





Article

Characteristics of Nutrition, Growth, Carcass and Meat of Male Goats Fed Babassu Mesocarp Flour

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Abstract: Twenty-eight Boer × Saanen castrated male goats (21.6 ± 3.0 kg of initial body weigh) were distributed in a randomized complete block design to evaluate the effects of increasing levels (0, 100, 200 or 300 g/kg, in dry matter basis) of dietary babassu mesocarp flour (BMF) on performance, nutrient digestibility, carcass characteristics, and meat physical and chemical composition. When significant treatment effects were found, data were submitted to orthogonal polynomials for treatment responses. BMF did not change the intake and digestibility of dry matter and crude protein. However, it increased linearly the total carbohydrates intake ($p = 0.013$), neutral detergent fiber intake ($p < 0.001$) and digestibility ($p = 0.027$), while it decreased linearly the intake of non-fibrous carbohydrates ($p < 0.001$) and ether extract ($p < 0.001$), without changing their digestibility ($p > 0.05$). The dressing percentage ($p = 0.003$) and rib eye area ($p = 0.024$) had a quadratic effect with increasing levels of BMF. The total gastrointestinal weight (TGI) had an increased linear effect ($p = 0.001$), while the proportion of rumen ($p = 0.010$), omasum ($p < 0.001$) and abomasum ($p = 0.001$) increased linearly with BMF addition. The same effects were presented in leg weight ($p = 0.045$) and muscle weight ($p = 0.049$). Weight and yields of commercial cuts and meat physicochemical composition did not change ($p > 0.05$) with inclusion levels of BMF. The addition of babassu mesocarp flour up to 200 g/kg in the diet of male goat can improve the dressing percentage without major changes in meat physical and chemical traits, representing an attractive alternative feed.

Keywords: average daily gain; co-product; commercial cuts; fiber digestibility; *Longissimus lumborum*

1. Introduction

The modernization of agribusiness has made Brazil the largest producer of food located in the tropical region. Brazil has been the world's first largest global corn producer [1], however, the use of both corn and soybeans has grown substantially over the last 15 years, supported mostly by feed use, especially in intensive production systems.

The feedlot system is an efficient strategy to reduce the age at slaughter and to increase average daily gain, resulting in an increment of meat production. However, there is a greater demand for grains, which are also used in human nutrition, in formulation of diets. Because of this, studies with co-product addition to replace conventional grains in ruminant diets have increased [2–4].

Among many vegetable species in Brazil, babassu (*Attalea speciosa*) is a palm tree found between the Cerrado and the Amazon Forest, which is native to the northern and northeastern states of Brazil [5]. The babassu coconut comprises the epicarp, mesocarp, endocarp, and kernel, each accounting for 110, 230, 590, and 70 g/kg of the total mass, respectively [6]. The oil extracted from their kernels is marketed locally and the important co-products are available during the off-season of conventional grains, thus making it an important alternative to regional producers.

The babassu mesocarp flour (BMF), extracted from mesocarp, is offered in the market at low cost. It is considered an energetic ingredient because of the high starch content [7] and has been used to replace ground corn in the diets of lambs [3,4].

Except for a few studies with lambs [3,4] that reported a decrease in dry matter intake, nutrient digestibility, and average daily gain, there is no available information on the efficacy of babassu mesocarp flour (BMF) addition in male goat diets. It is known that goat species are more efficient in fiber digestibility [8], and because of this, we hypothesized that male goats fed diets with BMF addition would have similar growth performance, carcass characteristics, and meat quality as those fed diets with conventional grains in the diet.

Thus, the aim of this study was to determine the effects of increasing levels of BMF in diets of finishing male goats on growth, nutrient digestibility, and carcass characteristics, as well as the physical and chemical composition of the meat.

2. Materials and Methods

2.1. Location, Animals and Experimental Facilities

The experiment was conducted at the Small Ruminant Sector, Center of Agrarian and Environmental Sciences, Federal University of Maranhão, located in Chapadinha, MA (03°44'33" S, 43°21'21" W), Brazil. All animal use procedures were according to the guidelines recommended by the Animal Care and Use Committee at the same institution (Process number 23115.010734/2016-81).

A total of 28 Boer-Saanen castrated male goats, with an initial average body weight (BW) of 21.6 ± 3.0 kg and average age of 8 months were used in the study. Castrated males were used because in confinement it is the animals that present performance responses close to whole males and these animals have the quality meat most desired by the consumer market, especially considering the organoleptic characteristics. The animals were housed in covered pens (one animal per pen; 0.75 m × 1.50 m) with concrete floors for 58 days: 12 days for the adaptation of animals to the diets and management and 46 days for the experimental period. All animals were dewormed with 2.5 g/kg monepantel at a dose of 1 mL/10 kg of body weight before the start of the experiment.

During the experimental period (from September to November, 2017), the mean relative humidity was 65%, while the minimum and maximum temperature registered were 25.4 °C and 40.1 °C, respectively [9]. The length of light day is about 11 h.

