ACTA
AMAZONICA

http://dx.doi.org/10.1590/1809-4392202100843

ORIGINAL ARTICLE

Cassava residues in the diet of slow-growing broilers

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ABSTRACT

Cassava by-products are abundant and largely unused in familiy agro-industries in the Amazon region, where slow-growing broilers are commonly raised. Thus the incorporation of cassava by-products in broiler feed may provide starch enrichment for better zootechnical performance. We evaluated the use of cassava residues instead of corn in the diet of slow-growing broilers. We determined the chemical composition of cassava scrapings (CS) and cassava starch residue (CSR), and tested the digestibility of the residues in 192 broilers and three treatments: inclusion of 30 g kg^{-1} CS or CSR and a control without residue, with eight replicates of eight broilers each. Digestibility was assessed through collection of total excreta from 19 to 22 days of age. Apparent and corrected metabolizable energy, and apparent digestibility coefficients of dry matter, crude protein and crude energy were significantly higher for CSR than CS. Therefore, only CSR was used in a performance experiment using 324 broilers 30 to 90 days old, distributed in four treatments (0; 6.8; 13.4 and 20 g kg^{-1} CSR in feed) with nine replicates of nine broilers each. There was no significant difference among treatments in weight gain, feed intake, yield of carcass, breast and viscera, meat color, luminosity, pH, shear force, cooking-weight loss and drip loss. As there was a significant reduction in feed conversion and thigh and drumstick yield for 20 g kg^{-1}, we suggest the incorporation of CSR up to 13.4 g kg^{-1}.

KEYWORDS: consumption, chicken, digestibility, *Manihot esculenta*, meat quality, performance

Resíduos de mandioca na dieta de frangos de crescimento lento

RESUMO

Subprodutos da mandioca são abundantes e pouco utilizados nas agroindústrias familiares na Amazônia, onde é comum a criação de frangos de corte de crescimento lento. Portanto, a incorporação de subprodutos de mandioca na alimentação destes frangos pode proporcionar enriquecimento de amido para melhor desempenho zootécnico. Avaliamos a utilização de resíduos da mandioca na alimentação de frangos de crescimento lento em substituição ao milho. Determinamos a composição química da raspa de mandioca (RM) e do resíduo de amido de mandioca (RAM), e testamos a digestibilidade dos resíduos utilizando 192 frangos e três tratamentos: inclusão de 30 g kg^{-1} RM ou RAM e um controle sem mandioca, com oito repetições de oito frangos cada. Digestibilidade foi determinada por coleta de excretas totais dos 19 aos 22 dias de idade. Energia metabolizável aparente e corrigida e os coeficientes de digestibilidade aparente da matéria seca, proteína bruta e energia bruta foram significativamente maiores para RAM que RM. Assim, apenas RAM foi usado em um experimento de desempenho com 324 frangos de 30 a 90 dias de idade e quatro tratamentos (0; 6,8; 13,4 e 20 g kg^{-1} RAM na ração), com nove repetições de nove frangos cada. Os tratamentos não diferiram significativamente em ganho de peso, consumo de ração, rendimento de carcaça, peito e vísceras, cor da carne, luminosidade, pH, força de cisalhamento, e perda de peso por cozimento e gotejamento. Como houve redução significativa na conversão alimentar e no rendimento de coxa e sobrecoxa com 20 g kg^{-1}, sugerimos o uso de RAM até 13,4 g kg^{-1}.

PALAVRAS-CHAVE: consumo, frangos, digestibilidade, *Manihot esculenta*, qualidade da carne, desempenho.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is an important crop worldwide and is well adapted for various tropical regions of the world, with a production in 2020 of approximately 302 million tons worldwide and 18.2 million tons in Brazil (FAO 2020; IBGE 2021). In Brazil, 90% of cassava production comes from family farming (FAO 2017). The main purpose of cassava root processing in agroindustries is the production of cassava flour and starch. The production efficiency of starch industries is approximately 30%, resulting in a large amount of waste (André and Santos 2012). Several studies have

CITE AS: Vieira, S.S.; Vieira, E.S.; Barbosa, F.R.S.; Lima, A.C.S.; Marinho, A.M.; Reis, C.P.; Tavares, F.B.; Oliveira, L.R.S.; Alves, K.S.; Neta, E.R.S. 2022. Cassava residues in the diet of slow-growing broilers. *Acta Amazonica* 52: 189-198.

evaluated the use of agroindustrial residues as an alternative ingredients in poultry feed (Amorim *et al.* 2015; Broch *et al.* 2017; Parente *et al.* 2018).

Cassava residues such as bark, bagasse, and starch waste contain a large amount of residual starch, since this tuber has 80% starch in its composition and its residues contain 60 to 80 g $100g^{-1}$ of starch (Edhirej *et al.* 2015). However, cassava residues also may contain more than 10% of crude fiber (Amorim *et al.* 2015; Parente *et al.* 2018) and have low protein content, with values between 0.5 and 10% of crude protein (Picoli *et al.* 2014; Broch et al. 2017), which limits their inclusion in animal feed.

About 80% of Brazilian family farmers raise slow-growing broilers for their own livelihood, and more than half of these producers use a part of broiler production to complement their income (MDA 2018). The feed of these animals is based on the use of corn as a source of energy (Holanda *et al.* 2015). However, corn is an agricultural commodity, which implies high production costs (Oliveira 2018).

