Effect of potato on kibble characteristics and diet digestibility and palatability to adult dogs and puppies

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ABSTRACT

The objective was to evaluate kibble characteristics, coefficients of total tract apparent digestibility (CTTAD) of nutrients, metabolisable energy (ME), palatability, and faecal characteristics of diets containing potato starch (PS) fed to adult dogs and puppies. Four diets containing 0, 100, 200, or 300 g/kg PS, at the expense of corn, were evaluated in three experiments. Experiment 1 evaluated the physical characteristics of the diets. Experiment 2 evaluated diet digestibility and faecal characteristics in eight adult dogs (7 years old) and eight puppies (6 months old) according to a double 4\times4 Latin square design. Experiment 3 evaluated palatability (0 vs. 100 g/kg of PS and 0 vs. 300 g/kg of PS diets) using 16 puppies. Diets with the highest PS level presented the largest kibbles expansion ratio, greater hardness and number of pores while the density was decreased ($p < 0.001$). The inclusion of PS increased ($p < 0.05$) CTTAD of dry matter (DM) and gross energy, and ME of diets and faecal DM, for adult dogs and puppies, and CTTAD of crude protein and total starch in puppies ($p < 0.05$). Potato starch reduced ammonia levels in the faeces of puppies ($p < 0.001$). Faecal pH and score were not influenced by dietary PS inclusion either in adult dogs or puppies ($p > 0.05$). Puppies preferred diets ($p < 0.05$) containing higher PS levels. The addition of PS in the diets produces kibbles with a high expansion index and low density. Potato starch is a good starch source for adult dogs, and particularly for puppies, as it improves the digestibility of dietary nutrients and increases faecal DM, in addition of being more palatable than corn.

HIGHLIGHTS

- Potato starch increases expansion and reduces density of kibbles.
- Potato starch presents higher digestibility and metabolizable energy than corn.
- Potato starch improves diet palatability.

Introduction

One of the growing trends in the pet food market is the manufacturing of diets with nutritional composition close to that of wild dogs. For instance, grain-free foods, with a marked reduction of carbohydrate levels (average 14 to 26% nitrogen free extract in grain-free vs. 30 to 60% in conventional extruded diets) and high protein and lipid contents, have been launched in the market (Phillips 2011).

In grain-free foods, starch from tubers, such as potatoes, is used as carbohydrate source. Although consumption of vegetables, including tubers, is very low (0.1 to 3% of total diet) by wild wolves (Bosch et al. 2015), tubers are a starch source closer than cereals to the fed habits of these animals on nature.

Potato is a carbohydrate-source feedstuff and supplies about 268 kJ/100 g of edible part; 1.8 g of protein; 14.7 g soluble starch, and 1.2 g of dietary fibre on ‘as fed’ basis (TACO 2011). Potato starch (PS) consists, on average, of 80% amylopectin and 20% amylose, while corn has on average 23 to 28% amylose and 77 to 72% amylopectin. Amylopectin has high gelatinisation capacity, and it is responsible for starch digestibility. On the other hand, amylose has high retrogradation potential, reducing starch digestibility (Zhou and Kaplan 1997; Corradini et al. 2005). Potato starch also contains high levels of phosphate monoesters, which induce a more rapid and greater extent of granule swelling, favouring its expansion during food extrusion. Furthermore, the absence of starch lipids and phospholipids in tuber
starches, differently from corn starch, intensifies the effects of phosphate monoesters on starch gelatinisation and plasticity (Schirmer et al. 2013).

Potato starch is a highly digestible carbohydrate source (Thompson 2008), and presents high dry matter (DM, 83.6%) and starch digestibility (99.80%) values for adult dogs (Murray et al. 1999). However, further research on the inclusion of PS in dog foods is needed, particularly relative to its behaviour during food extrusion and to its nutritional value for puppies, whose digestive capacity is different from that of adult dogs (Félix et al. 2013). The objective of this study is to evaluate the effects of dietary PS inclusion on kibble physical characteristics, power consumption and specific mechanical energy during extrusion, diet digestibility and palatability, and faecal characteristics of adult dogs and puppies.