2.2. Experimental Design, Feeding Management, and Data Collection

The male goats were distributed in a completely randomized design, with four treatments, and the initial weight of animals was used as covariate.

The experimental diets (Table 1) were defined by the addition of BMF (Florestas Brasileiras S.A., Itapecuru Mirim, MA, Brazil; Table 2) and contained 700 g/kg (in dry matter basis, DM) of concentrate and 300 g/kg DM of forage (Tifton-85 hay) [10]. The treatments were as follows: (1) control diet without BMF, (2) inclusion of 100 g/kg BMF, (3) 200 g/kg BMF, and (4) 300 g/kg BMF. Experimental diets were fed as total mixed rations every other day at 08.00 h, and animals were allowed ad libitum access to feed and fresh water.

Table 1. Proportion of ingredients and chemical composition of experimental diets in g/kg of dry matter.

| Ingredients | Babassu Mesocarp Flour (g/kg DM ³) | | | |
|------------------------------------|--|-------|-------|-------|
| | 0 | 100 | 200 | 300 |
| Tifton-85 Hay | 300.0 | 300.0 | 300.0 | 300.0 |
| Ground corn | 480.0 | 370.0 | 260.0 | 150.0 |
| Soybean meal | 110.0 | 120.0 | 130.0 | 140.0 |
| Babassu mesocarp flour | 0.0 | 100.0 | 200.0 | 300.0 |
| Wheat bran | 100.0 | 100.0 | 100.0 | 100.0 |
| Mineral premix ¹ | 8.0 | 8.0 | 8.0 | 8.0 |
| Limestone | 2.0 | 2.0 | 2.0 | 2.0 |
| Chemical composition (g/kg DM) | | | | |
| Dry matter (g/kg FM ²) | 885.0 | 884.0 | 882.0 | 881.0 |
| Ash | 39.0 | 41.0 | 43.0 | 45.0 |
| Crude protein | 127.0 | 127.0 | 127.0 | 127.0 |
| Ether extract | 42.0 | 39.0 | 35.0 | 32.0 |
| Neutral detergent fiber | 345.0 | 381.0 | 416.0 | 456.0 |
| Acid detergent fiber | 165.0 | 189.0 | 213.0 | 237.0 |
| Non-fiber carbohydrates | 444.0 | 411.0 | 377.0 | 339.0 |
| Total carbohydrates | 790.0 | 792.0 | 794.0 | 795.0 |
| Metabolizable energy, Mcal/kg | 2.8 | 2.9 | 2.9 | 2.8 |

¹ Composition: Calcium 140 g/kg; Phosphorus 70 g/kg; Sodium 14.8 g/kg; Magnesium 13 g/kg; Sulphur 12 g/kg; Manganese 3690 mg/kg; Iron 2200 mg/kg; Zinc 4700 mg/kg; Iodine 61 mg/kg; Selenium 15 mg/kg; ² g/kg FM—grams per kilograms of fresh matter; ³ dry matter basis.

Table 2. Chemical composition of babassu mesocarp flour g/kg of dry matter.

| Chemical Composition | Babassu Mesocarp Flour |
|------------------------------------|------------------------|
| Dry matter (g/kg FM ¹) | 875.0 |
| Organic matter | 970.9 |
| Mineral matter | 29.1 |
| Crude protein | 49.4 |
| Ether extract | 17.1 |
| Neutral detergent fiber | 463.9 |
| Acid detergent fiber | 260.1 |
| Non-fiber carbohydrates | 440.5 |
| Total carbohydrates | 904.4 |

¹ g/kg FM—grams per kilograms of fresh matter.

Corn was coarsely ground with a grinder (Trapp, TRF 80, Jaraguá do Sul, SC, Brazil) and mixed with soybean meal, babassu mesocarp flour, wheat bran, limestone, and mineral premix. Tifton hay was coarsely chopped to reduce the animal diet selection and feed wastage. The concentrate and Tifton hay were separately weighed using an electronic scale (Welmy, BCW 6/15/30, 1 g, Santa Bárbara d'Oeste, SP, Brazil), mixed, and offered daily. The amount of feed offered and refused was recorded daily to adjust feed offered for 100 g/kg refusal. Both feed and ortos were sampled weekly and frozen at -18°C for later analysis.

To determine the average daily gain (ADG) and feed efficiency (grams of body weight gain per gram of feed), the animals were weighed every week, using an electronic scale (Welmy, W 300, 50 g, Santa Bárbara d'Oeste, SP, Brazil).

After the feedlot period, the male goats remained in the pens for another 5 days for digestibility data collection. The leftovers were weighed at 07.30 h in the morning to obtain the dry matter intake (DMI) per animal and the total amount of feces generated in 24 h. A harness equipped with a bag was used for fecal collection to prevent urine from mixing with feces. To determine the digestibility, the data of nutrient intake and leftovers were used only in these 5 days.