Dry cassava residue can be added up to 10% in the feed of slow-growing broilers without causing harm to the animal's performance (Almeida *et al.* 2020), but higher levels of inclusion remain to be tested. Also, the digestibility of cassava residue by slow-groth broilers and the performance and cutting yield of broilers fed with added cassava residue have not yet been evaluated. Thus, to further evaluate the use of cassava residue as alternative feed ingredient and to minimize biomass waste of cassava by-products, this study aimed to evaluate the replacement of corn with cassava by-products in the feed of slow-growing broilers on digestibility, zootechnical performance indicators, organoleptic characteristics, and meat quality.

MATERIAL AND METHODS

The study was previously approved by the Ethics Committee on the Use of Animals of Universidade Federal Rural da Amazônia (protocol # 018b/2018 CEUA-UFRA). Initially, the chemical composition of cassava residues in the region was evaluated, then an experiment was carried out to evaluate the digestibility of two types of residues and, finally, the by-product with the greatest potential was used for the experimental assessment of animal performance.

Cassava scrapings (CS) and cassava starch residue (CSR) were obtained from an agroindustry producing cassava flour in the rural area of the municipality of Parauapebas (Pará state, Brazil) in June 2018. CS and CSR samples were processed on the same day they were collected and their chemical composition was determined. The same samples were used for the diet formulation for the digestibility assay and the performance test.

The residues were dried in the sun for four days and then ground in a mill. The residues were analyzed for the levels of dry matter (DM) (AOAC 2007), ash (AOAC 2010), crude protein (CP) (AOAC 2007), ether extract (EE) (AOAC 2007), neutral detergent fiber (NDF) (AOAC 2002) and fiber in acid detergent (ADF) (AOAC 2002).

Digestibility assay

For the digestibility assay, a total of 192 10-day-old slow-growing tricolor-strain male and female broilers were used. The broilers weighed 110 ± 11 g and were transferred to metal pens (0.34 m x 0.34 m x 0.15 m) in a completely randomized experimental design composed of three treatments: inclusion of 30 g kg^{-1} CS in the feed; inclusion of 30 g kg^{-1} CSR in the feed; and a control (feed without cassava residues). Each treatment consisted of eight replicates with eight broilers each, totalling 24 experimental units. Water and feed were supplied *ad libitum*. The diets were prepared based on conventional ingredients (Table 2) to which CS or CSR were added, according to the methodology of Sakomura and Rostagno (2016).

To evaluate digestibility, total excreta per experimental unit was collected for four days (when the broilers were 19 to 22 days old). The excreta were collected twice a day at 07:00 and 17:00 and were subsequently cleaned, weighed, labelled and frozen. At the end of the collection period, the amount of feed consumed and the total amount of excreta produced were determined. The excreta were thawed at room temperature, homogenized and aliquots were removed for analysis of dry matter (AOAC 2007), crude protein (AOAC 2007), ether extract (AOAC 2007) and crude energy (bomb calorimeter IKA WER, model 2000), neutral detergent fiber (AOAC 2002), acid detergent fiber (AOAC 2002) and ash (AOAC 2010).

The data on nutrient consumption and nutrients presents in the excreta were used to calculate the parameters below for the diets with added CS and CSR according to Matterson *et al.* (1965). The apparent metabolizable energy (AME) was calculated using the following formula, with appropriate corrections made for differences in the DM content:

$$\text{AME}\left(\text{Kcal kg}^{-1}\text{diet reference}\right) = \frac{[(\text{feed intake x GE}_{\text{diet}})-(\text{excreta output x GE}_{\text{excreta}})]}{\text{feed intake}}$$

where GE_{diet} is the GE content in the diet and $GE_{excreta}$ is the GE content in the excreta.

The N-corrected AME (AME_n) values were calculated by correcting for the N equilibrium (zero retention) by using a factor of 36.52 MJ g^{-1} N retained in the body (15). The apparent N retention coefficient was calculated as follows:

$$\text{Retention coefficient} = \frac{[(\text{Feed intake x N}_{\text{diet}})-(\text{Excreta output x N}_{\text{excreta}})]}{(\text{Feed intake x N}_{\text{diet}})}$$

where the energy values are expressed in MJ kg^{-1} of sample, and the feed intake and excreta output in kg experimental $unit^{-1}$. Nitrogen was measured in g kg^{-1} of sample, in dry matter.

Using the analytical results, the apparent digestibility coefficient (ADC) was obtained for dry matter (ADCDM), crude protein (ADCCP), gross energy (ADCGE), ether extract (ADCEE) and apparent metabolizable energy corrected by nitrogen (AMEn), as described by Sakomura & Rostagno (2007):

$$ADC = \frac{\text{g of nutrient ingested} - \text{g of nutrient excreted}}{\text{g of nutrient ingested}} \; x \; 100.$$

AMEn (Kcal kg-1 DM) = GFE - [DGE x IF]+8.22 x NB

where NB is N balance, representing N in the diet (excreted N× IF), and GFE and DGE correspond to gross food energy and digesta gross energy, respectively.

Performance test

For the performance test, 324 30-day old tricolor slow growing broilers were used. The birds were distributed into one shed divided into boxes made of wood and galvanized wire mesh measuring 1 m x 2 m in a completely randomized design of four treatments and nine replicates with nine broilers each, totalling 36 experimental units. Each box had a density of 4.5 broilers m^{-2} containing a tubular feeder, a pressure drinker and access to a paddock (1 m x 27 m) with a density of 3 m^2 $broiler^{-1}$. To maximize uniformity, a standard deviation of ± 10% of the average weight of broilers was used.

Only CSR (seelcted in the digestibility test) was used. The experimental diets were formulated to meet the nutritional requirements of two developmental phases of the broilers: growth phase (30 to 61 days), and finishing phase (61 to 84 days), according to Rostagno *et al.* (2011). The four treatments were diets containing 0.0 (control), 6.8, 13.4 and 20 g kg^{-1} CSR (Table 1).