Material and methods

Experiment 1: kibble physical characteristics

Diets

Four experimental diets were formulated to supply the nutritional requirements of puppy dogs according to the National Research Council (NRC 2006). After the ingredients were mixed, diets were ground into 1.2-mm particles, and extruded in a double-screw extruder (Ferraz, Ribeirao Preto, Brazil). Diets contained increasing levels of PS (0, 100, 200, and 300 g/kg) at the expense of corn. The ingredients and chemical composition of PS and of the experimental diets are shown in Table 1.

Extrusion parameters

Conditioning temperature and volume of water added to the conditioner during food processing were measured. The following extruder variables were measured: knife speed (Hz), feeding rate (Hz), screw speed (Hz), amperage (A), and output (kg/h). Extruder barrel temperature was measured using a digital infra-red thermometer.

Laboratory analyses

Kibble density. The density of kibbles was measured in 10 samples per treatment at the extruder exit (at each 10 minutes) and expressed as the ratio of diet weight (grams) by volume (litres). Samples were

Table 1. Ingredients and analysed chemical composition of the experimental diets containing increasing potato starch (PS) levels and chemical composition of PS and corn used.

| Item                              | 0    | 100  | 200  | 300  |
|-----------------------------------|------|------|------|------|
| Ingredients, g/kg as fed          |      |      |      |      |
| Corn                              | 300  | 200  | 100  | 0    |
| Potato starch                     | 0    | 100  | 200  | 300  |
| Poultry fat                       | 117  | 117  | 117  | 117  |
| Soya meal 46%                    | 150  | 150  | 150  | 150  |
| Corn gluten meal 60%             | 170  | 170  | 170  | 170  |
| Poultry by-product meal          | 220  | 220  | 220  | 220  |
| Common white salt                | 5    | 5    | 5    | 5    |
| Poultry liver hydrolyzate        | 30   | 30   | 30   | 30   |
| BHA                               | 0.1  | 0.1  | 0.1  | 0.1  |
| BHT                               | 0.2  | 0.2  | 0.2  | 0.2  |
| Citric acid                      | 0.3  | 0.3  | 0.3  | 0.3  |
| Calcium propionate               | 2    | 2    | 2    | 2    |
| Choline chloride                 | 2    | 2    | 2    | 2    |
| Vitamin and mineral premixa      | 3.0  | 3.0  | 3.0  | 3.0  |
| Chemical composition, g/kg dry matter |      |      |      |      |
| Dry matter                       | 879.8| 877.3| 950.4| 954.3| 960.0| 970.4|
| Crude protein                     | 75.5 | 5.9  | 367.8| 354.3| 358.9| 353.7|
| Ether extract after acid hydrolysis| 36.3 | –    | 178.1| 170.1| 156.1| 155.0|
| Ashes                             | 10.1 | 3.3  | 69.4 | 70.0 | 69.3 | 70.1 |
| Crude fibre                       | 18.9 | 7.1  | 39.9 | 39.1 | 34.9 | 31.5 |
| Calcium                           | 0.4  | –    | 18.2 | 18.0 | 17.7 | 17.5 |
| Phosphorus                        | 3.9  | –    | 11.0 | 10.8 | 10.2 | 10.0 |
| Available starch                  | 721.9| 958.9| 309.6| 354.5| 373.7| 386.3|
| Resistant starch                  | 21.3 | 6.1  | 50.8 | 38.0 | 32.1 | 29.5 |
| Total starch                      | 743.2| 965.0| 360.4| 384.0| 405.8| 424.3|
| ME, MJ/kg<sup>a</sup>             | 16.8 | 16.6 | 16.4 | 16.4 |      |      |

<sup>a</sup>Enrichment per kg of food – 1: Vit. A – 20,000 IU, Vit. D3 – 2000 IU, Vit. E – 480 IU, Vit. K3 – 48 mg, Vit. B1 – 4 mg, Vit. B2 – 32 mg, B12 – 0.2 mg, Pantothenic Acid – 16 mg, Niacin – 56 mg, Choline – 800 mg, Zinc – 150 mg, Iron – 100 mg, Copper – 15 mg, Iodine – 1.5 mg, Manganese – 30 mg, Selenium – 0.2 mg and 240 mg antioxidant.