2.3. Animal Slaughter, Gastrointestinal Components, and Carcass Traits

Before the slaughter, the male goats were kept in a solid fasting state for 16 h and then were weighed to determine the body weight at slaughter (BWS) on an electric scale with an accuracy of 50 g (Welmy, W 300, Santa Bárbara d'Oeste, SP, Brazil). The slaughter proceeded according to the guidelines recommended by the Animal Care and Use Committee of the Federal University of Maranhão (process number 23115.010734/2016-81), following the rules of the Regulation of Brazilian Industrial and Sanitary Inspection of Animal Products.

The total gastrointestinal (TGI) tract, defined by the sum of the rumen, reticulum, omasum, abomasum, and intestines weights, was removed from each carcass and immediately weighed within 60 min of slaughter on an electric scale with an accuracy of 2 g (Welmy, BCW 6/15/30, Santa Bárbara d'Oeste, SP, Brazil). These data were used to calculate the empty body weight (EBW). The components of TGI were separated and excess adipose tissue on the rumen, reticulum omasum, and abomasum was removed before weighing again, without digesta content, after being cleaned.

After the slaughter, carcasses were weighted to determine hot carcass weight on an electric scale with an accuracy of 50 g (Welmy, W 300, Santa Bárbara d'Oeste, SP, Brazil). After 24 h of cooling at 4 °C, the carcasses were weighed again to obtain the cold carcass weight (CCW). Dressing percentage (DP) was calculated as follows:

$$DP = (HCW/BWS) \times 100 \quad (1)$$

where: HCW = hot carcass weight and BWS = body weight at slaughter.

The kidney fat was removed from carcass and then weighed. For the assessment of conformation, the carcasses were graded 1 (poor), 2 (fair), 3 (good), 4 (very good), or 5 (excellent) with emphasis on the following anatomical regions: hind limbs, rump, loin, shoulder, and their muscle plains.

The *Longissimus lumborum* (LL) muscle was transversely cut and then subcutaneous fat thickness was measured using an outside digital caliper (DIGIMESS, São Paulo, SP, Brazil). The maximum thickness of cover fat on the surface of the 13th rib, 11 cm from the dorso-lumbar region, was called grade ruling (GR). It was determined by the depth of the fat on the 12th rib at 11 cm from the middle line loin, using the same digital caliper. The exposed side of the LL was measured using a transparent paper to draw the rib eye area (REA) [11].

The values obtained from the right and left sides of the carcass were used to calculate the arithmetic mean of the subcutaneous fat thickness and LL area per carcass. The LL was removed from the left half of the carcass of each animal and separated from the bone. It was then divided into two subsamples, which were individually vacuum-sealed, and one of them was frozen in a commercial freezer at −18 °C for later chemical analyses, while the samples for instrumental analyses were maintained in a refrigerator for 24 h to determine texture, water holding capacity, and cooking losses.

The commercial meat cuts were determined using methodologies described by [11], who cut the half carcass into the shoulder, leg, rack, and neck. The rack was divided into the rib, flank, and loin. Cut yields were estimated in relation to reconstituted cold carcass weight.

2.4. Chemical Composition and Calculations

After the end of the trial, samples of feed, leftovers (pooled by diet and week) and feces (100 g/kg of the total) were thawed and dried in a forced-ventilation oven (55 °C) for 72 h. The samples were ground with a Wiley-type mill through a 1 mm screen (Marconi, Piracicaba, Brazil) for subsequent laboratory analyses according to the method of [12] for dry matter (DM; Method 930.15), ether extract (EE; Method 954.05), and nitrogen (N; Method 968.06). Crude protein (CP) was obtained by multiplying the total N content by 6.25. The neutral detergent fiber was assayed with a heat stable amylase according to [13].

The total carbohydrates and non-fiber carbohydrates were determined according to [14]. The total digestible nutrients (TDN) were calculated according to [15]. The metabolizable energy (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 [10].

2.5. Physicochemical Evaluation of Meat

The meat pH was measured after carcass chilling using a digital potentiometer (DIGIMED, 300M, São Paulo, Brazil) that had been calibrated with buffer solutions of pH 7.0 and pH 4.0. The meat color was estimated using the L * a * b * system using a colorimeter (Model Minolta CR-400, Minolta Co., Osaka, Japan) 24 h post-slaughter. Measurements were taken three times for each sample and averaged. The saturation index (Chroma) was determined using methodology by a* and b* data according to the formula:

$$\text{Chroma} = \sqrt{(a^*{}^2) + (b^*{}^2)} \quad (2)$$

The definition of Metric Hue angle (h*) was determined using the methodology described by [16] arctangent from the ration of b* and a* data according to the formula:

$$h^* = \arctangent (b^* / a^*) \quad (3)$$

To determine the water holding capacity (WHC), the LL samples were maintained in a refrigerator for 24 h. Meat samples weighing 500 ± 20 mg were placed on a filter paper between two acrylic plates, and then a 10 kg weight was placed on top of the plates for 5 min. The results are expressed as percentages relative to the initial weight, as follows:

$$\text{WHC} = 100 - [(IW - FW) / IW \times 100] \quad (4)$$

where IW = initial weight and FW = final weight.