To evaluate the zootechnical performance in the experimental period (30 to 84 days), we determined weight gain (WG), feed intake (FI) and feed conversion rate (FCR) of the broilers, corrected by mortality, as proposed by Sakomura and Rostagno (2016). The average temperature during the experimental period was 28.4 °C, thermal comfort was measured with a Black Globe sensor (AKRON, model WBGT8758) and aveaged 28.7 °C during the experimental period, with an average relative humidity of 84.8%.

At 84 days of age, the broilers were subjected to fasting for 12 hours, and two broilers from each experimental unit were sampled, totaling 72 broilers with body weight close to the average weight of the lot (± 10%). The broilers were individually identified, slaughtered by cervical displacement, plucked, and eviscerated. The hot carcass and viscera weights were determined and were then cooled for about 24 hours in a cold chamber at temperatures ranging from -3 to -5 °C.

After cooling, we weighed the entire carcass and the cuts (breast, back, wings, thighs, and drumsticks). The cuts were weighed on a digital scale, with 0.1 g precision. We determined the yields (%) of the cuts in relation to the weight of the eviscerated carcass, and the absolute weight (g) and yield (%) of the carcass (without feet, head and neck). The 72 carcasses were divided in half (a total of 144 carcass halves), 36 were used to evaluate the chemical composition, 36 to evaluate the drip loss, 36 to evaluate the cooking loss and 36 for the sensory evaluation and shear force.

To evaluate the chemical composition of the broiler meat, the thigh, drumstick, and breast cuts were boned and skinned, and fat and ligaments were removed. For laboratory analysis, the cuts were crushed separately in a cutter, pre-dried in an oven at 55 °C and pre-degreased in a Soxhlet apparatus to remove excess water and fat. The samples were then crushed in a ball mill and were analyzed for chemical composition (dry matter, crude protein, ether extract, ash), following (AOAC 2007; AOAC 2010). The water and fat contents removed in pre-drying and pre-degreasing were taken into account to correct the values in subsequent analyses.

Colorimetric parameters were determined for the hot carcass (measured on the skin) and after 24 hours of cooling (on the skinless meat). Measurements were made at four points of the skin-free breast, drumstick and thigh pieces using a FI-400 colorimeter (Konica Minolta). We determined the parameters L (luminosity, from dark to white), a* (red/green intensity) and b* (yellow/blue intensity) in the CIELAB system (CIE 1986). The pH of the cold cuts was measured with a portable penetration pH meter (Hanna Instruments, model HI99163). After the colorimetric measurements, the carcasses were frozen (identified by experimental unit) for later use in the other analyses.

Drip weight loss (DL) and cooking loss (CL) of the thigh, drumsticks and breast cuts were evaluated using the procedures described by Aladi (2006) for broilers. The cuts were thawed, deboned, and divided into halves (one half for DL and the other for CL) and immediately weighed on a semi-analytical scale with 0.1 g precision. To assess drip loss, the samples were placed in a net bag, labelled, tied above the sample with a thick string and suspended in a refrigerator grille. After 24 hours of cooling (1 – 5 °C), the samples were weighed again. To assess cooking loss, the breast samples were packed in a polyethylene plastic bag and cooked in an ultra-thermostatic bath (Marconi, model MA184) at 85 °C for 10 minutes. After cooking, they were cooled to room temperature and weighed. Both DL and CL were determined by the equation: ((initial weight - final weight)/initial weight)*100), expressed as percentages.

Table 1. Percentage and nutritional composition of experimental diets containing cassava starch residue (CSR) for digestibility and performance (growth and finishing phase) tests with slow-growing broilers. Column headers indicate the proportion of added cassava residue (in g kg^{-1}).

Ingredients	Digestibility 30	Growth phase (30–60 days old)				Finishing phase (61–84 days old)			
		0.0	6.8	13.4	20.0	0.0	6.8	13.4	20.0
Corn (g kg^{-1})	598.5	613.0	542.0	476.0	413.2	691.0	598.5	508.5	418.5
Soybean meal (g kg^{-1})	353.0	317.0	330.0	338.0	345.0	268.0	280.0	295.0	309.0
Cassava starch residue (g kg^{-1})	0.0	0.0	68.0	134.0	200.0	0.0	68.0	134.0	200.0
Dicalcium phosphate (g kg^{-1})	20.0	15.0	14.6	15.5	15.6	9.0	9.5	9.5	10.0
Limestone (g kg^{-1})	13.5	13.0	12.1	9.6	7.7	9.0	9.1	9.1	8.6
Soybean oil (g kg^{-1})	0.0	7.0	7.5	12.0	18.0	15.0	26.0	35.0	45.0
Sodium bicarbonate	9.0	5.0	6.0	4.2	4.3	2.5	3.0	3.0	3.0
Premix* (g kg^{-1})	4.0	4.0	4.0	4.0	4.0	3.0	3.0	3.0	3.0
Salt (g kg^{-1})	2.0	2.0	2.0	2.2	2.3,	2.6	2.9	2.9	2.9
Inert(g kg^{-1})	0,0	24.0	13.8	5.0	0.0	0.0	0.0	0.0	0.0
Calculated nutritional composition									
Crude protein (g kg^{-1})	210.1	195.2	196.1	195.1	194.0	181.2	180.1	180.5	180.4
AME (MJ kg^{-1})	11.79	11.92	11.97	12.13	12.05	12.97	13.01	12.97	12.97
Lysine (g kg^{-1})	1.13	1.03	1.05	1.06	1.06	0.82	0.83	0.85	0.87
Calcium (g kg^{-1})	1.12	0.97	1.00	0.99	0.99	0.68	0.69	0.69	0.69
Non-phytate phosphorus (g kg^{-1})	0.48	0.39	0.38	0.39	0.39	0.27	0.28	0.27	0.28
Analyzed nutritional composition									
Dry matter (g kg^{-1})	912.8	913.5	922.1	884.5	877.2	903.2	919.4	896.1	905.4
Crude protein (g kg^{-1})	208.5	194.9	197.9	190.8	195.7	185.3	179.1	183.2	184.1
Ether extract (g kg^{-1})	37.4	29.3	30.8	49.5	65.5	46.9	60.58	86.7	89.9

