Digestion of sweet potato foliage (*Ipomoea batatas* (L.) Lam) in pigs. Ileal and rectal digestibility of nutrients and energy

Ivonne Díaz[1,2], C. González[1], J.L. Reyes[2] y J. Ly[2]
[1]*Facultad de Agronomía, Universidad Central de Venezuela. El Limón, Maracay, Venezuela*
[2] *Instituto de Investigaciones Porcinas. Punta Brava, La Habana, Cuba*
Correo electrónico: caraujo2@gmail.com

Two experiments were performed, according to Latin square 4x4, to determine the ileal and rectal digestibility of nutrients and energy in growing Yorkshire x Landrace pigs. They were fed with variable levels (0, 10, 20 and 30 % on dry basis) of sweet potato foliage meal (*Ipomoea batatas* (L.) Lam). In experiment 1, four castrated males, of 35 kg and prepared with an ileo-rectal anastomosis, were used. In experiment 2, eight non castrated pigs of 38 kg were used. It was confirmed that the ileal digestibility of DM, organic matter and energy decreased significantly (P < 0.05) with the inclusion of the foliage. However, there were no differences between the treatments with 0 and 10 % of the foliage, nor with 10 and 30 %. The rectal digestibility showed the same fact (P < 0.05) for the DM, organic matter and energy. The ileal and rectal digestibility, measured by difference, were 34.4 and 61.1% for the organic matter of the foliage, and 40.6 and 59.0 % for the energy. From the digestive point of view, the sweet potato foliage meal can be provided to pigs in levels not higher than 30 % of the food, as a source of proteins and minerals in diets of very low amount of fiber.

Key words: *pigs, digestion, ileum, nutrients, sweet potato foliage*

In another experiment, carried out at the same time, the *in situ* digestibility of the meal of sweet potato (*Ipomoea batatas* (L.) Lam) foliage was evaluated through the use of the mobile nylon bag, introduced into the duodenum of pigs (Díaz *et al*. 2012). Studies carried out in Venezuela have made determinations of *in vivo* digestibility of this meal of sweet potato foliage, in non castrated animals, at the ileal or rectal level (Arrioja 1995, Romero *et al*. 2002 and González *et al*. 2011).

There are not many evaluations developed in different tropical environments (Domínguez and Ly 1997, Le Van *et al*. 2004 and Du Than *et al*. 2009), which would provide information about the digestive processes taking place in different sections of the gastrointestinal tract of pigs fed with products of foliar sweet potato. The nutritional value of the meal resulting from the aerial part of the sweet potato plants has been examined up to the ileum and the rectum (Domínguez and Ly 1997 and Du Than *et al*. 2009). The nutritional value of leaves of ensiled, dry or fresh sweet potatoes has also been studied up to the ileum and the rectum (Le Van *et al*. 2004). Other evaluations have compared the ileal and the rectal digestibility of different cultivated varieties of foliage, included as a constant proportion on the diet (Arrioja 1995).

The objective of this study was to determine the ileal and rectal digestibility of nutrients in pigs fed with variable levels of Venezuelan sweet potato foliage meal. The digestibility of N and amino acids is not stated in this study becaused it has been informed in other references (Díaz *et al*. 2013).

Materials and Methods

Two experiments were performed, according to Latin square 4x4, to determine the ileal and rectal digestibility of nutrients and energy in growing Yorkshire x Landrace pigs, fed with variable levels (0, 10, 20 and 30 % on a dry basis) of sweet potato foliage meal (*Ipomoea batatas* (L.) Lam). Table 1 shows the chemical composition of a representative sample, through the quartering method, and the details related to studied diets.

The sweet potato foliage came from plantations located in the Faculty of Agronomy, and it was harvested only once, using periodically cut crops. It came from different cultivated varieties that were mixed conveniently in the same proportion, to be used as a unique lot. The foliage was constituted by the aerial part of the plant (Díaz *et al*. 2012 and 2013). The cultivated varieties were UCV-2, UCV-5, UCV-7, UCV-8, Carolina, Catemaco and Topera (Arrioja 1995). It came from leaves and petioles, and it was dried under roof. Later, it was ground to obtain a meal that was mixed with the rest of the dry ingredients for being later provided to the animals.

Table 2 shows the characteristics of the chemical composition of the diets and of the foliage used. The diets were, approximately, iso-proteic and iso-energetic.

