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The influence of graded levels of Jerusalem artichokes and body weight on the digestibility of dietary components in a sugar cane molasses-based pig diet

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ABSTRACT

Crossbred growing barrows weighing an average of 15 kg were divided into four groups of eight pigs in a completely randomised experiment in a 2 x 4 factorial design (20 or 55 kg, fed 0, 205, 410 or 760 g/kg Jerusalem artichokes). Apparent digestibility of dry matter, organic matter, energy and crude protein was progressively decreased and apparent digestibility of crude fibre and neutral detergent fibre was progressively increased by adding Jerusalem artichokes. The lower dry matter in faeces of pigs fed Jerusalem artichokes was associated with a higher faecal bulk and is suggested as being responsible for the lower digestibility of nutrients and energy in pigs fed high Jerusalem artichoke diets. Except for energy, pigs at 55 kg body weight had significantly higher or lower apparent digestibility of nutrients than pigs at 20 kg, when Jerusalem artichokes or sugar cane molasses were the main energy source in the diet, respectively. Increasing Jerusalem artichokes increased daily faecal flow of short chain fatty acids and ammonia and reduced faecal pH. It is concluded that there is significant adaptation to high amounts of Jerusalem artichokes in the diet with age.

KEY WORDS: pig, Jerusalem artichokes, sugar cane molasses, digestibility

INTRODUCTION

Jerusalem artichokes (*Helianthus tuberosus* L.) are tubers very rich in inulin, a fructan which yields fructose upon hydrolysis. Although hydrolysis of inulin does not appear to be efficient in the pig, faecal digestibility of organic matter is rather high (Ly et al., 1995). In contrast, Jerusalem artichokes may be responsible for a depression in N digestibility of the diet (Ly et al., 1995).

Sugar cane molasses is a common feed in several tropical countries (Gohl, 1975). In Cuba, sugar cane molasses type B is utilised in pig feeding practice. This type of molasses originates from the second of three sugar extractions in a sugar factory. The nutritive value of sugar cane molasses type B is well established (Ly, 1996).

On the other hand, the ability of the pig to digest several components of conventional diets may increase with age (Everts et al., 1986; Fernández et al., 1986; Shi and Noblet, 1993) or not (Kass et al., 1980; Everts et al., 1986). Therefore it could be of interest to determine if digestibility of diets based on Jerusalem artichokes and sugar cane molasses could be improved with age or body weight.

The present experiment was designed to determine the effect of graded levels of Jerusalem artichokes in the diet and body weight on the digestibility of dietary components in a sugar cane molasses-based diet. In addition some fermentative indices from faeces of pigs were estimated.

MATERIAL AND METHODS

Crossbred growing barrows (Yorkshire x Landrace x Duroc) weighing on average 15 kg were from an earlier feeding trial (Macías, 1994; unpublished data). The animals were divided into four groups of eight to a completely randomised experiment in a 2 x 4 factorial design and fed *ad libitum* the diets presented in Table 1. The energy sources of the diets were sugar cane molasses type B (751.5 g/kg DM) and Jerusalem artichoke tubers (244.1 g/kg DM). The Jerusalem artichokes were harvested in Cuba and frozen immediately until utilisation (Modler et al., 1993). Graded levels of Jerusalem artichokes were incorporated into diets at the expense of the sugar cane molasses but adjusting the soyabean meal proportion in the dietary formula in order to maintain the constant protein level (160 g/kg in dry basis). Sugar cane molasses was mixed with soyabean meal, minerals and vitamins and then given to the animals. Thereafter the tubers were offered to the pigs in order to assure the complete consumption of the other components of the ration. The animals were fed once a day at 9.00 h.

Pigs were individually kept in 0.5 x 1.25 m concrete-floor pens in an open shed-type house. The pens were equipped with individual feeding stalls and nipple-waterers.