<sup>b</sup>ME: metabolisable energy = 0.01465 × crude protein + 0.03558 × ether extract after acid hydrolysis + 0.01465 × nitrogen free extract.
homogenised, placed in a 1-L burette, and weighed on a digital scale (2000 g capacity).

**Kibble size and expansion index.** Kibble width of 10 samples per treatment was measured using a digital calliper. Expansion index (EI) was calculated as the ratio between kibble width and die diameter.

**Kibble hardness.** Kibble hardness was determined in 10 samples per treatment in a durometer (Ethik Technology; 298 PGD) and expressed in kilogram-force (kgf).

**Kibble porosity.** All diets were examined under scanning electron microscopy (SEM) at ×40 magnification to determine kibble porosity (4 kibbles per treatment). Kibbles were longitudinally cut to allow better pore visualisation. Kibble pore area (mm²) was measured using the software ImageJ® (Wayne Rasband, National Institutes of Health, Bethesda, MD, USA). The number of pores was manually counted in the image generated at SEM. All pores presented in the image were counted after applying the threshold tool of ImageJ® to highlight the pores.

**Power consumption.** Power consumption (kW/h) during extrusion was calculated using the equation proposed by Riaz (2000): Electrical phase of the system × feeding rate × amperage × engine cos γ/1000, where engine cusing osγ = 0.86.

**Specific mechanical energy (SME).** The specific mechanical energy (SME) transferred to the mass (kW/h/ton) during extrusion was obtained according to the equation proposed by Riaz (2000): SME (kW h ton⁻²) = (power consumption) × 1000/extruder output (kg h⁻¹).

**Statistical analyses**

Kibble density, size, hardness, and EI data were analysed for normality by the Shapiro-Wilk test (p < .05), and then submitted to analysis of regression, considering 10 replicates per treatment at p < .05 significance level. The other measured variables are presented descriptively.

**Experiment 2: digestibility assay and faecal characteristics**

The experimental procedures performed on dogs were approved by the Committee of Ethics on Animal Use of the Sector of Agricultural Sciences of the Federal University of Paraná, Curitiba, PR, Brazil, under protocol n. 019/2015.

**Experimental diets**

The same diets described in Experiment 1 were evaluated.

**Dogs, facilities, and digestibility assay**

Eight adult Beagles (four males and four females) with 7 years of age and 12 ± 1.6 kg body weight (BW) and eight Beagle puppies (four males and four females) with 6 months of age and 7 kg ±0.38 BW were used. All dogs were submitted to clinical and physical examination and were vaccinated and de-wormed before the experiment. During the digestibility assay, dogs were individually housed in concrete kennels (5-m long ×2-m wide).

The method of total faecal collection was applied, according to the recommendations of the Association of American Feed Control Officials (AAFCO 2008). The trial was divided in four 10-day periods (five days of adaptation followed by five days of total faecal collection). Dogs were fed twice daily, at 08:00 and 16:00 hours, in sufficient amount to supply their metabolisable energy (ME) requirements, according to the National Research Council (NRC 2006) for adult dogs: MJ/day = 0.54 × BW⁰.⁷⁵ and growing dogs: MJ/day = 0.54 × BW⁰.⁷⁵ × 3.2 × (e⁻⁰.⁸⁷w – 0.1), where w = current BW/mature BW. Water was offered ad libitum. Faeces were collected at least twice daily, weighed, and frozen (~14 °C) per individual dog, and pooled per collection period.

Faecal pH and ammonia were determined in duplicate in fresh faeces collected within 15 minutes after defeacation. Faecal pH was determined in 2.0 g fresh faeces diluted in 20 mL distilled water using a digital pHmeter (331, Politeste Instrumentos de Teste LTDA, São Paulo, SP, Brazil). Faecal ammonia content was determined according to Félix et al. (2013).

Faecal texture was scored according to 1–5 scale: 1 = watery faeces (can be poured from the container); 2 = unshaped stools (take the shape of the container); 3 = soft, shaped, and moist stools; 4 = well-shaped and uniform stools; 5 = hard and dry stools (Carciofi et al. 2009). The frozen faeces of each individual dog pooled per collection period were thawed, homogenised and dried in a forced-ventilation oven at 55 °C for 48 h until constant weight for analyses.