In both experiments, pigs of commercial crossings, mainly Yorkshire x Landrace, castrated males, were used. In experiment 1, four animals, of 35 kg and prepared with an ileo-rectal anastomosis, were used (Domínguez *et al*. 2000). In experiment 2, other eight non castrated pigs were used, without anastomosis. The surgically prepared animals were used after a recovery period of two weeks. During this recovery period, as well as during the experimental stage, the pigs were kept in metabolism cages, in a room without temperature conditioning. Likewise, the non castrated pigs were kept in individual pens or metabolism cages during the period of adaptation and excretion recollection. The metabolism

Tabla 1. Diet ingredients (per cent on a dry basis)

Ingredients	Sweet potato foliage, %			
	0	10	20	30
Corn meal	82.60	74.34	66.08	57.82
Soy meal	13.75	12.38	11.00	9.63
Sweet potato foliage meal	-	10.00	20.00	30.00
$CaCO_3$	0.85	0.77	0.68	0.60
$CaPO_4H.2H_2O$	1.15	1.02	0.92	0.81
NaCl	0.85	0.77	0.68	0.54
Premixture [1]	0.80	0.72	0.64	0.60

[1] Vitamins and trace elements, according to NRC (2012)

Table 2. Chemical composition of experimental diets and of the meal of sweet potato foliage (per cent on a dry basis)

Indicator	Sweet potato foliage meal, %				Sweet potato foliage
	0	10	20	30	
Dry matter	89.51	89.92	90.33	90.74	91.20
Ashes	6.21	7.00	7.80	8.58	14.36
Organic matter	93.79	93.00	92.20	91.42	85.64
Crude fiber	3.64	5.17	6.69	8.21	19.36
ADF	5.01	7.24	9.48	11.72	22.40
NDF	15.00	16.68	18.36	20.04	32.31
Lignin	0.84	2.94	3.35	4.62	12.79
Cellulose	4.17	5.14	6.13	7.10	9.70
Hemicellulose	10.00	9.44	8.88	8.32	9.91
Crude protein, N x 6.25	14.00	14.00	14.00	14.00	15.50
Gross energy, kJ/g DM	17.87	17.78	17.71	17.64	17.08

cages were locally built and they contained a feeding trough and a water drinking nipple.

The level of feed intake was 0.08 g DM/kg LW^{075}. It was offered to animals in a single ration, at 9:00 am in the case of the ileo-rectostomized pigs, while the non castrated animals were fed at 8:00 am and 6:00 pm. The food was wetted with water, in a 2:1 proportion, according to weight. The drinking water was always available. Each experimental period had five days for adapting to diet, and two days for sampling in the ileo-rectostomized animals. For the non castrated animals, the period of the collection of fecal material lasted two days, after five days of cages adaptation and seven of diet adjustments.

The details of the procedure for collecting ileal digesta during two consecutive days have been described by Ly *et al*. (1998). In experiment 2, a representative fecal sample was prepared from the faeces collected for five days. The samples of ileal digesta, as the excretions, were mixed and homogenized before storing them at -5 ºC until the moment of the analysis.

The analysis carried out to food, ileal digesta and excretions were practiced, at least, by duplicate. The determination of DM was made in aliquots of fresh samples (AOAC 2005). The rest of the sample was dried at 60 ºC in forced air ovens, for being ground afterwards. In the dried samples, the ashes and crude fiber was measured by known procedures (AOAC 2005), while the gross energy was determined in an adiabatic calorimetric pump. The determination of the different fractions of the cellular wall, NDF, ADF and lignin was made according to the scheme of solubility in detergent solutions of van Soest *et al*. (1991). The content of hemicellulose was considered to be a result from subtracting the value of ADF from the NDF, and the content of cellulose resulted from the substracting the concentration of lignin from the ADF.

The ileal and retal apparent digestibility was estimated according to recommendations made by Schneider and Flatt (1975) and Adeola (2001). Besides, the digestibility of nutrients and energy of the sweet potato foliage was calculated as such, at the level of the ileum and rectum, through the method of difference (Crampton and Harris 1969). The analysis of variance was used for contrasting the means (Steel *et al*. 1997). When it resulted to be significant ($P < 0.05$), the comparison of these means was made by the Duncan test (1955). The statistical package of SAS (2000) was used for analyzing the information.

Results

The sweet potato foliage was evaluated according to the presence of antitryptic factors, by the method proposed by Martínez and Domínguez (2009). There was no presence of these factors in any circumstance.

Experiment 1. The surgically prepared animals maintained a good health during all the experiment. They were positively balanced in their live weight. At the end of the evaluation, the necropsy of these pigs did not reveal any anomaly that could imply changes in the examined digestive processes.