*Premix commercial vitamin and micro-mineral additive (content information provided by the manufacturer): folic acid = 118.5 mg kg^{-1}; pantothenic acid = 525 mg kg^{-1}; BHT = 20.5 g kg^{-1}; biotin = 0.625 mg kg^{-1}; hill = 13.75 g kg^{-1}; iron = 6.25 mg kg^{-1}; phytase = 52.5 FTU kg^{-1}; iodine = 105.25 mg kg^{-1}; lysine = 263.75 g kg^{-1}; methionine = 247.5 g kg^{-1}; selenium = 37.5 mg kg^{-1}; vitamin A = 350,000 UI kg^{-1}; vitamin B1 = 2.5 mg kg^{-1}; vitamin B12 = 525 mg kg^{-1}; vitamin B2 = 250 mg kg^{-1}; vitamin B6 = 12.5 mg kg^{-1}; vitamin D3 = 100,000 UI kg^{-1}; vitamin E = 3,000 UI kg^{-1}; vitamin K3 = 100 mg kg^{-1}; zinc = 7500 mg kg^{-1}. AME = apparent metabolizable energy.

For the analysis of shear force (SF) half of the breast section of each of the 36 experimental units was used after thawing in refrigerator for 24 hours. The samples were baked in an electric oven for 10 minutes or until they reached 85° C and then four to five 1-mm aliquots were taken with a cylinder and organized with the fibers oriented perpendicularly and sheared once with a Warner-Bratzler shear force (WBSF) device attached to a texture analyzer (Model TA-XTplus, Texture Technologies Corp, USA).

The sensory evaluation was performed using fillets of the thigh, drumsticks and breast in an acceptance test with a 9-point hedonic scale from 9 (like extremely) to 1 (dislike extremely) (Dutcosky 2013). The cuts were thawed, boned, and treated with a brine solution (10%) for approximately 5 minutes and then wrapped in foil and grilled on a metal plate for 10 minutes until reaching 85 °C. The pieces were then immediately cut into cubes, coded with three digits and served in 15-g portions on disposable plates together with an individual form to complete the hedonic scale and a free and informed consent form. Sensory evaluation was carried out within the UFRA with 270 randomly selected students and professors. Each taster evaluated one cut of one experimental unit for the four treatments, totaling 1080 questionnaires. Each replicate of each cut was evaluated by 10 persons, and each cut in each treatment received 90 evaluations.

Data analysis

The normality of data distribution of the digestibility and performance response variables was assessed and confirmed with the Shapiro-Wilk test. The digestibility variables were compared among treatments with analysis of variance, and the performance variables were analyzed by pairwise comparison of the mean of each treatment with the control using the Dunnett's test. The analyses were carried out with the GLM module of the SAS 9.0 software (SAS 2014) at a 5% significance level. As the data of the sensory evaluation did not conform to normal distribution, the nonparametric Kruskal-Wallis test and the Wilcoxon test for pairwise comparisons was used with the R program (R core Team 2019).

RESULTS

Chemical composition and digestibility of CSR and CS

The chemical composition of CSR and CS is presented in Table 2. CSR and CS had high levels of ADF and NDF (> 39 g kg^{-1}) (Table 2). The digestibility of CSR was higher for the variables EMA (F = 181.88, df = 1, P < 0.01) , EMAn (F = 186.05, df = 1, P < 0.01), CMAEB (F = 69.89, df = 1, P <0.01) and CMAMS (F = 109.63, df = 1, P < 0.01) when compared to CS (Table 3).

Performance test

Feed intake, average weight and weight gain did not vary significantly among treatments, but there was a significant effect of treatments on FCR, which was significantly higher in the diet of 20 g kg^{-1} relative to the others in the finishing phase (F = 4.15, df = 3, P = 0.0137) and total phase (F = 4.36, df = 3, P = 0.0111) (30-84 days) (Table 4). There was no significant effect of CSR level on carcass yield, breast yield and viscera (ventricle, gizzard, liver, pancreas, and abdominal fat). The diet containing 20 g kg^{-1} resulted in significantly lower carcass weight (F = 4.84, df = 3, P = 0.0067), thigh yield (F = 4.98, df = 3, P = 0.0059) and drumstick yield (F = 3.83, df = 3, P = 0.0186) (Table 4).

In comparison with the control, the ash content was significantly higher in breast and drumstick cuts in the 13.4 g kg^{-1} treatment (F = 4.01, df = 3, P = 0.0157 and F = 3.90, df = 3, P = 0.0176, respectively) and in the 13.4 and 20 g kg^{-1} treatments in thigh cuts (F = 4.46, df = 3, P = 0.0100). The levels of ether extract were significantly higher in breast cuts in the 13.4 and 20 g kg^{-1} treatments (F = 3.52, df = 3, P = 0.0259), and the crude protein content was significantly higher in the 20.0 g kg^{-1} treatment in the thigh cuts (F = 5.27, df = 3, P = 0.0046) (Table 5).

