Digestion of sweet potato (*Ipomoea batatas* (L.) Lam) foliage in pigs. Ileal and fecal *in vitro* digestibility

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The ileal (pepsin/pancreatin) and rectal (fecal inoculum) *in vitro* digestibility of organic matter (OM) and N were determined in four samples of sweet potato (*Ipomoea batatas* (L.). Lam) foliage meal and was compared with that of soybean and maize. The ileal *in vitro* digestibility of DM and OM of the sweet potato foliage meal was of 40.6 and 40.3 %, respectively, while these same indexes at fecal level were of 46.4 and 51.0 %, respectively. The production of total short-chain fatty acids ($P < 0.001$) related, significantly, with the fecal *in vitro* digestibility of the OM (R^2 1.000). It is suggested that the nutritive value of sweet potato foliage meal may be inversely proportional to its content in mineral material and cell wall.

Key words: *pigs, in vitro digestibility, pepsin, pancreatin, fecal inoculum, sweet potato foliage*.

In Venezuela, assessing the alternative raw materials that allow the total or partial substitution of imported cereals is of great importance, particularly if it is about the protein sources assigned to pigs' rations. The sweet potato (*Ipomoea batatas* (L.) Lam) foliage is a foliar resource with relatively high protein content (González 1994 and González *et al*. 2003), compared with the foliages of tropical legumes (Carvajal 2010). Therefore, deepening in the use of its nutrients is necessary so a data base could be establish for formulating the balanced rations for swine feeding.

With this purpose, studies on digestibility of raw material with agroecological advantages for the tropics are needed. In the case of sweet potato foliage, digestibility assessments up to the ileum are required, because the degradation of this protein in the large intestine of the animals does not have nutritive value for pigs (Zebrowska 1973). Under this research conditions, the simulation techniques of *in vitro* digestibility highlight for being cheap and fast, apart from propitiating data strongly correlated with the *in vivo* results, at least from the OM and energy digestibility point of view in swine (Anguita *et al*. 2006, Noblet and Jaguelin-Peyraud 2007 and Regmi *et al*. 2008).

In previous studies of Díaz *et al*. (2012) the *in situ* nutrient digestibility of sweet potato foliage was examined in form of meal. The objective of this experiment was to determine the ileal and fecal *in vitro* digestibility of nutrients in pigs fed Venezuelan sweet potato foliage meal.

Materials and Methods

Two experiments were conducted to determine the ileal and rectal *in vitro* digestibility of nutrients of sweet potato (*Ipomoea batatas* (L.) Lam) foliage meal. The sweet potato foliage is constituted for the air part of the plant, cut periodically to harvest the foliage. The plantations were located in the Agronomy Faculty of the Central University of Venezuela. The varieties cultivated were UCV-2, UCV-5, UCV-7, UCV-8, Carolina, Catemaco and Topera (Arrioja1995). The foliage was dried under roof and ground to obtain the meal resulting from the proper mixture of all the sweet potato variables in the same proportion, for its use as four lots addressed to experiments of *in vivo* digestibility with pigs (González *et al*. 2003 and Díaz *et al*. 2012). The table 1 shows the characteristics of sweet potato foliage meal used in this experiment.

The chemical composition and energy content of the meal, resulting from the mixture of seven types of sweet potato foliages were similar to that calculated from the product of the mixture of the seven varieties in equal proportion. This indicates that, in the practice, the mixture and homogenization were good (table 2).

In the digestibility studies reported here, a sample of maize meal and other of soybean, both from commercial origin, were used. They were obtained from random samplings in the feed deposit, specifically of animal concentrate, located in factories of Maracay. Casein was used as reference substance for the evaluations of ileal *in vitro* digestibility. Under conditions of ileal and fecal simulation, rice starch and wood cellulose, with analytic quality available in the lab were used.

In the first experiment, the successive incubation technique with pepsin in acid culture was used. Later, pancreatin was applied in lightly alkaline culture, according to Dierick *et al*. (1985), and very close to that described by Ly (2008). For conducting the incubations, 0.5 g of sample was suspended in 20 mL of swine pepsin solution, suspended in HCl 0.075 N at a rate of 1 g/L.