Faeces were collected from individual pigs at 8.00 h by grab sampling from each animal at 20 and 55 kg on average. The pH value was measured potentiometrically in fresh faeces. The SCFA and ammonia were determined in fresh faeces as described by Ly et al. (1995). Faeces from each pig were dried in a forced-air oven at 65°C for 48 h. The oven-dried faeces were allowed to come to equilibrium with

TABLE 1

Composition of the diets

	Jerusalem artichokes, g/kg			
	0	205	410	760
Ingredients, g/kg				
soyabean meal	332.6	295.4	257.7	194.0
sugar cane molasses type B	621.4	453.6	256.3	–
Jerusalem artichoke tubers	–	205.0	410.0	760.0
$CaHPO_4 \cdot 2H_2O$	30.0	30.0	30.0	30.0
NaCl	6.0	6.0	6.0	6.0
vitamins and trace elements[1]	10.0	10.0	10.0	10.0
Chemical composition, g/kg				
dry matter	801.0	548.4	416.7	295.6
in dry matter				
ash	108.6	104.7	99.5	93.7
organic matter	891.4	895.3	900.5	906.3
crude protein	160.0	160.0	159.0	159.0
crude fibre	27.8	41.7	54.7	72.0
NDF	43.6	64.3	85.1	95.0
energy, KJ/10 g DM	146.8	152.4	158.0	167.5

[1] supplied per kg of diet: 1600 I.U. A, 160 I.U. D_3, 2 mg thiamine, 3 mg riboflavine, 300 mg choline, 15 mg niacin, 5 mg panthotenic acid, 15 mg pyridoxine, 0.5 mg folic acid, 25 µg cyanocobalamin, 10 mg tocopheryl acetate, 2 mg vitamin K, 10 mg Cu, 40 mg Fe, 0.5 mg I, 0.4 mg Co acetate, 2 mg vitamin K, 10 mg Cu, 40 mg Fe, 0.5 mg I, 0.4 mg Co

the air moisture and ground in a Willey type mill to pass through a 1 mm screen. Dry matter (DM), crude protein, crude fibre and ash were determined by AOAC methods (1984). Neutral detergent fibre (NDF) was estimated according to the procedure of Van Soest and Wine (1967). The gross energy of the feed and faeces were determined with an adiabatic bomb calorimeter. Acid insoluble ash was used as an indicator for determining apparent digestibility coefficients. Concentrations of acid insoluble ash in feed and faeces were estimated by the method of Van Keulen and Young (1977).

The estimates of daily faeces output were calculated using the equation:
fresh faeces flow (g) = feed intake (g DM)

$$\times \frac{100 - \text{apparent DM digestibility (g/kg)}}{100} \times \frac{100}{\text{faceal DM (\%)}}$$

Least square analysis was used to examine the data collected on the pigs (Harvey, 1987), and the following model was used:

$$Y_{ijk} = \mu + a_i + b_j + ab_{ij} + e_{ijk}$$

where: Y_{ijk} is the digestion index in the k^{th} pig on the ai diet on the b_j body weight; μ is the overall mean; a_i is the effect of the i^{th} diet; b_j is the effect of the j^{th} body weight; ab_{ij} is the interaction term and e_{ijk} is the random error.

The Duncan multiple range test was used to compare the means when the F test was significant. Some data were subjected to regression analyses, with linear components measuring the relationships between organic matter (OM) digestibility and other digestion parameters, as outlined by Steel and Torrie (1980).

RESULTS

Voluntary intake of the diet accounted for 0.131 ± 0.011 kg DM/$W^{0.75}$ per day and no differences due to the nature of the diet were noted.

The nutrient digestibilities of the diets are shown in Table 2, and the statistical analysis in Table 3. Apparent digestibility of DM and energy appeared to increase and apparent digestibility of NDF to decrease with decreasing the level of Jerusalem artichokes in the diet, and feeding zero g of these tubers per kg of diet appeared to result in greater DM, energy and NDF digestibility at 20 kg of body weight than at 55 kg. In fact energy was best digested in all diets at 20 kg. The diet effect was more evident in energy and NDF ($P<0.001$) than in DM digestibility