The L and a* colorimetric parameters, as well as pH, SF, drip loss and cooking loss did not vary significantly among diets (Table 5). The b* values varied significantly among treatments for breast skin (F = 8.81, df = 3, P < 0.01) and meat (F = 8.49, df = 3, P < 0.01), thigh skin (F = 6.05, df = 3, P < 0.01) and meat (F = 3.44, df = 3, P = 0.0283), and drumstick skin (F = 9.77, df = 3, P < 0.01), in all cases due to significantly lower values for the inclusion level of 20 g kg^{-1} (Table 6).

Regarding the sensory evaluation of breast fillets, appearance, aroma and texture did not vary significantly among treatments, but there was a tendency for significantly lower scores for flavor in the 13.4 g kg^{-1}, and for global acceptance in the 20 g kg^{-1} treatment (Table 7). In thigh fillets, there was no significant difference among treatments and the 6.8 and 13.4 g kg^{-1} treatments yielded the highest scores. For the drumsticks, there was no significant difference in appearance, texture and flavor, but aroma tended to significantly higher scores in the 6.8 g kg^{-1} treatment (Table 7).

Table 2. Chemical composition of cassava starch residue (CSR) and cassava scrapings (CS from Parauapebas (Pará state, Brazil).

Parameter	Cassava starch residue	Cassava scrapings
Dry matter (g kg-^{1})	190.4	241.6
Ashes (g kg-^{1})	11.0	51.7
Crude protein (g kg-^{1})	84.7	60.8
Ether extract (g kg-^{1})	29.8	19.2
Crude energy (kcal kg-^{1})	38.9	40.2
NDF[1] (g kg-^{1})	42.34	418.4
ADF[2] (g kg-^{1})	401.4	399.1
Hemicellulose (g kg-^{1})	22.0	19.3
NSC[3] (g kg-^{1})	702.1	713.3

[1]NDF = neutral detergent fiber; [2]ADF = fiber in acid detergent; [3]CNE = non-structural carbohydrates.

Table 3. Digestibility values of cassava starch residue (CSR) and cassava scraping (CS).

Variable	CSR	CS	P-value	SEM
AME (kcal kg^{-1})	4634.0 ± 0.1	3191.0 ± 0.3	< 0.01	0.92
AME_N (kcal kg^{-1})	4555.0 ± 0.1	3175.0 ± 0.3	< 0.01	0.93
ADCDM (g kg^{-1})	898.9 ± 0.9	709.5 ± 1.2	< 0.01	0.88
ADCCP (g kg^{-1})	453.3 ± 2.6	393.5 ± 2.8	0.21	0.11
ADCGE (g kg^{-1})	954.7 ± 0.1	734.6 ± 2.0	< 0.01	0.83
ADCEE (g kg^{-1})	884.1 ± 3.6	901.0* ± 2.7	< 0.01	0.88

AME = apparent metabolizable energy; AMEn = apparent metabolizable energy corrected for nitrogen balance; ADCDM = apparent digestibility coefficient of dry matter; ADCCP = apparent digestibility coefficient of crude protein; ADCGE = apparent digestibility coefficient of gross energy; ADCEE = apparent digestibility coefficient of ether extract. P-value = statistical significance of the comparison between CSR and CS with ANOVA; SEM = standard error of the mean.

DISCUSSION

CSR presented a higher digestibility value for ingested energy in relation to CS, which may be due to the greater amount of ether extract in the diet containing CSR, which causes extra caloric effects of fat (Sakomura *et al.* 2014). Among other benefits, these effects act by reducing the rate of food passage, improving the absorption of nutrients through a greater performance of digestive enzymes (Ozturk *et al.* 2010). CSR and CS had low levels of crude protein when compared to other energy feedstuffs, so that the incorporation of the cassava by-products caused a reduction in the protein content relative to the original composition of the feed. Furthermore, the low digestibility of crude protein observed for the cassava-enhanced diets indicates less availability of nutrients for animal use. Changes in the composition of feeds and thus their physicochemical characteristics, can affect the acceptance and consumption of diets by slow-growing broilers, causing a reduction in feed intake (Chukwukaelo *et al.* 2018).

Table 4. Performance and yield of carcass, meat cuts and organs of slow-growing broilers fed with increasing levels of cassava starch residue (0, 6.8, 13.4 and 20 g kg^{-1}) in the diet. Values are the mean ± SD of nine replicates.