Table 3 shows data about the ileal digestibility of nutrients and energy. It was confirmed that the ileal digestibility of DM, organic matter and energy decreased significantly (P < 0.05) with the inclusion of the foliage, but there were no differences between the treatments with 0 and 10 % of the foliage, nor between 10 and 30 %. There was no significant effect of the treatment on the ileal digestibility of crude protein, NDF and cellulose, but there was a significant effect (P < 0.05) for the ileal digestibility of ADF and hemicellulose.

Table 4 shows the evaluations of the ileal digestibility of nutrients and energy of the sweet potato foliage *per se*. There was no significant effect of the treatment on the evaluated indicators, therefore, the their mean value was calculated.

Experiment 2. Table 5 shows data corresponding to the rectal digestibility. The rectal digestibility behaved like the ileal digestibility (P < 0.05), for the digestibility of DM, organic matter and energy. Similar to the information about the ileal digestibility, the effect of the treatment on the rectal digestibility of the fraction that would identify the non amylaceous polysaccharides was variable. There was no significant effect of the treatment on the rectal digestibility of crude protein, NDF and cellulose, but there was a significant effect (P < 0.05) for the rectal digestibility of ADF and hemicellulose.

Table 6 shows data about digestibility of nutrients and energy within the rectum for the sweet potato foliage, when they were estimated by difference. There was no significant effect of the treatment on the rectal digestibility for the studied indicators, therefore, like in the case of the ileal digestibility, the mean value of the three treatments was determined in all the opportunities.

The disappearance of nutrients and energy of diets was calculated from the data from experiments 1 and 2. Table 7 shows the results of the estimations.

Table 3. Ileal digestibility of nutrients in pigs fed with variable levels of meal of sweet potato foliage

	Meal of sweet potato foliage, %				SE ±
Digestibility, %	0	10	20	30	
Dry matter	76.52[a]	72.09[ab]	67.03[b]	67.96[b]	2.76*
Organic matter	79.51[a]	75.77[ab]	69.82[b]	70.53[b]	2.66*
Crude fiber	16.61	22.49	24.61	29.55	4.74
ADF	18.08[b]	20.95b	32.90[ab]	40.18[a]	6.95*
NDF	39.95	42.92	43.98	48.06	4.90
Celullose	16.10	17.41	22.95	24.22	3.75
Hemicellulose	66.31[ab]	67.50[a]	65.07[ab]	59.09[b]	2.06*
Energy	78.84[a]	74.31[ab]	70.01[b]	70.88[b]	2.45*

[abc] Means with different letter in the same line differ significantly(P < 0.05) among them, according to Duncan (1955)
*P < 0.05

Table 4. Ileal digestibility of nutrients and energy of sweet potato foliage *per se* in pigs, estimated by difference

	Meal of sweet potato foliage, %				SE ±
Digestibility, %	10	20	30	x[1]	
n	4	4	4	-	-
Dry matter	33.75	31.67	38.84	34.76	3.61
Organic matter	46.65	34.11	22.64	34.47	10.02
Crude fiber	16.23	21.25	29.55	22.35	6.39
ADF	8.04	32.89	40.18	27.04	14.58
NDF	69.60	60.10	66.97	65.56	4.55
Celullose	29.20	60.75	43.17	44.37	13.08
Hemicellulose	58.20	60.15	42.33	53.56	8.06
Gross energy	53.11	39.11	29.50	40.67	10.94

[1] Average of the three treatments

Tabla 5. Rectal digestibility of nutrients in pigs fed with variable levels of meal of sweet potato foliage

	Meal of sweet potato foliage, %				SE ±
Digestibility, %	0	10	20	30	
Dry matter	85.01[a]	81.77[ab]	79.93[bc]	77.56[c]	2.02*
Organic matter	86.52[a]	83.52[b]	81.86[bc]	79.63[c]	2.01*
Crude fiber	30.40	30.01	30.33	31.92	3.33
ADF	28.08[b]	30.95[b]	32.90[b]	40.18[a]	4.07*
NDF	57.11	51.91	53.98	59.22	3.80
Celullose	30.15	31.15	32.51	33.00	3.51
Hemicellulose	71.70[b]	71.00[b]	76.47[ab]	86.18[a]	6.05*
Gross energy	81.42[a]	79.07[ab]	77.00[b]	73.37[c]	2.21*

[abc] Means with different letter in the same line differ significantly ($P < 0.05$) among them, according to Duncan (1955)

*$P < 0.05$

Table 6. Rectal digestibility of nutrients of sweet potato foliage in pigs, estimated by difference

