Aquaculture Nutrition

Aquaculture Nutrition 2012 doi: 10.1111/anu.12000

Digestibility of feed ingredients for the striped surubim *Pseudoplatystoma reticulatum*

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Abstract

Knowledge on apparent digestibility coefficients (ADC) is necessary to maximize the feed efficiency, thus lessening dietary nutrient and energy losses. This study tasks the determination of apparent digestibility of selected feedstuff to striped surubim *Pseudoplatystoma reticulatum*, a carnivorous, South American catfish of economic importance for fisheries and fish culture alike. Juvenile striped surubim (82.4 ± 17.7 g and 23.0 ± 1.6 cm) was distributed in 21 cylindrical, plastic cages (80 L), housed in seven 1000 L feeding tanks under constant water flow and aeration and conditioned to a two daily meals (20h00m and 22h00m) feeding regimen on a practical, reference diet (RD) (460.0 g kg^{-1} crude protein (CP); 19.23 kJ g^{-1} gross energy (GE)]. Test diets were obtained by adding of 1 g kg^{-1} chromium III oxide and 300 g kg^{-1} of one the following feedstuffs: fish meal (FM), meat and bone meal (MBM), poultry by-product meal, feather meal, blood meal, soybean meal, wheat bran, corn and corn gluten meal to the RD. After the last daily meal, fish were transferred to cylindrical, conical-bottomed aquaria (200 L) under aeration and continuous water exchange, coupled to refrigerated plastic bottles for faeces collection by sedimentation. Best ADC of protein (99.36%) and energy (86.25%) were recorded for poultry by-product meal and MBM, respectively, which are thus deemed ideal surrogate feedstuffs to FM in the formulation and processing of diets for striped surubim.

KEY WORDS: alternative sources, apparent digestible, chromic III oxide, striped surubim

Received 31 October 2011; accepted 19 July 2012

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Introduction

The striped surubim *Pseudoplatystoma reticulatum* is a carnivorous catfish from the Amazon and Prata Basin (Barthem & Goulding 1997; Santos *et al*. 2006), with high market value and considered an excellent species for sport fishing and a prime candidate for the development of aquaculture industry (Campos *et al*. 2006; Turra *et al*. 2009). Buitrago-Suárez & Burr (2007) divided the *Pseudoplatystoma* sp. cluster into distinct species, termed *Pseudoplatystoma fasciatum* from the Guyana group and *P. reticulatum* from the Prata Basin group. In spite of their high rate of cannibalism in early life, surubins can be feed-trained and adapted to commercial, extruded dry feed (Baras & Jobling 2002) and raised in intensive cage systems, and thus rationally farmed in large water bodies all along South America (Coelho & Cyrino 2006; Scorvo Filho *et al*. 2008).

Feeding carnivorous fish is no ordinary task and relies on availability of fish meal (FM), a palatable and highly digestible feedstuff with adequate bioavailability of essential amino acids, vitamins and minerals, and ideal essential fatty acids profile for fish nutrition (Wang *et al*. 2010). On the other hand, because of its high quality, relative scarcity and possible unavailability in the near future (Tacon 2004), FM is expensive, so using fish-meal-based diets for fish farming purposes not only increase production costs but also compromises sustainability. Thus, studies on replacement of FM with alternative ingredients in animal feeds, especially those including the determination of digestibility and use of plant protein sources are very opportune (Quartararo *et al*. 1998; Tacon & Forster 2003; Sitjà-Bobadilla *et al*. 2005; Ai & Xie 2006; Gatlin *et al*. 2007).

The determination of the digestibility of feedstuffs is an important tool for the formulation of balanced diets for minimum cost and low environmental impact (Silva *et al*. 2005; Pezzato *et al*. 2009). Studies related to feeding and nutrition of the striped surubim are still incipient (Arslan *et al.* 2008; Nuñez *et al.* 2008). The objective was to determine the apparent digestibility of various ingredients of animal and plant origin in the nutrition of juvenile striped surubim.

Material and methods

Determination of ADC and preparation of diets

The determination of apparent digestibility coefficients (ADC) of the tested ingredients was performed using chromium III oxide (Cr_2O_3) added to the diet (1 g kg^{-1}) as inert marker (Furuya *et al.* 2001; Pezzato *et al.* 2002a,b; Bremer Neto *et al.* 2003; Borghesi *et al.* 2009). Test diets were prepared replacing 300 g kg^{-1} of a reference diet (RD) (Table 1) by the tested feedstuffs: FM, meat and bone meal (MBM), poultry by-product meal, feather meal, blood meal, soybean meal (SBM), wheat bran, corn and corn gluten meal (Table 2).