To measure cooking loss (CL), the samples (approximately 2.5 cm thick) were weighed and cooked in an industrial oven preheated to 170 °C until the internal temperature of the samples reached 71 °C, which was monitored by an internal thermocouple (iCEL TD950, Manaus, Brazil). CL was calculated as the difference between the weight of the steaks before and after oven broiling. Subsequently, these samples were then equilibrated at 4 °C overnight for instrumental texture analysis conducted according to the method of [17]. Three cores (1.27 cm in diameter and 2.0 cm in length) were removed from each steak, parallel to the long axis of the muscle fibers using a cork borer.

The instrumental measurement of texture (kg.f) was assessed using a texture analyzer (TA-XT /Express Enhanced, Hamilton, MA, USA) equipped with a Warner–Bratzler (WB) shearing device.

2.6. Tissue Composition

After obtaining the tissue composition, the left legs were identified; stored in plastic bags and frozen in a freezer at -18 °C; then thawed in a refrigerator at 10 °C for 24 h; inside the plastic bags; then removed and weighed individually; subsequently being dissected with the help of a scalpel, to determine the composition of the tissues in fat, muscle and bone, which were individually weighed to be expressed as a percentage of the weight of the leg, as described by McCutcheon et al. [18].

2.7. Statistical Analysis

Data were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC, USA) for a randomized complete design with initial weight as covariate. The homogeneity of variances was checked for each variable. The means were obtained using the LSMEANS command. When significant treatment effects were found, orthogonal polynomials for treatment were determined by linear and quadratic responses to increase the levels of BMF addition. Significance was considered at $p < 0.05$.

For the subjective carcass variables (conformation and finishing), the Kruskal–Wallis' test was performed followed by Conover's procedure at $p < 0.05$ significance for comparison of means.

3. Results

3.1. Growth Performance and Digestibility

The increasing level of babassu mesocarp flour (BMF) in the diet did not change the dry matter intake (DMI) ($p = 0.599$), crude protein intake (CPI) ($p = 0.126$), and metabolizable energy intake (MEI) ($p = 0.094$) (Table 3). However, the neutral detergent fiber intake (NDFI) ($p < 0.001$) and total carbohydrates intake (TCI) ($p = 0.013$) increased linearly with BMF addition, while the ether extract intake (EEI) ($p < 0.001$) and non-fibrous carbohydrates intake (NFCI) ($p < 0.001$) decreased linearly as increasing levels of BMF were added. Because of the lack of effects on MEI (metabolizable energy intake), the final body weight ($p = 0.521$), average daily gain ($p = 0.962$), and gain:feed ratio ($p = 0.529$) also did not change with BMF addition.

Table 3. Nutrients intake, digestibility and performance of goats fed increasing levels of babassu mesocarp flour.

| Item | Babassu Mesocarp Flour (g/kg DM) | | | | SEM ¹ | p-Value ² | |
|-----------------------------------|----------------------------------|-------|-------|-------|------------------|----------------------|-------|
| | 0 | 100 | 200 | 300 | | L | Q |
| Dry matter | | | | | | | |
| Intake (g/d) | 752.5 | 805.9 | 813.0 | 840.1 | 16.59 | 0.599 | 0.681 |
| Digestibility (g/kg) | 784.6 | 798.2 | 781.3 | 764.4 | 8.62 | 0.369 | 0.422 |
| Crude protein | | | | | | | |
| Intake (g/d) | 98.1 | 107.2 | 106.2 | 107.8 | 21.43 | 0.126 | 0.356 |
| Digestibility (g/kg) | 747.4 | 780.0 | 764.2 | 762.6 | 13.85 | 0.820 | 0.551 |
| Neutral detergent fiber | | | | | | | |
| Intake (g/d) ³ | 233.9 | 288.3 | 329.8 | 398.2 | 79.23 | <0.001 | 0.593 |
| Digestibility (g/kg) ⁴ | 484.6 | 609.7 | 591.6 | 642.2 | 22.70 | 0.027 | 0.377 |
| Ether extract | | | | | | | |
| Intake (g/d) ⁵ | 33.4 | 32.5 | 28.9 | 27.4 | 0.67 | <0.001 | 0.799 |
| Digestibility (g/kg) ⁶ | 872.8 | 899.6 | 893.9 | 866.3 | 6.18 | 0.654 | 0.040 |
| Non-fiber carbohydrates | | | | | | | |
| Intake (g/d) ⁷ | 331.4 | 332.4 | 294.9 | 253.2 | 74.96 | <0.001 | 0.084 |
| Digestibility (g/kg) | 957.8 | 962.9 | 983.2 | 977.9 | 5.50 | 0.170 | 0.662 |
| Total carbohydrates | | | | | | | |
| Intake (g/d) ⁸ | 566.0 | 621.1 | 631.6 | 651.1 | 13.16 | 0.013 | 0.456 |
| Digestibility (g/kg) | 801.9 | 816.5 | 792.5 | 777.0 | 8.65 | 0.247 | 0.416 |
| Metabolizable energy | | | | | | | |
| Intake (Mcal/d) | 2.13 | 2.37 | 2.33 | 2.37 | 0.047 | 0.094 | 0.247 |
| Performance | | | | | | | |
| Final body weight (kg) | 25.1 | 25.7 | 26.1 | 26.1 | 0.83 | 0.521 | 0.786 |
| Average daily gain (g/d) | 157.4 | 163.7 | 151.2 | 160.2 | 10.13 | 0.962 | 0.943 |
| Gain:feed ratio | 0.205 | 0.187 | 0.183 | 0.186 | 0.0113 | 0.529 | 0.654 |