	Meal of sweet potato foliage, %				SE ±
Digestibility, %	10	20	30	x[1]	
n	8	8	8	-	-
Dry matter	52.60	59.60	60.16	57.45	3.50
Organic matter	56.50	63.25	63.56	61.10	3.55
Crude fiber	26.50	30.05	35.47	30.67	3.68
ADF	56.89	52.20	65.52	58.17	6.60
NDF	72.60	77.90	76.27	75.59	3.06
Celullose	40.10	41.90	39.63	40.54	2.52
Hemicellulose	94.70	95.55	99.96	96.40	11.01
Gross energy	57.90	59.30	60.03	59.07	1.20

[1] average of the three treatments

Tabla 7. Disappearance of nutrients and energy with variable levels of the meal of sweet potato foliage in the intestine of pigs (experiments 1 and 2)

	Meal of sweet potato foliage, %			
Digestibility %	0	10	20	30
Dry matter	8.49	9.68	12.90	9.60
Organic matter	7.01	7.75	12.04	9.10
Crude fiber	14.30	7.52	5.72	2.37
ADF	10.00	10.00	-	-
NDF	17.16	8.99	10.00	11.16
Celullose	14.05	13.74	9.66	8.78
Hemicellulose	5.39	5.50	11.40	27.09
Gross energy	2.58	4.76	6.99	2.49

Discussion

The presence of anti-nutritional factors with anti-tryptic characteristics is known, not only in the sweet potato roots, but also in the foliage (Ly 2009). This could have a negative effect on the digestive use of the sweet potatoes and on the diet in general. This negative effect was not confirmed in this research.

Ileal digestive of nutrients. The introduction of growing levels of sweet potato foliage meal decreased the ileal digestibility of nutrients in growing pigs, like it was stated with the meal of foliage of Cuban (Domínguez y Ly 1997), Vietnamese (Du Than *et al*. 2009) and Guadeloupian (Régnier *et al*. 2011) sweet potato. This has also happened with the meal of plant leaves (Le Van *et al*. 2004). In Venezuela, Arrioja (1995) previously stated that if the sweet potato foliage in meal should be included at 15 % in a conventional diet of maize/soybean, the ileal digestibility of organic matter could vary between 49.8 and 70.7 %, depending on the variety, when the nutritional value of seven varieties was compared. In the evaluation of Arrioja (1995), the content of dietary NDF was 23.2 % in the maize/soybean, without foliage. However, in those with foliage, the NDF value was between 31.1 and 44.9 %. It could be inferred that the content of cell wall was related to these results, like it could has happened in this study and others similar, carried out with products from the aerial part of the sweet potatoes (Le Van *et al*. 2004 and Du Than *et al*. 2009). It is known the effect of the cell wall on the digestive processes of pigs, particularly in pre-caecal areas (Bach Knudsen and Hansen 1991 and Jorgensen *et al*. 1996).

The consequences of including important levels of foliages in diets for pigs have been discussed in different times (Wenk 2001, Degen *et al*. 2007, Bindelle *et al*. 2008 and Bach Knudsen 2011). It is known that not only the proportion of fibrous fractions, but also its structure and chemical and physical properties, can influence significantly on the ileal and rectal digestibility of nutrients, mainly on growing pigs, which have not still reached the total development of their large intestine. This study has confirmed results obtained in Cuba about the effect of the sweet potato foliage on ileal digestibility of nutrients. At the same time, it was confirmed that an important part of cellulose and hemicellulose degrade before these entities arrive to the caecum of the individuals.

It was confirmed that when up to 30 % of the sweet potato foliage was included in the diet of pigs, the ileal digestibility of organic matter and energy might decrease, approximately, from 79.5 to 70.5 %, and from 79.8 to 70.8 %, respectively, when conventional diets are used, like the one formulated in this experiment. Higher levels of inclusion should not be expected, at least in growing pigs, if it is considered that the sweet potato foliage meal would be used probably as a source of protein and amino acids.

Rectal digestion of nutrients. Data of rectal digestibility of nutrients reported in this experiment generally agree with those of other evaluations carried out with the same type of sweet potato foliage, *in situ* and *in vitro* (Díaz *et al*. 2012 and 2013). Likewise, these data coincide with others, as to the rectal digestibility, which is slightly higher than the ileal digestibility in the different evaluated nutrients, like other experiments with sweet potato foliage (Domínguez and Ly 1997, Le Van *et al*. 2004 and Régnier *et al*. 2011). It is important to mention that the level of inclusion of foliage in the diet could also cause changes in the rectal digestibility of pigs, which could be inversely proportional to the inclusion level (Wenk 2001 and Bindelle *et al*. 2008). Other sources of variability could be the of sweet potato variety (Arrioja 1995) or the animal genotype (Ly *et al*. 2003 and Nin Thi *et al*. 2009). These last two factors were not taken into consideration for carrying out this research.