Diets were extruded, oven dried (forced air flow; 45 °C; 24 h), stored in plastic bags and frozen (−18 °C). Aliquots of diets for immediate use were kept in plastic, sealed bags in refrigerator (4 °C). The ADC of diets and tested ingredients were calculated using the equations (De Silva 1989; Bureau *et al.* 2002):

$$\mathrm{ADC}(\%) = 100 - \left[100 \times \left(\frac{\%\,\mathrm{Cr_2O_3\ diet}}{\%\,\mathrm{Cr_2O_3\ feces}}\right) \times \left(\frac{\%\mathrm{nutrient\ or\ gross\ energy\ feces}}{\%\,\mathrm{nutrient\ \ or\ gross\ energy\ diet)}}\right)\right]$$

$$\mathrm{ADC_n} = \frac{\mathrm{ADC_{TD}} - \mathrm{ADC_{RD}}Y}{Z \times \mathrm{ADC_{TD}}}$$

where % Cr_2O_3 diet, chromic oxide per cent in the diet; and % Cr_2O_3 faeces, chromic oxide per cent in faeces; ADCn, apparent digestibility coefficient of nutrient or energy; ADC_{TD}, apparent digestibility coefficient of nutrient or energy in the test diet; ADC_{RD}, apparent digestibility coefficient of nutrient or energy in the reference diet; Y = reference diet proportion; and Z = test diet proportion.

Table 1 Composition of reference diet

Ingredients/nutrients	Contents (g kg^{-1})
Fish meal	400.00
Poultry by-product meal	100.00
Soybean meal	175.10
Corn	150.00
Corn gluten meal	87.30
Fish oil	66.40
Mineral mix[1]	10.00
Vitamin mix[2]	10.00
BHT[3]	0.20
Chromic oxide III	1.00
Total	1000
Starch (g kg^{-1})	122.10
Gross energy (kJ g^{-1})	19.23
Crude fibre (g kg^{-1})	14.70
Lipid (g kg^{-1})	132.00
Crude protein (g kg^{-1})	460.00

[1] Mineral mix (Agroceres®, Rio Claro, SP, Brazil) per kg of product: Fe 100 000 mg; Cu 15 000 mg; Zn 150 000 mg; I 4 500 mg; Mn 60 000 mg; Se 400 mg e Co 2000 mg.
[2] Vitamin mix (Agroceres®) per kg of product: vitamin A 6 000 000 UI; vitamin D_3 2 250 000 UI; vitamin E 75 000 mg; vitamin K 3000 mg; thiamine (B1) 5000 mg; riboflavin (B2) 10 000 mg; niacin 30 000 mg; pyridoxine 8000 mg; pantothenic acid 30 000 mg; biotin 2000 mg; folic acid 3000 mg; cobalamin 20 000 μg; ascorbic acid (Vitamin C) 192 500 mg.
[3] Butyl-hydroxy-toluene.

Fish and experimental conditions

Juvenile striped surubim *P. reticulatum* (82.4 ± 17.8 g; 23.0 ± 1.6 cm L_T) was adapted to laboratory conditions for 30 days and then stocked in 21, 80-L cylindrical plastic cages (five animals per cage) housed in 1000-L plastic tanks, and fed manually to apparent satiation twice a day (20h00min and 22h00min). Two hours after last meal, fish were transferred to cylindrical, conical-bottomed aquaria (200 L) under aeration and continuous water exchange, coupled to refrigerated plastic bottles for faeces collection by sedimentation; faecal material was collected twice (6h00min and 12h00min) according to recommendation of Kitagima & Fracalossi (2010).

Water quality parameters remained constant and within the comfort zone of the species (average temperature 28.0 ± 1.5 °C, dissolved oxygen 5.5 ± 1.2 mg L^{-1}; pH 7.6 ± 0.4; unionized ammonia levels remained below detection threshold) for the duration of the trial. Faeces were collected in refrigerated flasks (0 °C) coupled to the bottom of the aquaria (Portz & Cyrino 2004) and transferred to 50-mL tubes, centrifuged under refrigeration (3100 ***g***; 4 °C; 10 min) and lyophilized (−50 °C; 1 mbar) for subsequent analysis.