Samples of the diets, PS, and dried faeces were analysed for dry matter (DM) at 105 °C for 12 h, crude protein (CP, method 954.01), ashes (method 942.05),
crude fibre (CF, method 962.10), ether extract after acid hydrolysis (EEAH, method 954.02), and total, available and resistant starch (method 996.11), according to AOAC (1995). Gross energy (GE) was determined in a bomb calorimeter (Parr Instrument Co., Model 1261, Moline, IL, USA).

Calculations and statistical analyses

The coefficients of total tract apparent digestibility (CTTAD) and ME of diets were estimated according to AAFCO (2008) using the formulas:

\[
\text{CTTAD} = \frac{\text{g of nutrient intake} - \text{g of nutrient excretion}}{\text{g of nutrient intake}}
\]

\[
\text{ME (kJ g}^{-1}\text{)} = (\text{kJ g}^{-1}\text{GE intake} - \text{kJ g}^{-1}\text{faecal GE}) - [(\text{g CP intake} - \text{g faecal CP}) \times 5.23 \text{kJ g}^{-1}\text{DM intake}]
\]

Data were first analysed for normality by the Shapiro-Wilk test. When the normality assumption was satisfied, data were submitted to analysis of variance according to a 4 × 4 Latin Square experimental design repeated 4 times. Briefly, dogs were distributed per row (2 adults and 2 puppies for each latin square) and periods per column. Diets were distributed within the latin square in order to assign every treatment once to each column as well as to each row. The experimental unit was the individual dog. Sums of squares of ANOVA of the model were separated into animal, period, and treatment effects. The effects of PS levels on the evaluated parameters were submitted to regression analysis. When interactions between PS and age were detected, means were compared by Tukey’s test. All analyses were carried out considering 5% probability level. Nonparametric parameters (faecal score, pH, and ammonia nitrogen) were analysed by the Kruskal–Wallis test at 5% probability level.

Experiment 3: Palatability trial. Experimental diets

In the palatability trial, two tests were conducted, one comparing the diets with 0 vs. 100 g/kg PS, and the other comparing the diets with 0 vs. 300 g/kg of PS. Considering that diets 0 and 300 g/kg PS have different moisture levels (4.96% vs. 2.96%, respectively), and the great impact that moisture may have on diet palatability (Brito et al. 2010), an additional test compared the palatability of these diets corrected for equal moisture level. Food allowance was 30% higher than the ME requirements recommended by the NRC (2006).

Animals, facilities, and procedures

In total, 16 six-month-old Beagle puppies (eight males and eight females), with 7 ± 0.38 kg BW, were used. During the palatability trial, dogs were housed in individual concrete kennels (5-m long × 2-m wide).

Each palatability test was performed on three consecutive days. The two diets to be compared were offered in two bowls of the same material, shape, colour, and size, once daily, at 08:00 hours, for a period of 30 minutes. The position of the bowls was daily switched in order to prevent dogs from being conditioned to feeding always at the same location. Palatability was determined by measuring food preference and first choice between the foods offered. The food offer and food residues were weighed to calculate food preference as a function of the intake ratio (offer minus residues) of diets A and B, which was calculated as g of diet A or B intake/g of total food consumed (A + B).

The first bowl to which the dog approached when the two test foods were simultaneously offered was recorded as first choice.

Statistical analyses

A completely randomised experimental design was applied, including 16 puppies, totalling 48 replicates per test (16 dogs × three days). First choice results were submitted to the chi-square test and the intake ratio to the paired Student’s t-test, both at 5% probability level.

Results

Experiment 1: kibble physical characteristics

The extrusion parameters measured in each diet are shown in Table 2. Die diameter and shape was kept