Parameter	0.0	6.8	13.4	20.0	P-value	SEM
Growth phase (30 - 60 days old)						
FI (g^{-1})	2547.2 ± 0.1	2443.2 ± 0.2	2472.0 ± 0.1	2438.5 ± 0.13	0.30	0.02
AW (g^{-1})	1457.0 ± 0.1	1392.7 ± 0.1	1430.4 ± 0.1	1357.8 ± 0.1	0.09	0.01
WG (g^{-1})	1148.6 ± 0.1	1082.0 ± 0.1	1119.1 ± 0.1	1046.3 ± 0.1	0.08	0.01
FCR	2.2 ± 0.1	2.2 ± 0.1	2.2 ± 0.2	2.3 ± 0.15	0.32	0.02
Finishing phase (61 - 84 days old)						
FI (g^{-1})	2991.0 ± 0.3	2869.4 ± 0.3	2977.5 ± 0.2	3014.3 ± 0.4	0.75	0.04
AW (g^{-1})	2465.1 ± 0.1	2346.8 ± 0.2	2413.1 ± 0.1	2309.8 ± 0.1	0.14	0.02
WG (g^{-1})	1008.2 ± 0.1	954.1 ± 0.1	1000.8 ± 0.2	958.1 ± 0.1	0.51	0.01
FCR	3.0 ± 0.1	3.1 ± 0.1	3.0 ± 0.1	3.2* ± 0.1	0.01	0.02
Total phase (30 - 84 days old)						
FI (g^{-1})	5538.2 ± 0.4	5312.7 ± 0.4	5449.6 ± 0.2	5452.7 ± 0.5	0.65	0.06
AW (g^{-1})	2465.1 ± 0.1	2346.8 ± 0.2	2413.1 ± 0.1	2307.8 ± 0.1	0.14	0.02
WG (g^{-1})	2156.8 ± 0.1	2036.1 ± 0.2	2120.1 ± 0.1	2004.4 ± 0.1	0.12	0.03
FCR	2.5 ± 0.1	2.6 ± 0.1	2.6 ± 0.1	2.7* ± 0.1	0.01	0.02
Yield						
Carcass weight (g)	1917.0 ± 1.9	1799.4 ± 1.6	1888.7 ± 0.1	1697.5* ± 1,5	0.01	26.34
Carcass (%)	75.0 ± 1.0	73.5 ± 2.0	74.1 ± 1.3	75.4 ± 2.5	0.12	0.32
Breast (%)	22.6 ± 1.6	21.5 ± 1.3	22.4 ± 1.8	22.3 ± 2.0	0.55	0.29
Thigh (%)	12.9 ± 3.5	11.6 ± 0.1	12.3 ± 1.1	11.1* ± 1.0	0.01	0.21
Drumsticks (%)	14.9 ± 2.4	13.3 ± 1.5	13.3 ± 1.3	12.3* ± 1.8	0.02	0.31
Proventriculum (%)	1.2 ± 0.1	0.8 ± 0.7	1.2 ± 0.7	0.4 ± 0.6	0.70	0.28
Gizzard (%)	1.6 ± 0.1	1.5 ± 0.1	1.6 ± 0.1	1.5 ± 0.1	0.57	0.04
Liver (%)	1.4 ± 0.2	1.4 ± 0.3	1.4 ± 0.3	1.5 ± 0.3	0.89	0.04
Pancreas (%)	0.3 ± 0.1	0.2 ± 0.4	0.2 ± 0.1	0.1 ± 0.2	0.56	0.05
AF[1] (%)	1.3 ± 0.5	1.2 ± 0.1	1.2 ± 0.3	1.4 ± 0.1	0.84	0.08

FI = feed intake per broiler; AW = average weight per broiler; WG = weight gain per broiler; FCR = feed coversion ratio; AF = abdominal fat; SEM = standard error of the mean; * indicates values that differ significantly from the control (0.0 g kg^{-1} CSR) according to the Dunnet test. The P-value indicates the significance level of the analysis of variance for all groups.

Table 5. Chemical composition of meat cuts of slow-growing broilers fed different levels of cassava starch residue (CSR) (0, 6.8, 13.4 and 20 g kg^{-1}) in the diet. Values are the mean ± SD of nine replicates.

Parameter	0.0	6.8	13.4	20.0	P-value	SEM
Breast						
Dry matter (%)	30.6 ± 3.2	30.1 ± 3.8	30.3 ± 2.4	29.9 ± 2.8	0.97	0.49
Crude protein(%)	20.7 ± 1.7	21.2 ± 1.3	23.8 ± 4.5	22.4 ± 3.6	0.17	0.53
Ether extract (%)	3.4 ± 0.8	3.3 ± 0.6	4.3* ± 1.0	4.3* ± 1.1	0.03	0.16
Ashes (%)	6.7 ± 0.7	7.2 ± 0.7	8.3* ± 1.0	7.5 ± 0.1	0.02	0.19
Thigh						
Dry matter (%)	27.7 ± 4.0	28.6 ± 3.3	29.1 ± 3.0	29.8 ± 3.8	0.65	0.58
Crude protein (%)	19.4 ± 0.4	19.3 ± 0.8	20.6 ± 1.6	22.0* ± 2.8	0.01	0.32
Ether extract (%)	3.2 ± 0.8	3.6 ± 0.9	3.6 ± 0.9	4.4 ± 1.3	0.13	0.17
Ashes (%)	6.8 ± 0.6	7.7 ± 0.8	8.2* ± 0.7	8.4* ± 1.6	0.01	0.19
Drumsticks						
Dry matter (%)	33.3 ± 4.5	33.1 ± 4.1	33.6 ± 3.3	33.2 ± 2.8	0.99	0.58
Crude protein (%)	20.9 ± 0.5	19.6 ± 1.9	20.4 ± 0.6	19.9 ± 3.6	0.52	0.34
Ether extract (%)	4.9 ± 1.8	5.3 ± 0.9	5.3 ± 1.2	5.0 ± 1.4	0.93	0.22
Ashes (%)	6.5 ± 0.3	7.4 ± 0.7	7.7* ± 0.7	7.1 ± 1.1	0.02	0.14

SEM = standard error of the mean; * indicates values that differ significantly from the control (0.0 g kg-1 CSR) according to the Dunnet test. The P-value indicates the significance level of the analysis of variance for all groups.

Table 6. Colorimetric parameters, pH, shear force (SF) and water loss by cooking and dripping in meat cuts of slow-growing broilers fed with different levels of cassava starch residue (CSR) (0, 6.8, 13.4 and 20 g kg^{-1}) in the diet. Values are the mean ± SD of nine replicates.