Chemical and statistical analyses

Chemical composition of feedstuffs, diets and faeces was determined according to procedures of Association of Offi-

Table 2 Chemical composition of ingredients

Nutrient	SBM	WB	COR	CGM	FM	MBM	PBM	BM	FEM
Gross energy (kJ g^{-1})	17.31	16.71	16.52	21.97	18.41	15.28	19.86	21.06	21.37
Crude Protein (g kg^{-1})	461.8	156.3	78.8	635.4	633.8	448.7	583.5	910.7	842.0
Starch (g kg^{-1})	nd	419.1	601.6	117.4	nd	nd	nd	nd	nd
Lipids (g kg^{-1})	11.4	33.2	33.3	76.9	95.9	126.5	141.4	2.1	28.0
Crude fibre (g kg^{-1})	64.7	86.6	18.1	7.9	nd	nd	nd	nd	nd
Ash (g kg^{-1})	63.2	49.2	13.8	66.9	146.0	340.1	150.1	16.5	34.0
Moisture (g kg^{-1})	114.8	116.1	115.6	94.9	124.2	76.9	86.0	75.0	81.0

SBM, soybean meal; WB, wheat bran; COR, corn; CGM, corn gluten meal; FM, fish meal; MBM, meat and bone meal; PBM, poultry by-product meal; BM, blood meal; FEM, feather meal; nd, not determined.

cial Analytical Chemists – AOAC (2000). Moisture was determined by the gravimetric method, at 105 °C to constant weight. Ash contents were determined by gravimetric method after and incineration of organic matter in a furnace at 550 °C. Crude protein contents were determined by micro-Kjedahl method and ether extract by extraction with petroleum ether, Soxhlet method. The gross energy was estimated in adiabatic calorimeter bomb using benzoic acid as standard. The levels of chromium III oxide were quantified by atomic absorption spectrophotometry after acid digestion. Collected data were submitted to ANOVA, and differences in treatment means detected by Tukey's test (α = 0.05%) through SAS statistical analysis software (SAS Institute, Cary, NC, USA).

Results

Apparent digestibility coefficients determined for FM, MBM, poultry by-product meal (PBM), feather meal (FEM), blood meal (BM), soybean meal (SBM), wheat bran (WB), corn (COR) and corn gluten meal (CGM), and are presented in Table 3. The highest ADCs of crude protein were recorded PBM, MBM, FM (99.36, 87.36, 82.84%, respectively), whereas the ADC of crude protein of MBM and FM did not differ from that of SBM and BM (66.00% and 59.98%, respectively). By its turn, the ADCs of crude protein for WB and COR (53.65% and 51.40%, respectively) did not differ from values recorded for SBM and BM, and ADC of crude protein for COR did not different from FEM (19.75%), which did not differ from CGM, the lowest ADC recorded for crude protein, 11.48%.

Regarding of gross energy, the best ADCs were recorded for MBM, SBM, PBM, BM and FM (93.63%, 88.89%, 86.25%, 84.61% and 78.59%, respectively). The ADC of FEM (53.77%) differed only of the MBM; ADC of gross energy for FM and FEM was equal to those of CGM and COR (47.41% and 43.24%, respectively). Finally, values of ADC of gross energy values for FEM, CGM and COR did not differ from the ADC of WM (40.45%).

The best ADC for gross energy and protein was recorded for FM, MBM and poultry by-product meal. In regard to plant feedstuffs, only SBM had good ADC values for energy and protein.