| Item                          | Potato starch inclusion, g/kg | 0    | 100  | 200  | 300  |
|-------------------------------|------------------------------|------|------|------|------|
| Conditioner                  |                              |      |      |      |      |
| Temperature, °C              |                              | 100.0| 98.6 | 95.0 | 85.0 |
| Water addition, L/h          |                              | 320  | 320  | 290  | 225  |
| Extruder                     |                              |      |      |      |      |
| Blade velocity (cutting), Hz |                              | 37   | 36   | 30   | 25   |
| Feeding rate, Hz             |                              | 19   | 19   | 19   | 19   |
| Screw velocity, Hz           |                              | 83   | 84   | 110  | 133  |
| Amperage, a                  |                              | 1400 | 1400 | 1400 | 1400 |
| Output, kg/h                 |                              | 13.60| 13.76| 18.02| 21.79|
| Extruider barrel temperature, °C |                            | 75.0 | 78.0 | 89.4 | 100.0|
| Specific mechanical energy transferred to the mash, kw/h/ton | | 9.71 | 9.83 | 12.87 | 15.57 |
constant during extrusion of experimental diets. The inclusion of PS in the diets reduced conditioner temperature. Water addition to the conditioner was also reduced when diets contained 200 and 300 g/kg PS. Feeding rate and extruder screw velocity remained constant for all diets. On the other hand, amperage increased with increasing dietary PS inclusion levels. The temperature of the extruder barrel also increased as dietary PS levels increased as well as electricity consumption and SME. Drier temperature was increased with dietary PS addition.

Kibble density, size, EI, and hardness results are shown in Table 3. Kibble density was linearly reduced as a function of increasing dietary PS inclusion levels ($p < .01$), whereas kibble size, EI, and hardness linearly increased ($p < .01$).

The dietary inclusion of PS increased kibble pore number and area, as shown in Figure 1 and Table 4.

### Experiment 2: Digestibility assay and faecal characteristics

The experimental diets offered were totally consumed by the dogs. No episodes of vomiting or diarrhoea were observed. The CTTAD and ME of diets and faecal DM of dogs are shown in Table 5. Increasing dietary PS levels linearly increased ($p < .05$) DM and GE

| Item                  | Potato starch, g/kg | $p$ value |
|-----------------------|---------------------|-----------|
| Density, g/L          | 480.0 473.3 434.3 425.3 | $<.001$ .870 |
| Size, mm              | 7.24 7.69 9.03 10.40 | $<.001$ .143 |
| Expansion index       | 1.60 1.70 1.97 2.23  | $<.001$ .142 |
| Hardness, kgf         | 4.57 5.05 6.27 6.51  | $<.001$ .999 |

**Table 4.** Total area and number of pores of the kibbles of diets containing increasing potato starch levels.

| Item                  | Potato starch, g/kg |
|-----------------------|---------------------|
| Total area, mm²       | 32.88 39.84 52.49 63.65 |
| Number of Pores       | 16 22 24 37 |

Figure 1. Scanning microscopy (40× magnification) of the longitudinal section of kibbles of diets containing increasing potato starch (PS) levels ($n = 4$).
Regression content both in adult dogs and puppies (puppies (linear increase in dietary ME levels for adult dogs and puppies faecal ammonia was significantly reduced in ME contents (dog age for faecal DM, and CTTAD of CP and TS and digestibility were detected in adult dogs compared with puppies (linearly increased digestibility both for adult dogs and puppies. However, the CTTAD of CP and TS linearly increased as a function of PS dietary addition only in puppies (PS in Puppies: adults < 0.001, p < 0.001, Table 6). There was interaction between PS inclusion and dog age for faecal DM, and CTTAD of CP and TS and ME contents (p < 0.05). Dietary PS content promoted a higher intake ratio of the 300 g/kg PS diet compared to the 0 g/kg PS diet (Table7), whereas no intake difference was detected (p < 0.05) when the 0 vs. 300 g/kg PS diets were compared (Table 7) in puppies. However, when calculated using equal dietary moisture content, a higher intake ratio of the 300 g/kg PS diet compared to the 0 g/kg PS diet (p < 0.001). Faecal pH and score were not influenced by dietary PS inclusion neither in adult dogs or puppies (p > 0.05, Table 6).

**Experiment 3: Palatability trial**

When the original dietary moisture levels were considered, the highest intake ratio (p < 0.05) was obtained with the 100 g/kg PS diet, when compared with the 0 g/kg PS diet (Table 7), whereas no intake ratio or first choice differences were detected (p > 0.05) when the 0 vs. 300 g/kg PS diets were compared (Table 7) in puppies. However, when calculated using equal dietary moisture content, a higher intake ratio of the 300 g/kg PS diet compared to the 0 g/kg PS diet (p < 0.05) was detected in puppies.

