JT. 1989. Influence of varying protein and starch degradabilities on performance of lactating cows. J Dairy Sci. 72:1477–1483.

Johnson TR, Combs DK. 1991. Effects of prepartum diet, inert rumen bulk, and dietary polyethylene glicol on dry matter intake of lactating dairy cows. J Dairy Sci. 74:933–944.

Makkar HPS. 1999. Recommendation for quality control of in sacco nylon bag technique. In: Makkar HPS, editor. Proceedings of the 1st Research Coordination Meeting of the FAO/IAEA Coordinated Research Project Food and Agriculture Organization of the United Nations for Use of Nuclear and Related Techniques to Develop Simple Tannin Assays for Predicting and Improving the Safety and Efficiency of Feeding Ruminants on Tanniniferous Tree; Mar 8–12; Vienna. Vienna (AUT): FAO/IAEA. p.3.

Mcmanus C, Paim TP, Louvandini H, Dallago BSL, Dias LT, Teixeira RA. 2013. Ultrasoundography evaluation of sheep carcass quality of Santa Inês breed. Ci Anim Bras. 14(1):8–16.

Mertens DR, Loften JR. 1980. The effect of starch on forage fibre digestion kinetics in vitro. J Dairy Sci. 63:1437–1446.

Mertens DR. 1994. Regulation of forage intake. In: Fahey GC editor. Forage quality: evaluation and utilization. Madison, Wisconsin: American Society Agronomy, 450–493.

Neta ERDS, Alves KS, Mezzoro R, Gomes Dí, Oliveira LRS, Carvalho FFR, Luz JB, Lacerda NG, Bourdon VDDS. 2017. Behavior of sheep fed babassu cake (Orbignya speciosa) as a substitution for elephant grass silage. Anim Sci J. 88(8):1171–1177.

Nonato RC, Ferreira PRB, Sá LLF, Oliveira FA, Nunes LCC, Albuquerque WF. 2013. Centesimal and phytochemical composition of the babassu mesocarp (Orbignya sp) from Piauí and Maranhão regions. Rev Biol Farm. 9(2):130–138.

NRC. 2001. Nutrient requirements of dairy cattle. 7th ed. Washington (D.C): National Academic Press.

NRC. 2007. Nutrient requirements of small ruminants: sheep, goats, cervids, and new world camelds. 1st ed. Washington (D.C):National. Academic Press.

Ørskov DER. 1986. Starch digestion and utilization in ruminants. J Anim Sci. 63:1624–1633.

Ørskov DER, McDonald I. 1979. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. J Agric Sci. 92:499–503.

Osbourn DF, Terry RA, Outen GE, Cammell SB. 1974. The significance of determination of cell walls as the rational basis for the nutritive evaluation of forages. Proceedings of the 12th International Grassland Congress; June 11–20; Moscow: Organising Committee, XII International Grassland Conference, 1974. p. 374–380.

Sá HCM, Borges I, Macedo Júnior GL, Neiva JNM, Martins TLT, Campolina JP. 2016. Nutritional evaluation of babassu endocarp meal type II with different inclusions in sheep diets. Semina Ciências Agrárias. 37:321–330.

Sá HCM, Borges I, Macedo Júnior GL, Neiva JNM, Sousa LF. 2015. Babassu mesocar flour in formulation diets for lambs. R Caatinga. 28:207–216.

Sampaio IBM. 1988. Experimental designs and modeling techniques in the study of roughage degradation in rumen and growth of ruminants [dissertation]. Reading (Berks): University of Reading.

Santana AEM, Neiva JNM, Restle J, Sousa LF, Miottto FRC, Alencar WM, Silva RO, Araújo VL. 2014. Feeding behavior of crossbred steers fed diets containing babassu mesocarp meal and corn in kernels or ground. Rev Bras Zootec. 43:266–272.
Santos RS, Ribeiro KG, Valadares Filho SC, Pereira OG, Villela SDJ, Rennó LN, Silva JL. 2015. Effects of diets with high and low protein contents and two concentrate levels in Santa Inês x Texel lambs. Livestock Sci. 177:79–87.

Silva SR, Afonso JJ, Santos VA, Monteiro A, Guedes CM, Azevedo JMT, Dias-da-Silva A. 2006. In vivo estimation of sheep carcass composition using real-time ultrasound with two probes of 5 and 7 MHz and image analysis. J Anim Sci. 84:3433–3439.

Silva CM, Araújo GGL, Oliveira BYL, Azevedo JAG, Furtado DA. Performance and economic viability of feedlot sheep fed different levels of roughage, concentrate, and water. 2016. Performance and economic viability of confined sheep receiving different offers of bulky, concentrated and water. Semina Ciênc Agrárias. 37(3):1595–1606.

Silva NR, Ferreira ACH, Faturi C, Silva GF, Missio RL, Neiva JNM, Araújo VL, Alexandrino E. 2012. Performance in feedlot of beef cattle, castrated or not, fed with increasing levels of babassu mesocarp bran. Ciência Rural. 42:1882–1887.

Soler MP, Vitali AA, MUTO EF. 2007. Technology of breaking the babassu coconut (Orbignya speciosa). Ciência Tecnol Aliment. 27(4):717–722.

Sousa Júnior A, Oliveira ME, Alvez AA, Azevedo DMMR, Lopes JB, Araújo DLC. 2006. Digestibility of diets containing babassu bran for finishing lambs. Arch Zootec. 56:967–970.

Sousa LF, Macedo Júnior GL, Santos RP, Silva AGM, Borges I. 2014. Bromatological composition and kinetic ruminal fermentation of diets containing babassu residues. R Ciência Agron. 45:177–185.

Teixeira MA. 2007. Babassu – A new approach for an ancient Brazilian biomass. Biomass and Bioen. 32:857–864.

Tomich TR, Sampaio IBM. 2004. A new strategy for the determination of forage degradability with an in situ technique through the use of one fistulated ruminant. J Agric Sci. 142:589–593.

Van Soest, PJ. 1963. Use of detergents in the analysis of fibrous feed. II. A rapid method for the determination of fibre and lignin. J AOAC. 46:829–835.

Van Soest, PJ. 1994. Nutritional ecology of the ruminant. 2th ed. Ithaca: Cornell University Pressomstock Publishing Associates.

Van Soest PJ, Robertson JB, Lewis BA. 1991. Methods for dietary fibre, neutral detergent fibre and nonstarch polysaccharides in relation to animal nutrition. J Dairy Sci. 74:3583–3597.

Van Soest, PJ, Wine, RH. 1967. Use of detergents in analysis of fibrous feeds. IV. Determinations of plant cell-wall constituents. J Assoc Anal Chem. 50:50–55.

Waldo DR. 1986. Effect of forage quality on intake and forage-concentrate interactions. J Dairy Sci. 69:617–631.

Waldo DR, Smith LW, Cox LEL. 1972. Model of cellulose disappearance from the rumen. J Dairy Sci. 55:125–129.

Weiss WP, Conrad HR, Pierre NRS. 1992. A theoretically-based model for predicting total digestible nutrient values of forages and concentrates. J Anim Sci Tech. 39:95–110.

Xenofonte ARB, Carvalho FFR, Batista AMV, Medeiros GR, Andrade RPX. 2008. Performance and nutrient digestibility of lambs fed diets containing babassu bran. Rev Bras Zootec. 37:2063–2068.

Xu B, Chang SKC. 2009. Total phenolic, phenolic Acid, anthocyanin, flavan-3-ol, and flavonol profiles and antioxidant properties of pinto and black beans (Phaseolus vulgaris L.) as affected by thermal processing. J Agric Food Chem. 57:4754–4764.