Table 1. Characteristics of the sweet potato (*Ipomoea batatas* (L.) Lam) foliage meals

Indicator	Cultivated variety of sweet potato						
	UCV-2	UCV-5	UCV-7	UCV-8	Carolina	Catemaco	Topera
DM, %	90.27	94.90	89.75	91.08	95.40	89.41	93.53
Ash, %	26.87	20.39	26.36	22.49	21.25	24.35	20.14
OM, %	73.13	79.61	73.64	77.51	78.75	75.65	79.86
NDF, %	31.12	37.77	35.77	39.58	38.27	44.99	38.16
N x 6.25, %	20.71	15.32	17.61	15.02	17.47	10.32	13.87
CE, kjoule/g DM	17.89	17.40	18.19	17.51	16.64	17.91	17.98

Table 2. Characteristics of the sweet potato foliage

Indicator	Sweet potato foliage meal	
	Theoretical value[1]	Practical value[2]
DM, %	92.05 ± 2.32	91.85 ± 2.35
Ash, %	23.12 ± 2.57	22.80 ± 2.04
OM, %	76.88 ± 2.57	77.20 ± 2.50
NDF, %	37.95 ± 3.85	38.16 ± 4.22
N x 6.25, %	15.76 ± 3.04	15.50 ± 4.04
CE, kjoule/g DM	17.65 ± 0.48	17.47 ± 0.48

[1] Mean and SE of the seven cultivated varieties described in table 1
[2] Mean and SE of four representative samples in both lots used in *in vivo* digestibility tests

The simulation of gastric digestion was conducted for four hours at 37 °C. The samples were agitated in a water bath with a thermostat, with sporadic agitation. The incubation culture was neutralized with Na OH 0.2 N. This solution with pH of 7.5 was added 20 mL of pancreatin solution, 1.5 g/L in phosphate buffer 0.2 M. Again the sample was incubated during other four hours in bath with thermostat, at 37 °C. At the end of the incubation, the incubation culture was mixed with 10 mL of phosphotungustic acid 0.02 M. Later, the sample was filtered and the remaining residue was dried in an oven at 60 °C with air circulation. The ash and N content were determined in this residue, according to the procedures of AOAC (2000). The *in vitro* digestibility was calculated according to that reported by Dierick *et al*. (1985). The ileal *in vitro* digestibility of four samples of sweet potato foliage meal was determined and compared with others of maize meal, soybean and casein, used as reference substrate.

In the second experiment, the fecal *in vitro* digestibility technique was applied through the use of an inoculum of fresh pig feces, according to the method of Lowgreen (1992). Recent fecal material from four donor animals fed 30 % of sweet potato foliage meal was used. The fresh feces sample was carefully mixed and suspended in a solution at 39 °C with continuous injection of CO_2, and at a rate of 1:2 in weight. The fecal saline suspension was homogenized for a minute. It was filtered through four muslin layers to use 10 mL as buffered inoculum in a mixture with 40 mL of phosphate buffered solution, with pH equal to 6.9.

An amount of 0.5 g of the insoluble residue of the samples was used after being previously incubated with pepsin/pancreatin (experiment 1). This insoluble residue was incubated with 50 mL of fecal inoculum buffered in CO_2 atmosphere. The incubation was conducted during 48 h through immersion of the recipients with the sample in a water bath with thermostat, at constant temperature of 39 °C, with occasional agitation. At the end of the incubation, the samples were filtered and the residue was dried at constant weight to calculate the fecal *in vitro* digestibility, according to Lowgreen (1992). The same four samples of sweet potato foliage meal, maize and soybean used in the experiment 1 were used in the 2. However, apart from casein, the substances of reference were the rice starch and wood cellulose. At the end of the incubation, samples from the liquid phase were taken and determined the concentration of short-chain fatty acids (SCFA) by the steam dragging technique and distilled assessment with NaOH 0.05 N (Phinmasan *et al*. 2004).

The data were compared by analysis of variance, according to linear model of simple classification. When the means contrast was significant ($P < 0.05$), they were separated by the Duncan's test (Steel *et al*. 1997). The statistical model of the Minitab (2009) was used for the data manipulation.

Results

The results of the ileal *in vitro* digestibility are presented in table 3. That of the casein was close to 100 %, and differed significantly ($P < 0.001$) from the three feed samples examined. The maize meal showed

ileal *in vitro* digestibility of DM superior to that of the soybean, occurring the contrary for the N. The sweet potato foliage showed relatively low values for the ileal *in vitro* digestibility of DM and N.