The available results about the rectal digestibility of diets of sweet potato foliage do not seem coherent, which could be because different types and levels of foliage have been tested, in fresh, ensiled or meal shape, as well as different levels of inclusion in the diet. The way of processing the sweet potato foliage could also explain some of the differences in the rectal digestibility of pigs (Nguyen Nhut Xuan *et al*. 2002, Hoang Huong *et al*. 2004, Chittavong and Preston 2006, Du Than *et al*. 2009). Likewise, it is difficult to compare the available experimental results because there is more information related to the digestibility of nutrients in diets that contain sweet potato foliage, regarding the foliage *per se*, which is generally determined by difference (Crampton and Harris 1969), when substituting a substantial fraction of the basic diet by the foliage. It could be suggested that the nutritional value of Indochinese products of foliar sweet potato, superior to the stated in Venezuela and Cuba (Ly and Diéguez 1995 and Domínguez and Ly 1997), could be possibly influenced also, to a certain extent, by the use of only leaves in Indochina, and not leaves and petioles, like in America. In this regard, the petioles have higher content of fiber than leaves (Le Van *et al*. 2003), so they can effectively diminish the rectal digestibility of nutrients in pigs (Wenk 2001 and Bindelle *et al*. 2008). Not using the petioles could increase the nutritional value of the sweet potato foliage, but this could also diminish the yield of biomass (González 1994 and Le Van *et al*. 2003). More studies on the rectal digestibility of nutrients in pigs fed with different products of sweet potato foliage are needed.

*Digestion in the large intestin*e. As long as the digestion in the large intestine is considered as the difference between the rectal and the ileal digestion, the values of this process will be subjected to the changes that could occur in the digestion up to the ileum and up to the rectum. In this study, the decrease of the ileal digestibility, determined by the growing inclusion of sweet potato foliage in the diet, was followed by a minor disappearance of the caecum and the colon in pigs. This was evident due to the decrease of the rectal digestibility of DM and different nutrients, which was also verified in studies by Domínguez and Ly (1997). Du Than *et al*. (2009) also stated a very poor participation of the large intestine in the digestion of nutrients (42 % of all the digested organic matter), but the Large White x Mong Cai pigs showed a low voluntary intake of food. This may have stimulated high digestive rates.

The phenomenon of low participation of the large intestine in the nutrient disappearance, when pigs were fed with sweet potato foliage, could be owed to the difficulty of the microorganisms from the large intestine to develop fermentative processes, making available part of the energy of the fibrous fractions for the animal (Shi and Noblet 1993, Wilfart *et al*. 2007 and Bindelle *et al*. 2008). This could have happened due to the minor retention time of the digesta in the caecum and in the colon, directly influenced by the fiber content in the diet.

In this respect, it is known that the presence of fibers in diets diminishes the retention time of the digesta between the ileo-caecal valve and the anal sphincter (Wilfart *et al*. 2007). This, likewise, provokes a decrease of diet digestibility in pigs (Kim *et al*. 2007).

Domínguez and Ly (1997), in an evaluation carried out, confirmed that the fecal excretion of short chain fatty acids (SCFA) in pigs that consumed up to 20 % of sweet potato foliage meal increased from 49 to 104 mmol/kg DM ingested, but the fecal concentration was constant. This could indicate minor retention time of the digesta in the large intestine. However, Nguyen Nhut Xuan *et al*. (2002) did not notice any changes in the retention of digesta in the entire gastrointestinal tract (32.9/38.9 h), when using Cr for comparing different types of Vietnamese forages. In that respect, Díaz *et al*. (1997) found a higher speed in the transit to the ileum when pigs consumed between 0 and 30 % of sweet potato foliage meal. Rodríguez (2000) also observed an acceleration of the digesta movement all over the tract with 15 % of the sweet potato foliage. In fact, the mean retention R passed from 32.9 to 22.5 h with 0 or 30 % of sweet potato foliage. It is difficult to compare these results because it is possible that, in the experiment of Nguyen Nut Xuan *et al*. (2002), all the fibrous sources have accelerated the movement of the digesta through the digestive tract of pigs.

In this research, the sweet potato foliage seems to diminish the participation of the large intestine in the disappearance of nutrients all over the gastrointestinal tract, specifically in some fibrous fractions that characterize the non amylaceous polysaccharides. From the digestive point of view, the meal of sweet potato foliage is suggested to be provided to pigs in levels not higher than 30 % of the feed, as a source of proteins and minerals in diets of very low amount of fiber. Searching for methods to increase efficiency in the digestion of fibrous fractions of the sweet potato foliage could be an attractive line of research for further studies.

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