Discussion

Fish meal

Values of ADC of protein (CP) and energy (GE) for FM ranged satisfactorily, but were considered low in comparison with ADCs reported for other species of similar weight class, such as the Atlantic cod *Gadus morhua* – respectively 93.3% and 92.8% for herring meal, and 92.2% and 86.4% for anchovy meal – and haddock *Melanogrammus aeglefinus* L. – 95.9 and 92.2%, respectively, for herring meal (Tibbetts *et al.* 2004, 2006). The ADC of CP and GE of carnivorous fish of different weight classes actually vary with size and dietary protein source. For the juvenile South American characin dourado *Salminus brasiliensis* (19.5 g), for instance, Borghesi *et al.* (2009) recorded ADC of 94.3% and 91% for CP and GE, respectively; juvenile rockfish *Sebastes schlegeli* (30 g) had ADC of 88% and 90% for CP and GE of white FM, and 92% and 93% for CP and GE of anchovy meal (Lee 2002); juvenile cobia *Rachycentrum canadum* (10 g) had ADC of 96.27% and 95.46% for CP and GE of Peruvian FM (Zhou *et al.* 2004); juvenile striped bass *Morone saxatilis* × *Morone chrisops* (50 g) averaged ADCs of 88.23% and 95.56% for CP and GE of menhaden meal (Sullivan & Reigh 1995); juvenile grouper *Epinephelus coioides* (12 g) had, respectively, ADC of 89.92% and 93.27% for PB and GE of white FM, and 87.43% and 89.46% for PB and GE of brown FM (Lin *et al.* 2004); and, finally, juvenile yellowfin seabream *Sparus latus* (41 g) had ADC for CP and GE of 86.4% and 93.6%, respectively, for white FM (Wu *et al.*

Table 3 Apparent digestibility coefficient and digestible values of energy and crude protein of tested ingredients

Ingredients	ADC gross energy (%)	SEM	Digestible energy (kJ g^{-1})	ADC protein (%)	SEM	Digestible protein (g kg^{-1})
Fish meal	78.59^{abc}	8.51	14.47^{ab}	82.84^{abc}	6.71	525.1^{a}
Meat and bone meal	93.63^{a}	2.64	14.30^{ab}	87.36^{ab}	3.22	392.0^{ab}
Poultry by-product meal	86.25^{ab}	9.07	17.13^{ab}	99.36^{a}	3.01	579.8^{a}
Feather meal	53.77^{bcd}	8.62	11.49^{abc}	19.75^{de}	10.80	166.3^{cd}
Blood meal	84.61^{ab}	3.13	17.82^{a}	59.98^{bc}	2.28	546.2^{a}
Soybean meal	88.89^{ab}	8.04	15.38^{ab}	66.00^{bc}	7.31	304.8^{bc}
Wheat meal	40.45^{d}	5.75	6.76^{c}	53.65^{c}	3.69	83.9^{d}
Corn	43.24^{cd}	6.30	7.14^{c}	51.40^{dc}	7.38	40.5^{d}
Corn gluten meal	47.41^{cd}	1.05	10.41^{bc}	11.48^{e}	1.91	72.9^{d}

Values followed by the same superscripts within columns do not differ ($P > 0.05$).
ADC, apparent digestibility coefficients; SEM, standard error of mean.

2006). All these ADCs were higher than those recorded for the striped surubim, and this can be explained by the possible use of better quality FM in those trials.

Values of ADC of protein and energy herein recorded were similar to those reported for speckled catfish *P. corruscans* (9.8 g) by Gonçalves & Carneiro (2003) – 84.14% and 72.8%, respectively – for surubim *Pseudoplatystoma* spp. (9.8 g) by Teixeira *et al.* (2010), who reported ADC of 86.56% and 86.15% for CP and GE, respectively; and for the largemouth bass *Micropterus salmoides* (8 g), for which Portz & Cyrino (2004) reported ADC of 87.7% for CP and 78.3% for GE. These three experiments probably used FM having quality standards matching that of this experiment, as they were carried out in the same region but at different times. Nonetheless, independently of age, weight class and feedstuff quality, surubim catfish *Pseudoplatystoma* spp. seemingly digest dietary FM less efficiently than other carnivorous fish.

Meat and bone meal

Apparent digestibility coefficients values of crude protein and gross energy of MBM for striped surubim were similar to those reported for rockfish – 91.0 and 93.0%, respectively, for 300-g fish, and 90.0% and 90.0%, respectively, for 30-g fish – and cobia – 87.21% and 90.37%, respectively (Lee 2002; Zhou *et al.* 2004). In contrast, lower results were determined for red drum *Sciaenops ocellatus* – 74.06% and 54.09%, respectively (McGoogan & Reigh 1996). These results can be related to the virtual lower quality of this ingredient, which may contain higher proportions of bone, a much less digestible material than muscle proteins (National Research Council 2011). However, because the chemical composition of the MBM reported in National Research Council (2011) – 509 g kg^{-1} crude protein; 97 g kg^{-1} lipids, 24 g kg^{-1} crude fibre; 292 g kg^{-1} ash – differ to a somewhat great extent from data herein reported, no further comparisons are allowable.