Parameter	0.0	6.8	13.4	20.0	P-value	SEM
Breast skin						
L*	62.5 ± 1.8	61.3 ± 1.6	62.9 ± 2.6	62.6 ± 2.5	0.39	0.35
a*	10.9 ± 2.1	10.6 ± 0.6	10.9 ± 2.3	10.6 ± 1.9	0.96	0.39
b*	22.8 ± 2.8	21.9 ± 3.8	19.1 ± 3.1	16.0* ± 2.1	<0.01	0.66
Breast meat						
L*	58.9 ± 1.9	57.7 ± 1.9	58.7 ± 2.4	57.8 ± 1.5	0.44	0.32
a*	10.0 ± 0.6	11.1 ± 1.2	10.5 ± 0.7	10.8 ± 1.0	0.09	0.15
b*	11.6 ± 1.9	11.5 ± 1.5	10.2 ± 1.4	8.3* ± 1.4	<0.01	0.33
pH	5.6 ± 0.2	5.5 ± 0.1	5.5 ± 0.1	5.6 ± 0.1	0.78	0.02
SF (KFG)	1.2 ± 0.3	1.2 ± 0.4	1.1 ± 0.2	1.0 ± 0.1	0.56	0.06
CL (%)	29.4 ± 3.2	28.3 ± 4.0	29.9 ± 4.5	30.4 ± 4.5	0.72	0.67
DL (%)	5.3 ± 1.2	5.8 ± 1.0	6.8 ± 3.2	5.8 ± 1.3	0.43	0.32
Thigh skin						
L*	60.2 ± 1.4	58.9 ± 1.8	60.1 ± 3.2	60.5 ± 2.3	0.48	0.38
a*	10.0 ± 2.4	9.5 ± 1.0	9.7 ± 1.7	9.8 ± 1.3	0.92	0.26
b*	16.6 ± 2.5	15.7 ± 3.4	13.4 ± 2.7	11.5* ± 2.6	<0.01	0.57
Thigh meat						
L*	55.9 ± 1.3	54.7 ± 1.2	56.4 ± 1.9	56.7 ± 1.7	0.05	0.27
a*	11.9 ± 0.7	11.6 ± 0.7	11.0 ± 1.0	11.5 ± 0.9	0.18	0.15
b*	6.4 ± 2.8	5.9 ± 1.8	5.0 ± 0.9	4.1* ± 1.0	0.03	0.30
pH	5.6 ± 0.1	5.6 ± 0.1	5.6 ± 0.1	5.6 ± 0.1	0.99	0.02
CL (%)	29.1 ± 5.6	29.7 ± 7.8	29.9 ± 2.8	29.9 ± 3.6	0.98	0.85
DL (%)	6.3 ± 2.1	4.2 ± 0.9	4.9 ± 1.8	5.1 ± 1.3	0.06	0.28
Drumstick skin						
L*	62.3 ± 2.4	60.7 ± 1.3	62.9 ± 2.9	62.2 ± 2.8	0.21	0.41
a*	9.9 ± 2.5	9.5 ± 1.5	8.8 ± 1.8	9.8 ± 2.3	0.68	0.33
b*	18.9 ± 2.2	18.0 ± 3.1	15.9 ± 2.5	12.7* ± 2.3	<0.01	0.58
Drumstick meat						
L*	54.6 ± 0.8	54.5 ± 1.7	54.4 ± 1.9	55.2 ± 1.5	0.70	0.25
a*	12.8 ± 0.5	12.1 ± 1.0	13.4 ± 2.5	12.4 ± 1.0	0.35	0.24
b*	6.8 ± 2.	6.8 ± 1.5	6.3 ± 1.4	5.4 ± 1.6	0.23	0.27
pH	5.6 ± 0.1	5.6 ± 0.1	5.6 ± 0.1	5.6 ± 0.1	0.92	0.02
CL (%)	35.2 ± 8.0	27.5 ± 8.2	29.5 ± 9.0	31.3 ± 6.4	0.23	1.35
DL (%)	4.2 ± 1.4	4.3 ± 0.9	4.8 ± 1.5	5.4 ± 1.3	0.19	0.22

L* = luminosity; a* = redness; b* = yellowing; SF = shear force; CL = cooking loss; DL = drip loss; SEM = standard error of the mean; * indicates values that differ significantly from the control (0.0 g kg^{-1} CSR) according to the Dunnet test. The P-value indicates the significance level of the analysis of variance for all groups.

However, feed intake and average weight of broilers were not significantly affected by the inclusion of CSR in our diet.

CSR presented high fiber concentration (see Table 2), resulting in an increase in fiber in the diets. This may have caused the decrease in the feed conversion rate in the 20-g kg^{-1} treatment, indicating that the broilers were unable to convert the food consumed into weight gain with the same efficiency. The high amount of fiber present in CSR can hinder the digestion and absorption of nutrients due to the higher viscosity of the digesta (Broch *et al.* 2017).

With the addition of CSR to the diets, it was necessary to increase the amount of soybean meal, to maintain isoproteic diets. Soybean is the main protein source used in animal feeds, and it also contains antioxidants, isoflavones, phospholipids, vitamins and minerals that improve its nutritional value (Lima *et al.* 2014). Thus the increase in the amount of soybean meal

Table 7. Sensory evaluation of the meat cuts of slow-growing broilers fed different levels of cassava starch residue (CSR) (g kg^{-1}) in the diet. Values are the mean ± SD of nine replicates.