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**Table 5. Coefficients of total tract apparent digestibility (CTTAD) of DM, CP, EEAH, GE, and TS and metabolisable energy content (ME, MJ/kg) of foods containing increasing levels of potato starch (PS) fed to adult dogs and puppies and faecal dry matter (fDM, %).**

| Item      | DM       | CP       | EEAH     | GE       | TS       | ME       | fDM     |
|-----------|----------|----------|----------|----------|----------|----------|---------|
| PS, g/kg  |          |          |          |          |          |          |         |
| 0 Adults  | 0.817    | 0.890b   | 0.919    | 0.868    | 0.961b   | 18.71c   | 31.9b   |
| 100 Adults | 0.819    | 0.889a   | 0.926    | 0.877    | 0.959b   | 19.534   | 34.9ab  |
| 200 Adults | 0.794    | 0.807b   | 0.922    | 0.846    | 0.967ab  | 19.04b   | 33.1ab  |
| 300 Adults | 0.828    | 0.890a   | 0.915    | 0.879    | 0.939b   | 19.644   | 34.2ab  |
|           | 0.820    | 0.828a   | 0.919    | 0.861    | 0.966ab  | 19.27b   | 31.8ab  |
|           | 0.841    | 0.893a   | 0.919    | 0.888    | 0.963ab  | 19.707   | 36.5ab  |
|           | 0.834    | 0.837b   | 0.922    | 0.879    | 0.970a   | 19.48b   | 32.8b   |
| SEM       | 0.031    | 0.017    | 0.020    | 0.027    | 0.010    | 0.12     | 0.3     |

**Table 6. Average faecal ammonia, pH, and score of puppies and adult dogs fed diets with increasing levels of potato starch (PS).**

| Item             | Age     | Ammonia, g/kg | pH  | Score |
|------------------|---------|--------------|-----|-------|
| Potato starch, g/kg |         |              |     |       |
| 0 Adults         |         | 0.0895b      | 6.98| 3.7   |
| Puppies          |         | 0.1711b      | 7.30| 3.2   |
| 100 Adults       |         | 0.1066b      | 7.13| 3.8   |
| Puppies          |         | 0.1322ab     | 7.20| 3.1   |
| 200 Adults       |         | 0.1069b      | 6.80| 3.7   |
| Puppies          |         | 0.1199b      | 7.20| 3.3   |
| 300 Adults       |         | 0.1041b      | 6.90| 3.8   |
| Puppies          |         | 0.1097b      | 6.98| 3.4   |
| Probability factorial |     |              |     |       |
| PS in Adults     | 0.695   | 0.380        | 0.778| 0.787 |
| PS in Puppies    | <0.001  | 0.372        | 0.622| 0.622 |
| Age              | 0.007   | <0.001       | <0.001| <0.001|

*a-b Different letters indicate statistical differences by Tukey’s test (p < 0.05). DM: dry matter; CP: crude protein; EEAH: ether extract after acid hydrolysis; GE: gross energy; TS: total starch; SEM: standard error of the mean. Regression equations: CTTADDM adults = 0.00008x + 0.8141 (R² = 0.8936); CTTADMM puppies = 0.00100x + 0.7893 (R² = 0.8975); CTTADCP puppies = 0.0007x + 0.8114 (R² = 0.6031); CTTADGE adults = 0.0006x + 0.8692 (R² = 0.953); CTTADGE puppies = 0.0012x + 0.8393 (R² = 0.9259); ME (MJ/kg) adults = −0.189x² + 1.254x + 17.677 (R² = 0.9259); ME (MJ/kg) puppies = 0.0308x² − 0.0298x + 18.879 (R² = 0.9202).