The data corresponding to the fecal *in vitro* digestibility and the SCFA concentration in the incubation culture is presented in table 4. All the data of fecal *in vitro* digestibility were significantly higher than those of the ileal digestibility (table 3). The fecal *in vitro* digestibility of sweet potato foliage was lower than that of maize or soybean ($P < 0.001$). That of casein, rice starch and wood cellulose was very high for the starch sample and very low for that of cellulose.

When the population size was meager and without considering the values found for casein, there was relevant correspondence (R^2, 1.000) ($P < 0.001$) between the fecal *in vitro* digestibility of OM and the concentration of total SCFA in the incubation medium (figure 1).

Table 3. Ileal *in vitro* digestibility of sweet potato foliage meals

Indicator	n	Ileal *in vitro* digestibility, %		
		DM	OM	N
Casein	4	98.5[a]	99.0[a]	98.2[a]
Maize meal	4	74.1[b]	74.6[b]	76.9[b]
Soybean meal	4	64.0[c]	62.6[c]	91.4[a]
Sweet potato foliage meal	4	40.6[d]	40.3[d]	56.3[c]
SE ±	-	4.3***	4.1***	6.5***

[abcd] Means in the same column, without common letter differ significantly ($P < 0.05$) among them .
*** $P < 0.001$

Table 4. Fecal *in vitro* digestibility of sweet potato foliage meal

Indicator	n	Fecal *in vitro* digestibility, %			SCFA
		DM	OM	N	mmol/g MO
Casein	4	95.5[a]	96.0[a]	96.6[a]	-
Rice starch	4	85.8[b]	86.6[b]	-	6.57[a]
Wood cellulose	4	25.8[d]	27.0[d]	-	4.35[d]
Maize meal	4	85.0[b]	88.0[b]	80.0[b]	6.62[a]
Soybean meal	4	70.1[c]	75.7[c]	96.6[a]	5.96[b]
Sweet potato foliage meal	4	46.4[d]	51.0[d]	59.8[c]	5.08[c]
SE ±	-	3.9***	3.1***	5.5***	0.004***

[abcd] Means in the same column without common letter differ significantly ($P < 0.05$) among them . *** $P < 0.001$

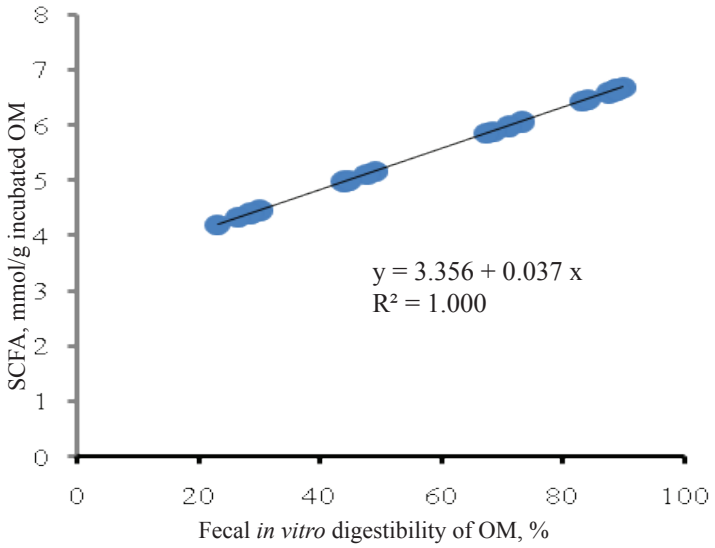

Figure 1. Fecal *in vitro* digestibility of OM and SCFA production in sweet potato foliage meal for pigs (Syx = ± 0.0031

Discussion

At present, there is scarce information about the data of *in vitro* digestibility of sweet potato foliage (Nguyen Nhut Xuan *et al*. 2002). Studies of Domínguez and Ly (1997) and of Ly *et al*. (2009) conducted in Cuba and those of Gonzalvo *et al*. (2001) and Ly *et al*. (2009), conducted in Venezuela are known. It should be considered in this aspect that all the values, even those of this study, tend to be similar, even when the experimental conditions did not coincide. It could be considered that there was tendency to the lowest values in the Cuban values rather than those from Venezuela. The table 5 presents this information.