Parameter	0.0	6.8	13.4	20.0
Breast				
Appearance	7.0 ± 1.6	7.3 ± 1.5	7.0 ± 1.6	7.0 ± 1.9
Aroma	7.1 ± 1.4	7.2 ± 1.7	6.9 ± 1.6	7.1 ± 1.7
Texture	7.5 ± 1.4	7.2 ± 1.6	7.0 ± 1.8	7.2 ± 1.4
Flavor	7.2^{a} ± 1.7	7.1^{ab} ± 1.6	6.8^{b} ± 1.7	7.0^{ab} ± 1.8
Global acceptance	7.4^{a} ± 1.3	7.1^{ab} ± 1.5	6.8^{ab} ± 1.6	6.8^{b} ± 1.7
Thigh				
Appearance	6.5 ± 1.8	7.1 ± 1.6	6.6 ± 1.8	6.2 ± 2.0
Aroma	6.9 ± 1.6	6.8 ± 1.6	6.8 ± 1.6	6.7 ± 1.8
Texture	7.2 ± 1.3	7.0 ± 1.5	6.9 ± 1.7	6.9 ± 1.8
Flavor	6.9 ± 1.8	6.9 ± 1.7	6.5 ± 1.9	6.4 ± 2.1
Global acceptance	6.8 ± 1.8	6.9 ± 1.5	6.5 ± 1.9	6.7 ± 1.7
Drumsticks				
Appearance	6.7 ± 1.9	6.9 ± 1.9	6.7 ± 2.2	6.8 ± 2.1
Aroma	6.7^{b} ± 1.7	7.3^{a} ± 1.5	6.9^{ab} ± 2.0	6.8^{ab} ± 1.8
Texture	7.0 ± 1.8	7.4 ± 1.4	7.1 ± 1.7	7.0 ± 1.8
Flavor	6.8 ± 1.8	7.1 ± 1.7	6.8 ± 2.1	6.6 ± 2.1
Global acceptance	6.7^{b} ± 1.7	7.2^{a} ± 1.6	6.9^{ab} ± 1.8	6.7^{b} ± 1.9

Different superscript letters within groupd indicate significant pairwise differences between medians.

in the diets may have contributed to carcass yield not having been affected by the inclusion of CSR up to the highest level studied.

As the diets were isonitrogenous and isoenergetic, but not isoaminoacidic, the reduction of corn meal in the formulations containing CSR may have reduced the amount of the aminoacids available to the animals. The content of the aminoacids methionine and lysine in corn amounts to 0.12% and 0.23%, respectively (She *et al.* 2018), while cassava meal contains 0.03% methionine and 0.10% lysine (Casas *et al*. 2018). Since these amino acids are essential for muscle deposition, this probably caused the reduction in the yield of thigh and drumstick cuts with the highest level of CSR (20 g kg^{-1}).

Although CSR had a higher amount of NDF (42.34 g kg^{-1}) (Table 2) when compared to corn (11.75 g kg^{-1}) (Rostagno *et al*. 2011), the lack of effect of the treatments on viscera yield may be explained by the fact that the starch values of CSR are similar to those of corn (Souza *et al*. 2010), characterizing both as energy feedstuffs. The fact that the animals are free-range and more adaptable to the variations in their diet may also justify the lack of difference in viscera yield.

The reduction in thigh yield at the 20-g kg^{-1} inclusion level was likely related to the increase in CP level. In addition to being rich in highly soluble fiber and starch, the 20-g kg^{-1} treatment may have contributed to a greater retention of CP in the musculature (Amorim *et al*. 2015). The increase in EE in breast cuts in the higher levels of CSR inclusion may be explained by the increased level of oil in CSR diets to keep them isoenergetic. An evaluation of different levels of purified glycerin (0, 2, 4 and 6%) in diets for broilers also found an increased fat levels in the chemical composition of the carcass, which was attributed to the increase in glycerin levels (Silva *et al*. 2019).

Carotenoids are responsible for the yellow to red natural pigmentation in plants, and corn has high amounts of xanthophyll carotenoids (around 25 mg kg^{-1}) (Paes *et al*. 2019), while cassava has beta-carotenoids in its composition, which are precursors of vitamin A (Harrison 2012). Carotenoids varied between 0.45 and 8.17 μg g^{-1}, and beta carotene between 0.44 and 7.24 μg g^{-1} in different cassava varieties (Silva *et al*. 2014). Thus the lower intensity of yellow tones (b* parameter) for our cuts in the highest CSR inclusion level was likely due to the lower yellow pigment content in cassava compared to corn, which provides a more whitish color to the meat.

The human sensory analysis of meat products is an important aspect in the evaluation of meat quality (Perenlei *et al.* 2014) as it allows to determine the preference profile of consumers. In general, the inclusion of CSR in the diets did not affect the quality attributes of the meat evaluated. All samples received a score above 5, which is the minimum value to consider the meat acceptable within the hedonic 9-point scale (Igbabul *et al*. 2013). The breast cut presented the highest scores in sensory evaluation, possibly because the lower amount of fat present in this cut made its appearance better to tasters, influencing the other scores.

CONCLUSIONS

Our results indicate that the inclusion of cassava starch residue up to a level of 13.4 g kg-^{1} can be an alternative to reduce the amount of corn in the feeds of slow-growing broilers. Inclusion up to this level did not negatively affect the performance and yield characteristics evaluated, and, therefore, it is a viable alternative for the sustainable rearing of slow-growing chickens.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the logistical support of Universidade Federal Rural da Amazônia, and thank Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES/PROCAD Amazônia) and the members of the research group NUPEAN Parauapebas who participated in the study. This research did not receive any specific funding.

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RECEIVED: 17/03/2021
ACCEPTED: 29/06/2022
ASSOCIATE EDITOR: Rodrigo del Rio do Valle