**Table 7. First choice and intake ratio (IR, mean ± standard error) of diet A relative to diet B determined in puppies fed diets containing or not potato starch (PS).**

| Item             | Age     | Ammonia, g/kg | pH  | Score |
|------------------|---------|--------------|-----|-------|
| Potato starch, g/kg |         |              |     |       |
| 0 Adults         |         | 0.0895b      | 6.98| 3.7   |
| Puppies          |         | 0.1711b      | 7.30| 3.2   |
| 100 Adults       |         | 0.1066b      | 7.13| 3.8   |
| Puppies          |         | 0.1322ab     | 7.20| 3.1   |
| 200 Adults       |         | 0.1069b      | 6.80| 3.7   |
| Puppies          |         | 0.1199b      | 7.20| 3.3   |
| 300 Adults       |         | 0.1041b      | 6.90| 3.8   |
| Puppies          |         | 0.1097b      | 6.98| 3.4   |
| Probability factorial |     |              |     |       |
| PS in Adults     | 0.695   | 0.380        | 0.778| 0.787 |
| PS in Puppies    | <0.001  | 0.372        | 0.622| 0.622 |
| Age              | 0.007   | <0.001       | <0.001| <0.001|

*a-b Different letters indicate statistical differences by Tukey’s test (p < 0.05). DM: dry matter; CP: crude protein; EEAH: ether extract after acid hydrolysis; GE: gross energy; TS: total starch; SEM: standard error of the mean. Regression equations: CTTADDM adults = 0.00008x + 0.8141 (R² = 0.8936); CTTADMM puppies = 0.00100x + 0.7893 (R² = 0.8975); CTTADCP puppies = 0.0007x + 0.8114 (R² = 0.6031); CTTADGE adults = 0.0006x + 0.8692 (R² = 0.953); CTTADGE puppies = 0.0012x + 0.8393 (R² = 0.9259); ME (MJ/kg) adults = −0.189x² + 1.254x + 17.677 (R² = 0.9259); ME (MJ/kg) puppies = 0.0308x² − 0.0298x + 18.879 (R² = 0.9202).
Discussion

Starch type and source significantly influence starch behaviour during food extrusion. Tuber starches, such as PS, contain a higher proportion of amylopectin (75–80%) relative to amylose (20–25%), promoting starch gelatinisation during extrusion. On the other hand, the gelatinisation of cereal starches requires higher temperatures and harsher conditions during processing (Zhou and Kaplan 1997; Borba et al. 2005).

Potato starch also contains high levels of phosphate monoesters, which are covalently bound to the amylose and amylopectin fraction. The negatively charged phosphate groups induce a more rapid and greater extent of granule swelling which favours its expansion during food extrusion. Furthermore, the absence of starch lipids and phospholipids in tuber starches, differently from corn starch, intensifies the various effects of phosphate monoesters on thermal pasting behaviour (Schirmer et al. 2013).

The amperage increase at increasing PS inclusion demonstrates that higher mechanical energy is required for the extrusion of the diets containing PS and this may be attributed to the plastic changes suffered by PS during processing. At a given feeding rate, diets containing high PS levels change the conditions inside the extruder barrel due to the high plasticity of PS, increasing the power requirements for their extrusion. As a result, power consumption and specific mechanical energy transferred to the dough increased as a function of increasing PS addition to the diets. The expansion of starchy materials is inversely proportional to the moisture of the material to be extruded (Arêas 1996). According to Ding et al. (2005), the addition of excessive water levels to the process may hinder expansion, as water plasticises starchy materials, reducing their viscosity and the dissipation of mechanical energy inside the extruder, resulting in denser products with smaller pores. This justifies adding less water in the conditioner when diets contain high PS levels, as observed in the present study. In the present study extrusion parameters were not subjected to statistical analysis, due to lack of repetition, so it is important that future works with repeated extrusion variables measures be conducted to confirm this data.

Increasing starch gelatinisation increases the expansion and reduces the density of extruded diets (Bhattacharya and Choudhury 1994). In the present experiment, the greater pores area of the diets with higher PS inclusion account for the lower kibble density observed. The results of the present study show that PS has high gelatinisation potential, and resulted in kibbles with low density and high El. Borba et al. (2005), evaluating the effects of extrusion on sweet potato flour, found that the El of the extruded products ranged between 1.85 and 2.60. These values are close to those obtained for the kibbles of the PS-containing diets in the present study.

High-density diets may indicate inadequate extrusion and low starch gelatinisation, and consequently, may present poor digestibility (Camire 2000). However, in the present study, PS was highly responsive to the extrusion process, producing kibbles with greater El and lower density compared with the diets with higher corn inclusion levels. This suggests better starch gelatinisation and consequently, better nutrient utilisation, as shown by the digestibility trial results.