Table 5. Values of *in vitro* digestibility of sweet potato foliage

Origin of the sweet potato foliage meal	*In vitro* digestibility, %			Reference
	DM	OM	N	
Up to ileum				
Artemisa, Cuba	-	-	42.2	Domínguez y Ly (1997)
Portuguesa, Venezuela	32.3	24.4	33.9	Gonzalvo *et al*. (2001)
Aragua, Venezuela	40.6	40.3	56.3	This experiment
Up to rectum				
Artemisa, Cuba	46.3	51.7	37.0	Ly *et al*. (2009)
Portuguesa, Venezuela	52.5	57.3	47.6	Ly *et al*. (2009)
Aragua, Venezuela	46.4	51.0	49.8	This experiment

The ash and cell wall (NDF) content was considerably high in the sweet potato foliage, 22.8 and 38.1% respectively (table 2). This undoubtedly had a marked influence on both ileal and fecal *in vitro* digestibility (Nguyen Nhut Xuan *et al*. 2002). On this respect, it has been suggested that the N digestibility is exposed to the nature of its connection with the cell wall, which could vary according to the type of foliar resource as such (Licitra *et al*. 1996). It is possible that this type of connection would be hard to break in the sweet potato foliage, especially by bacterial enzymes. This could lead to conduct more researches with this feeding resource if used in swine.

In respect to the substances of reference, the data of ileal *in vitro* digestibility of sweet potato foliage meal could be proved because the ileal *in vitro* digestibility of casein, used as substance of reference, was almost complete. In the exam presented here, the values of fecal *in vitro* digestibility of rice starch and cellulose agree with those of other experiment previously conducted (Ly 2005).

The relatively low values of ileal *in vitro* digestibility of sweet potato foliage meal corresponded with those of *in situ* conditions (Díaz *et al*. 2012), but were higher numerically. On this respect, Díaz (2013, unpublished data) found *in vitro* digestibility values for DM and OM equal to 34.7 and 34.4 % respectively, when calculated by difference. The ileal *in vitro* digestibility for the DM and OM obtained in this experiment was of 40.6 and 40.3 %. It has been stated that the values under *in vitro* conditions were superior to those *in vivo*, usually understood as the absent effect of the endogenous segregation and scaling of mucosa and the rest of the bacterial cell walls in the incubation culture. This makes the values of *in vitro* digestibility and true digestibility closer (Boisen and Fernández 1991, 1995 and Ly 2008).

From another perspective, Qiao *et al*. (2004) found notable discrepancies among their *in vitro* and *in vivo* digestibility data at ileal level in 25 samples of animal protein. These authors suggested that the *in vitro* test could be surpassed with better solubilization of the digestion or with more replicates. In this research, where the protein was of foliar nature, the difference found between both procedures was not of great magnitude.

In respect to the data of fecal *in vivo* digestibility of sweet potato foliage, similar to those of this assessment, were of 57.4 and 61.1% for DM and OM, while those of fecal *in vitro* digestibility were of 46.4 and 51.0 %, respectively. An acceptable explanation of the causes leading to these results is difficult, although it could be assumed that the bacterial population in the incubated inoculum was, undoubtedly, numerically inferior to that proved in the in natura excretions, due to the dilution process in the buffer solution, which could diminish its fermentative activity. Individual differences in the fecal microbial of pigs have also been suggested (Bauer *et al*. 2001). Nevertheless, the found general tendency, *in vitro* and *in vivo*, was of a poor participation of the large intestine in the nutrients digestion of sweet potato foliage meal. On this respect, González *et al*. (2003) did not find weight increase of the large intestine of growing-fattening pigs fed *ad libitum* with sweet potato foliage meal but proved lower contribution of the empty and fresh weight of the cecum and colon to the total of the digestive tract, from 40.8 % in the diet without foliage to 34.3-38.8 % in the treatments with animals consuming foliage *ad libitum*, between at about 10 and

20 % of the total diet.

These data could indication that there was not anatomic adaptation, that is, certain type of hypertrophy to accommodate higher amounts of roughage. This is typical of the high-fiber diets offered to the pigs (Jorgensen *et al*. 1996 and Whittemore *et al*. 2003). On the other hand, the correspondence between the fecal *in vitro* digestibility of OM and the SCFA production is supported by other studies, as those of Awati *et al*. (2006).

In this study, the *in vitro* digestibility of N, both ileal and fecal, reaching to 56.3 and 49.8 % respectively, may suggest that few nitrogen compounds that do not have a digestion in the small intestine, have null disappearance in cecum and colon.

It is suggested that the nutritive value of sweet potato foliage meal may be inversely proportional to its content in raw material and cell wall. This hypothesis should be subject of study of new researches. If tested, all the procedures that tend to diminish the content of these two foliage fractions should increase the digestibility of other fractions of this feeding resource.

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