¹ Standard error of the mean; ² Effect of diet. ³ $y = 232.39 + 5.344x$, $R^2 = 0.9911$; ⁴ $y = 513.82 + 4.5470x$, $R^2 = 0.7465$; ⁵ $y = 33.814 - 0.2151x$, $R^2 = 0.9484$; ⁶ $y = 873.33 + 3.828x - 0.136x^2$, $R^2 = 0.9928$; ⁷ $y = 343.79 - 2.721x$, $R^2 = 0.8779$; ⁸ $y = 577.58 + 2.658x$, $R^2 = 0.8847$.

The babassu mesocarp flour did not change the dry matter digestibility, which averaged from 764.4 to 798.2 g/kg (Table 3). The digestibility of crude protein ($p = 0.820$), non-fibrous carbohydrates ($p = 0.170$) and total carbohydrates ($p = 0.247$) also did not change with experimental diets, due to the similarity of the chemical composition of diets and the absence of effect on DMI. However, the neutral detergent fiber digestibility increased linearly ($p = 0.027$) and ether extract ($p = 0.040$) had a negative

quadratic effect with BMF addition. The maximum digestibility of EE (ether extract) was 900.21 g/kg at 147.23 g/kg of BMF addition.

3.2. Carcass Traits and Total Gastrointestinal Components

The increasing levels of BMF in the diet did not change the subcutaneous fat thickness (SFT) ($p = 0.257$), body weight at slaughter (BWS) ($p = 0.985$), and consequently the hot carcass weight (HCW); ($p = 0.393$) in addition, empty body weight (EBW) ($p = 0.984$) also remained unchanged (Table 4). However, dressing percentage (DP) ($p = 0.003$) and rib eye area (REA) ($p = 0.024$) have a negative quadratic effect with maximum DP and REA, which were 499.07 g/kg and 12.86 cm² at 103.42 g/kg and 120.38 g/kg of BMF addition, respectively. While cold carcass weight (CCW) ($p = 0.448$), kidney fat ($p = 0.701$) and grade ruling (GR) ($p = 0.618$) did not change with increasing levels of BMF. The subjective evaluations, as finishing ($p = 0.575$) and conformation ($p = 0.572$), also did not change with BMF addition (Table 4).

Table 4. Carcass traits and gastrointestinal components of goats fed diets containing increasing levels of babassu mesocarp flour.

| Item ¹ | Babassu Mesocarp Flour (g/kg DM) | | | | SEM ² | p-Value ³ | |
|-------------------------------------|----------------------------------|-------|-------|-------|------------------|----------------------|-------|
| | 0 | 100 | 200 | 300 | | L | Q |
| Carcass traits | | | | | | | |
| Body weight at slaughter, kg | 24.9 | 25.9 | 25.9 | 24.8 | 0.80 | 0.985 | 0.527 |
| Empty body weight, kg | 19.9 | 20.9 | 20.0 | 18.6 | 0.63 | 0.984 | 0.526 |
| Hot carcass weight, kg | 12.1 | 12.8 | 12.8 | 11.1 | 0.38 | 0.393 | 0.150 |
| Cold carcass weight, kg | 11.5 | 12.2 | 12.1 | 10.8 | 0.34 | 0.448 | 0.167 |
| Dressing percentage, % ⁴ | 48.8 | 49.3 | 49.4 | 44.9 | 0.51 | 0.001 | 0.003 |
| SFT, mm | 1.01 | 1.01 | 0.93 | 0.93 | 0.312 | 0.257 | 0.994 |
| Grade ruling, cm | 6.35 | 7.16 | 7.86 | 6.52 | 0.280 | 0.618 | 0.061 |
| Rib eye area, cm ^{2,5} | 11.29 | 12.29 | 11.58 | 10.50 | 0.240 | 0.122 | 0.024 |
| Kidney fat, kg | 0.22 | 0.23 | 0.25 | 0.19 | 0.022 | 0.701 | 0.464 |
| Subjective evaluations * | | | | | | | |
| Conformation | 1.43a | 1.57a | 1.67a | 1.43a | 0.098 | 0.572 | |
| Finishing | 1.43a | 1.43a | 1.50a | 1.14a | 0.094 | 0.575 | |
| Gastrointestinal components | | | | | | | |
| Total TGI, kg ⁶ | 3.48 | 3.52 | 3.96 | 4.61 | 0.186 | 0.001 | 0.049 |
| TGI content, kg | 1.44 | 1.50 | 1.54 | 1.57 | 0.049 | 0.132 | 0.857 |
| Rumen, g/kg ⁷ | 23.5 | 22.9 | 26.5 | 27.3 | 0.70 | 0.010 | 0.628 |
| Reticulum, g/kg | 4.50 | 4.30 | 4.50 | 4.82 | 0.012 | 0.235 | 0.212 |
| Omasum, g/kg ⁸ | 3.00 | 3.82 | 3.50 | 4.82 | 0.022 | <0.001 | 0.062 |
| Abomasum, g/kg ⁹ | 4.50 | 4.77 | 5.00 | 5.89 | 0.027 | 0.001 | 0.360 |
| Large intestine, g/kg | 14.0 | 13.3 | 14.0 | 14.9 | 0.03 | 0.218 | 0.213 |
| Small intestine, g/kg | 22.5 | 21.9 | 23.5 | 25.7 | 0.08 | 0.053 | 0.195 |