The inclusion of PS in the diet increased the digestibility of most nutrients and energy utilisation both in adult dogs and puppies. This may be attributed to the higher digestible starch and lower resistant starch contents of the diets with higher PS inclusion. The PS is more viscous than other starch sources, forming clear gels, and has low tendency to retrograde due to the high molecular weight of its amylose fractions and replacement by phosphate groups, thereby presenting lower resistant starch content (Alexander 1995). For puppies, the dietary inclusion of PS increased the digestibility of protein. These findings contrast with those reported by Murray et al. (1999), who obtained lower DM and CP coefficients of ileal digestibility including potato flour compared with corn, rice, sorghum, wheat, and barley in dogs. However, authors evaluated potato flour, which has fibre and protein, and not the PS, as the current study did.

Lower CTTAD of most nutrients, except for EEAH, were found in puppies compared with adult dogs. Gilham et al. (1993), Swanson et al. (2004), and Fahey et al. (2008) reported that nutrient digestibility improves as puppies ages (until young adults – around 1 year old, depending of breed) due to the maturation of their digestive tract. However, in the study of Félix et al. (2013), no differences in the CTTAD of DM, CP, or ME were detected between adult dogs and puppies fed extruded dry foods. The differences found among these studies are due to the variability of the age of puppies and adult dogs employed.

Relative to faecal characteristics, puppies presented lower faecal DM content, and consequently, worse faecal score compared with adult dogs. The wetter faeces produced by puppies may be explained by their higher intestinal transit velocity compared with adult dogs, resulting in lower water absorption in the large
intestine, as previously reported by Weber et al. (2003). Swanson et al. (2004) also observed that intestinal microbiota changes with dog age and may positively influence diet digestibility and consequently, faecal characteristics. The shorter transit time, associated with the developing intestinal microbiota of puppies, may explain the faecal characteristic differences between adult dogs and puppies. The results of the present experiment are in agreement with the findings of Zanatta et al. (2011) and Félix et al. (2013), who observed that the faeces of puppies presented higher moisture and ammonia content compared with those from adult dogs.

Regarding diet palatability, it is possible that the differences on kibble texture due to PS inclusion (reduced density and increased hardness) were the main factors that interfered on intake ratio by dogs in this study. Food particle size, shape, density, hardness, and moisture influence the palatability of dog foods (Felix et al. 2010). Those authors also mentioned that density also influences food texture, and consequently, its mastication (strength and number of mastication movements) by the dogs. In addition, density affects the contact surface and the absorption degree of fat and flavour coating on the kibbles, influencing food perception by the dogs.

The finding that the puppies’ preference changed after diet moisture was equalised shows the importance of this parameter on diet palatability (original diets moisture: 0 g/kg PS = 49.6 g/kg; 100 g/kg PS = 45.7 g/kg; 200 g/kg PS = 40.0 g/kg; and 300 g/kg of PS = 29.6 g/kg). This finding is consistent with the results of Brito et al. (2010), who observed that dogs preferred foods containing 100 g/kg moisture compared with 80 g/kg moisture. These results indicate that PS used as a food ingredient is more palatable for puppies than corn. However, dietary moisture content needs to be considered.

Unfortunately, the palatability of the diets in adult dogs was not evaluated in the present study. Although the results are likely to be the same as those obtained in puppies we suggest that future studies evaluate the effects of PS on diet palatability in adult dogs.

**Conclusions**

Potato starch is a good starch source for both adult dog and puppy foods, as it increases the digestibility of most nutrients and diet palatability compared with corn. In addition, it increases faecal dry matter and reduces faecal ammonia content in puppies. In addition, potato starch is very responsive to extrusion, presenting high expansion index and producing low density kibbles with a high number of pores. However, the processing of diets containing potato starch requires higher power consumption in the feed mill due to the complexity of its starch.

**Ethical Approval**

The experiment was approved by the Committee of Ethics on Animal Use of the sector of Agricultural Sciences of the Federal University of Parana (UFPR).

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**Disclosure statement**

No potential conflict of interest was reported by the authors.

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