Poutry by-product meal

The ADC value for crude protein of PBM for striped surubim was similar to those reported for Coho salmon *Oncorhynchus kisutch* (94.2%) and rainbow trout *Oncorhynchus mykiss* (95.9%) (Sugiura *et al.* 1998); however, values were higher than those reported for dourado (91.3%), speckled catfish (61.59%), largemouth bass (81.5%), sunshine bass *Morone chrysops* × *M. saxatilis* (75.16%) and cobia (90.9%) (Gonçalves & Carneiro 2003; Portz & Cyrino 2004; Zhou *et al.* 2004; Thompson *et al.* 2008; Borghesi *et al.* 2009). Values of ADC of gross energy neared those reported for dourado (90.3%), largemouth bass (85.2%) and cobia (90.58%) (Portz & Cyrino 2004; Zhou *et al.* 2004; Borghesi *et al.* 2009); however, a smaller value was reported for juvenile speckled catfish (48.98%) (Gonçalves & Carneiro 2003).

Chemical composition of PBM utilized in the cited studies was similar to that of PBM utilized in this study. The differences in the digestibility of nutrients by the surubim are more likely associated with ingredient manufacture and diets processing, both affecting nutrients availability at ingredients and diets levels (Allan *et al.* 2000). Processing conditions affect ADC of animal and plant ingredients, affecting the quality and availability of nutrients. Bureau *et al.* (1999) actually reported that the differences in apparent digestibility of protein and energy of feather meal recorded for rainbow trout (81% and 87%, and 76% and 80%, respectively) can be a result of the drying process.

Feather meal

Apparent digestibility coefficients of feather meal's GE was similar to that reported for speckled catfish by Gonçalves & Carneiro (2003) (51.26%), but lower than the ADCs reported for rockfish – 73.0% for 30-g fish and 85.0% for 300-g fish – by Lee (2002). Higher values of ADC of CP were registered for juvenile speckled catfish (39.56%), rockfish – 63.0% for 30-g fish and 79.0% for 300-g fish – rainbow trout (85.9%), and Coho salmon (79.7%), while juvenile striped surubim used only 19.75% of feather meal's protein (Sugiura *et al.* 1998; Lee 2002; Gonçalves & Carneiro 2003); however, the chemical composition of these ingredients was different. In this study, the ash contents of the feather meal were higher than that recorded in the others studies and that can explain the lower ADCs registered for protein.

Blood meal

Striped surubim digested blood meal's GE similarly to that reported for juvenile rockfish (86.0%), and digested blood meal's CP similarly to that reported for juvenile humpback grouper *Cromileptes altivelis* (55.2%) fed diets containing spray-dried blood meal (Lee 2002; Laining *et al.* 2003). According to Teixeira *et al.* (2010), juvenile surubim use dietary, dried blood plasma rather efficiently, having ADC of 79.18% for CP and 58.8% for DE; on the other hand, reported values of ADC for CP (10.47%) and GE (16.08%) for speckled catfish were very low (Gonçalves & Carneiro 2003). The low digestibility can be explained by a virtually low nutritional value of the ingredients; also in this case, the ash contents of the blood meal used for speckled catfish were higher than those used in other experiments.

Soybean meal

Soybean meal is the best plant protein source known and used for formulating and processing fish feeds, because it has good amino acids balance. This ingredient can replace up to 50% FM in diets for trout, and up to 94% for omnivorous fish. It is also cheaper than FM and presents better market availability (Lovell 1985, 1990; Davis *et al.* 1995; Chou *et al.* 2004; Ai & Xie, 2005; Ai & Xie 2006; Heikkinen *et al.* 2006; Refstie *et al.* 2006; Tibaldi *et al.* 2006; Venou *et al.* 2006; Wang *et al.* 2006; Hernández *et al.* 2007). The ADCs of GE and CP of SBM for striped surubim were deemed satisfactory and actually close to those recorded for speckled surubim, respectively, 83.47% and 61.52% (Teixeira *et al.* 2010). In comparison with other carnivorous fish, both marine and fresh water species, such as the red drum, Coho salmon, rainbow trout, sunshine bass, dourado, striped bass, haddock, largemouth bass, grouper, yellowfin tuna, seabream and Atlantic cod (Sullivan & Reigh 1995; McGoogan & Reigh 1996; Sugiura *et al.* 1998; Lin *et al.* 2004; Portz & Cyrino 2004; Tibbetts *et al.* 2006; Wu *et al.* 2006; Thompson *et al.* 2008; Borghesi *et al.* 2009), juvenile striped surubim averaged lower ADC of CP, well-matched only to juvenile pintado and speckled surubim in regard to SBM protein – 67.2% and 61.52%, respectively (Gonçalves & Carneiro 2003; Teixeira *et al.* 2010). As a matter of fact, utilization of dietary SBM protein by carnivorous catfishes seems to be very poor as a rule.