* a,b Different lowercase letters on the same line mean different means by the Kruskal-Wallis test. ¹ SFT: Subcutaneous Fat Thickness; Total TGI: total gastrointestinal weight; ² Standard error of the mean; ³ Effect of diet. ⁴ $y = 486.1 + 2.52x - 0.123x^2$, $R^2 = 0.9366$; ⁵ $y = 11.357 + 0.1252x - 0.0052x^2$, $R^2 = 0.9454$; ⁶ $y = 3.318 + 0.0038x$, $R^2 = 0.8855$; ⁷ $y = 22.818 + 0.1493x$, $R^2 = 0.7913$; ⁸ $y = 3.014 + 0.01514x$, $R^2 = 0.7464$; ⁹ $y = 4.380 + 0.0448x$, $R^2 = 0.8892$.

The total TGI weight presented an increased linear effect for ($p = 0.001$). The BMF addition in the diet promoted an increased linearly effect on rumen ($p = 0.010$), omasum ($p < 0.001$), and abomasum ($p = 0.001$) (Table 4). However, it did not change ($p > 0.05$) the commercial cuts (weights and yields, Table 5).

Table 5. Effects of increasing levels of babassu mesocarp flour in the diet of goats on weight (kg) and yield (g/kg) of commercial cuts in relation to reconstituted half carcass.

| Item | Babassu Mesocarp Flour (g/kg DM) | | | | SEM ¹ | p-Value ² | |
|----------|----------------------------------|-------|-------|-------|------------------|----------------------|-------|
| | 0 | 100 | 200 | 300 | | L | Q |
| Shoulder | | | | | | | |
| kg | 1.21 | 1.26 | 1.26 | 1.13 | 0.034 | 0.420 | 0.215 |
| g/kg | 212.7 | 210.6 | 210.9 | 212.7 | 2.18 | 0.949 | 0.383 |
| Leg | | | | | | | |
| kg | 1.72 | 1.86 | 1.83 | 1.65 | 0.041 | 0.503 | 0.057 |
| g/kg | 303.3 | 310.5 | 310.8 | 311.1 | 2.69 | 0.507 | 0.939 |
| Rib | | | | | | | |
| kg | 1.61 | 1.69 | 1.65 | 1.45 | 0.057 | 0.283 | 0.227 |
| g/kg | 279.3 | 283.3 | 275.7 | 270.0 | 3.65 | 0.307 | 0.789 |
| Flank | | | | | | | |
| kg | 0.23 | 0.24 | 0.26 | 0.24 | 0.010 | 0.651 | 0.583 |
| g/kg | 41.00 | 40.5 | 43.2 | 46.2 | 0.11 | 0.091 | 0.374 |
| Loin | | | | | | | |
| kg | 0.49 | 0.46 | 0.48 | 0.40 | 0.020 | 0.171 | 0.621 |
| g/kg | 85.4 | 77.5 | 79.8 | 76.3 | 0.16 | 0.810 | 0.368 |
| Neck | | | | | | | |
| kg | 0.45 | 0.46 | 0.48 | 0.44 | 0.019 | 0.920 | 0.564 |
| g/kg | 78.1 | 77.4 | 80.3 | 83.4 | 2.28 | 0.348 | 0.581 |

¹ Standard error of the mean; ² Effect of diet.

3.3. Instrumental Evaluation of Meat and Tissue Composition

The increasing levels of BMF did not change the contents of moisture ($p = 0.262$), protein ($p = 0.525$), ash ($p = 0.769$), and fat ($p = 0.584$) (Table 6). The pH ($p = 0.266$), water holding capacity (WHC) ($p = 0.071$), cooking loss (CL) ($p = 0.640$), and shear force (SF) ($p = 0.267$) also did not change. The L* ($p = 0.061$), a* ($p = 0.315$), b* ($p = 0.279$), chroma index (indicating the color saturation) ($p = 0.872$), and h* ($p = 0.057$) also did not change with experimental diets (Table 6).

There was a quadratic effect for leg weight ($p = 0.045$) and muscle weight ($p = 0.049$) (Table 7). The BMF addition did not change the weight and yields of bone ($p = 0.184$; $p = 0.726$) and fat ($p = 0.408$; $p = 0.653$), and the tissue proportions as the muscle:bone ($p = 0.583$) ratio and the muscle:fat ratio ($p = 0.436$).

Table 6. Physicochemical composition and color parameters (Lightness L*; redness a*; yellowness b*; Color saturation index Chroma; Hue angle h*) of the meat from goats fed with levels of babassu mesocarp flour diets.

| Item ¹ | Babassu Mesocarp Flour (g/kg DM) | | | | SEM ² | p-Value ³ | |
|---------------------------------------|----------------------------------|-------|-------|-------|------------------|----------------------|-------|
| | 0 | 100 | 200 | 300 | | L | Q |
| Proximate chemical composition (g/kg) | | | | | | | |
| Moisture | 755.2 | 754.4 | 762.2 | 762.9 | 2.83 | 0.262 | 0.946 |
| Protein | 218.4 | 215.7 | 223.2 | 221.9 | 3.01 | 0.525 | 0.932 |
| Ash | 11.7 | 10.5 | 11.5 | 11.0 | 0.28 | 0.769 | 0.494 |
| Fat | 48.2 | 55.1 | 42.0 | 48.0 | 0.26 | 0.584 | 0.795 |
| Physical characteristics | | | | | | | |
| pH | 5.79 | 5.74 | 5.67 | 5.71 | 0.027 | 0.266 | 0.443 |
| WHC, % | 67.98 | 64.50 | 62.62 | 64.18 | 0.792 | 0.071 | 0.126 |
| Cooking loss, % | 41.54 | 43.24 | 43.32 | 42.00 | 0.626 | 0.640 | 0.341 |
| Shear force, kg.f | 4.84 | 5.66 | 5.60 | 6.01 | 0.355 | 0.267 | 0.842 |
| Meat color | | | | | | | |
| L* | 39.1 | 39.0 | 41.6 | 43.6 | 0.53 | 0.061 | 0.230 |
| a* | 17.7 | 16.6 | 18.4 | 16.7 | 0.36 | 0.315 | 0.877 |
| b* | 3.90 | 3.39 | 4.45 | 4.07 | 0.169 | 0.279 | 0.812 |
| Chroma | 18.1 | 16.9 | 18.9 | 17.2 | 0.38 | 0.872 | 0.756 |
| h* ⁴ | 12.4 | 11.5 | 13.6 | 13.7 | 0.59 | 0.057 | 0.355 |

¹ WHC: water holding capacity; ² Standard error of the mean; ³ Effect of diet; ⁴ Hue angle.

Table 7. Mean tissue composition of leg from goats fed diets containing increasing levels of babassu mesocarp flour.

| Item. | Babassu Mesocarp Flour (g/kg DM) | | | | SEM ¹ | p-Value ² | |
|-------------------|----------------------------------|-------|-------|-------|------------------|----------------------|-------|
| | 0 | 100 | 200 | 300 | | L | Q |
| Leg weight | | | | | | | |
| (kg) ³ | 1.60 | 1.74 | 1.64 | 1.50 | 0.041 | 0.271 | 0.045 |
| Bone | | | | | | | |
| kg | 0.37 | 0.41 | 0.35 | 0.35 | 0.010 | 0.184 | 0.570 |
| g/kg | 231.3 | 235.6 | 213.4 | 233.3 | 3.23 | 0.726 | 0.087 |
| Muscle | | | | | | | |
| kg ⁴ | 0.82 | 0.87 | 0.87 | 0.78 | 0.018 | 0.539 | 0.049 |
| g/kg | 512.5 | 500.0 | 530.5 | 520.0 | 5.69 | 0.340 | 0.583 |
| Fat | | | | | | | |
| kg | 0.13 | 0.14 | 0.15 | 0.10 | 0.009 | 0.408 | 0.065 |
| g/kg | 81.2 | 80.4 | 91.4 | 66.6 | 4.78 | 0.653 | 0.075 |
| Tissue | | | | | | | |
| kg | 0.16 | 0.17 | 0.16 | 0.14 | 0.007 | 0.366 | 0.261 |
| g/kg | 100.0 | 97.7 | 97.6 | 93.3 | 3.74 | 0.611 | 0.665 |
| Proportions | | | | | | | |
| Muscle:Bone | 2.23 | 2.13 | 2.50 | 2.20 | 0.051 | 0.583 | 0.277 |
| Muscle:Fat | 7.27 | 6.48 | 5.93 | 6.90 | 0.581 | 0.436 | 0.173 |

¹ Standard error of the mean; ² Effect of diet; ³ $y = 1.6112 + 0.0169x - 0.0007x^2$, $R^2 = 0.9324$; ⁴ $y = 0.818 + 0.0093x - 0.0004x^2$, $R^2 = 0.9860$.