Wheat bran

The WB has a starch content of 419 g kg^{-1}, and the ADC of energy was <40%, thus demonstrating the how difficult it is for striped catfish digesting starch. A higher value of ADC of energy of WB was recorded for specked surubim (53.2%), which also demonstrates that carnivorous fish make poor use of starch as dietary energy source. WB protein was not also well digestible by striped catfish (53.655); similarly poor results were reported for speckled surubim (48.47%) by Gonçalves & Carneiro (2003). However, in comparison with results recorded for the omnivorous pacu *Piaractus mesopotamicus* (ADC of CP: 87.7% and ADC of GE: 74.4%) by Abimorad *et al.* (2008), results herein reported are very nothing but modest.

Corn

Same as for WB, corn is rich in starch (600 g kg^{-1}) so, as anticipated, ADC of CP and GE of COR for striped surubim were low. The poor utilization of nutrients of this ingredient also was reported for speckled catfish – ADC of CP 64.18% and ADC of GE 64.95% (Gonçalves & Carneiro 2003). This result can be related once again to the feeding habits of fish. For instance, higher digestibility values of CP (85.8%) and GE (758%) were recorded for the omnivorous pacu by Abimorad *et al.* (2008).

Corn gluten meal

In relation to the ADC of protein, CGM was a little used ingredient for striped surubim (only 11.48%). Carnivorous fish such as Coho salmon, rainbow trout, rockfish, cobia, dourado, haddock, largemouth bass and Atlantic cod (Sugiura *et al*. 1998; Lee 2002; Portz & Cyrino 2004; Zhou *et al*. 2004; Tibbetts *et al*. 2006 and Borghesi *et al*. 2009) average high ADC for protein of CGM (>80%). Juvenile speckles surubim can also efficiently digest protein and energy of CGM of 78.91% and 75.76%, respectively (Teixeira *et al*. 2010). Seemingly, the low utilization of CGM by juvenile striped surubim can be related to low palatability, processing, and also profile and availability of the remaining nutrients of this ingredient.

In summary, the best ADCs of animal rendered protein sources were recorded for PBM, MBM and FM, whose balance and amino acids profile near fish nutritional requirements. In contrast, BM and FEM were poorly digested by striped catfish, possibly as a result of the imbalance of amino acids or deficiency of some essential amino acids.

In regard to plant protein sources, SBM is the best known and used ingredient for formulating and processing fish feeds, because it has good amino acids balance. On the other hand, CGM is not a good plant protein source for striped surubim, and also not a good plant energy source, such as WM and C. The ADC of GE of these ingredients by striped catfish was lower than 50%. Carnivorous fish have limitations digesting and utilizing starch; starch digestibility may also be affected by temperature and salinity of the water and lipid levels in the feed (Krogdahl *et al*. 2005; Hua & Bureau 2009).

Crude protein of poultry by-product meal, and of gross energy of MBM, was comparatively better digested by striped surubim. These ingredients can thus be used for partially replacing FM, respectively, as dietary protein and energy sources for formulation and processing of diets for the species.

Acknowledgements

Authors are indebted to Fundação de Amparo à Pesquisa de São Paulo [São Paulo State Research Foundation – FAPESP], grant # 2008-56806-5, and Conselho Nacional de Desenvolvimento Científico e Tecnológico [National Council for Scientific and Technological Development – CNPq] for partial funding the research, grant # 2008-479519-0. TSCS is a doctoral candidate, FAPESP scholarship (2009/52584-0); GVM and JKD hold research appointment with Empresa Brasileira de Pesquisa Agropecuária [EMBPAPA]. JEPC is a CNPq research scholar.

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