4. Discussion

Growth performance was not affected by increasing levels of BMF, as evidenced by the lack of effect on DMI and MEI. The decrease of NFCI as BMF was added in the diets, is due to this co-product having lower NFC than ground corn.

The linear increase of NDFI is a consequence of higher neutral detergent fiber (NDF) levels in diets with BMF. Despite the BMF having a significant starch content [19], after mesocarp extraction, the flour may contain small amounts of epicarp and endocarp, resulting in a BMF with a greater fiber content and low starch content [7,20], which is likely for the BMF used in this study.

A study with cattle [21] also reported an increase of NDFI when 600 g/kg BMF was added to the concentrate. In all treatments evaluated, except for the control diet, male goats had NDFI greater than the limit (12.0 g/kg of BW) for ruminant species, which could reduce the DMI because of the effect of the rumen filling [22]. However, because of the fine particle of BMF, this filling effect was not observed, and the DMI was regulated by factors related to the energy demands of animals [22,23] and, despite the higher NDF contents in diets with increasing concentrations of BMF, the energy contents among diets and MEI were similar, resulting in these findings.

Although changes in kinetics of fermentation have been reported to result in a decrease of ruminal fermentation [4,24] and NDF digestibility [3] with BMF addition, because of the higher acid detergent fiber (ADF) content [25] in BMF, in this study, the NDF digestibility increased linearly.

It has been suggested that goats have a higher number of cellulolytic bacteria [8] and microbial protein production [26]. These factors could contribute to the results that differed from results reported with lambs [3]. However, the rate of digestion was related more to the diet than to the animal species consuming the diet [27]. Thus, changes in chemical, physical and nutritional values of agricultural co-products depend on the variety of products used, methods of processing and storage, among many factors [28].

It is likely that this fact contributed to increased linear effect on total TGI weight and proportions of rumen, omasum, abomasum, and small intestine, because of the little distension effect, as the inclusion of BMF did not change BWS, HCW and CCW (cold carcass weight). These increased linear effects on total TGI weight have promoted the quadratic effect on dressing percentage. In Northeast of Brazil, the components of non-carcass characteristics, such as TGI components, are very important for typical food, such as “buchada caprina”, and these parts increase the value added to the carcass [29], even with lower dressing percentages.

The rib eye area corresponded to the muscle deposition in the carcass, an important parameter because the meat is the tissue with higher commercial value. Among the commercial cuts of the carcass, the leg is the most important [30]. The lack of BMF effect on the muscle proportion of legs confirmed the potential of using this co-product. However, a negative quadratic effect on fat proportion was observed, which is an important component that protects the muscle during cooling against dryness, and because of this, a quadratic effect on leg weights after they thawed in a refrigerator was observed.

The absence effects of BMF addition on physical and chemical characteristics of meat is a consequence of minor effects of BMF on nutritional parameters. The meat pH values were within the range considered essential for the proper establishment of rigor mortis and are close to those reported by other studies for goat species [31,32]. The pH means were a little higher than the isoelectric point of myofibrillar proteins (5.2–5.3), which is a favorable result, because it is above the neutral charge and has an excessive negative charge that provides filament repulsion. This makes room for water molecules to bind, thus increasing moisture in the flesh, which can contribute to greater juiciness, lower mechanical force when cutting and lower proportional losses of water during cooking [33].

The increasing levels of BMF also did not change the physical traits of meat, such as WHC, and consequently cooking loss and shear force. The WHC represents the meat capacity to retain water during the application of external forces, and may be determined by several factors, including post-mortem glycolysis, pH, and cooling of the carcass [34]. Although the shear force did not change with BMF addition, the values found were slightly higher than other studies with goats [30,32,34].

The lack of subcutaneous fat thickness increases the probability of cold shortening during rapid chilling of carcasses, resulting in less tender meat [35]. Moreover, the slight increase in shear force values can be associate of meat from older goats, as used in this study, because of the preference of local consumers.

Adipose depots develop in a preferential order; visceral fat (omental, mesenteric, kidney and pericardial) is the earliest developing depot followed by intermuscular, subcutaneous, and intramuscular fat [36]. In this study, the diet effect on fat deposition was not observed on subcutaneous fat thickness, or intramuscular fat, or kidney fat. The comparatively poor fat covering of goat carcasses means that the criterion of subcutaneous fatness, which is a reliable predictor of yield in lamb carcass, is not suitable for classifying and grading goat carcasses and contributed to the downgrading of goat carcasses in several commercial enterprises [37].

Thus, our hypothesis that BMF should not impact the carcass characteristics of male goats is not supported by our data. Nevertheless, growth performance and meat quality did not change with BMF addition.

5. Conclusions

The addition of BMF up to 200 g/kg in the diet of male goat can improve the dressing percentage without major changes in physical and chemical traits, representing an attractive product for consumers because of the good values for luminosity.

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