TABLE 2

Nutrients and energy apparent digestibility

Faecal digestibility, g/kg	Body weight, kg	Jerusalem artichokes, g/kg			
		0	205	410	760
Dry matter	20	940	913	846	812
	55	899	873	855	841
Ash	20	861^{a}	818^{ab}	664^{c}	493^{d}
	55	751^{ab}	726^{b}	722^{b}	695^{b}
Organic matter	20	950^{a}	925^{ab}	866^{cd}	844^{d}
	55	914^{b}	882^{c}	871^{cd}	861^{cd}
Crude protein	20	886^{a}	825^{a}	698^{c}	594^{d}
	55	732^{b}	691^{c}	714^{c}	689^{c}
Crude fibre	20	522^{c}	566^{c}	635^{b}	635^{b}
	55	337^{d}	491^{c}	531^{c}	838^{a}
NDF	20	535	586	593	637
	55	532	660	670	754
Energy	20	943	918	860	847
	55	897	858	856	828

a, b, c, d – means within comparison groups bearing the same letter are not significantly different at $P< 0.05$

TABLE 3

Analysis of variance for faecal digestibility

	Source of variation			
	diet	body weight, kg	D x W	error
Degree of freedom	3	1	3	56
Mean square				
faecal digestibility				
dry matter	28023*	1903	5181	9571
ash	142268***	3306	85089***	4099
organic matter	20332***	3039**	3426**	683
crude protein	82151***	6687**	64341***	4725
crude fibre	250241***	11285	118284**	22907
NDF	57965***	87173***	5326	4221
energy	20644***	166641***	2540	914

* P <0.05; ** P , 0.01; *** P<0.001

(P<0.05). The apparent differences in the body weight effect were significant (P<0.001) in energy and NDF digestibility. In fact digestibility of NDF appeared to improve as pigs aged from 20 to 55 kg (588 and 662 g/kg, respectively), whilst digestibility of energy was impaired (982 and 858 KJ/MJ, respectively). In this connection, the apparent digestibilities of both DM and energy decreased with the increase of body weight in the case where sugar cane molasses was predominant in the diet. The interaction between diet and body weight of the pigs was not statistically significant for these parameters.

The effect of diet was highly significant (P<0.001) for apparent digestibility of ash, organic matter (OM), crude protein and crude fibre. In fact, ash, OM and crude protein digestibility decreased as long as crude fibre digestibility increased with the inclusion of graded levels of Jerusalem artichokes in the diet. On the other hand the effect of body weight was significant (P<0.01) for crude protein and OM digestibility. Both crude protein and OM digestibilities decreased from 751 and 896 g/kg at 20 kg to 707 and 882 g/kg at 55 kg, respectively. The interaction diet x body weight was significant (0.01<P<0.001) for ash, OM, crude protein and crude fibre digestion coefficients.

Faecal apparent energy digestibility (Y, %) correlated (r = 0.916, P<0.001) with faecal apparent OM digestibility (X, %) according to the regression equation:

$$Y = 1.011X (\pm 0.056) - 2.294$$

Faecal data of pigs fed Jerusalem artichokes and sugar cane molasses at different body weights are listed in Table 4, whilst the statistical analysis is presented in Table 5. Increasing the Jerusalem artichoke levels in the diet significantly decreased faecal DM and pH and increased SCFA concentration (P<0.001). Faecal ammonia

TABLE 4

Faecal indices and daily faeces output

	Body weight, kg	Jerusalem artichokes, g/kg 0	205	410	760
Faecal indices					
DM, g/100 g	20	22.49	18.55	16.88	13.56
	55	21.28	20.67	18.55	17.51
pH	20	6.90	6.43	6.18	6.00
	55	7.20	6.96	6.38	5.90
SCFA, mmol/100 g DM	20	19.2[a]	61.3[b]	54.3[ab]	110.6[c]
	55	35.2[ab]	41.2[ab]	45.7[ab]	48.3[ab]
NH_3, mmol/100 g DM	20	19.3	28.2	22.0	28.0
	55	43.1	39.4	35.9	29.0
Daily faecal output/kg DM intake					
fresh faeces, g	20	289[a]	469[ab]	865[c]	1386[d]
	55	531[ab]	619[b]	852[c]	908[c]
water, g	20	224[a]	382[b]	719[d]	1198[e]
	55	418[b]	491[bc]	694[cd]	749[d]
SCFA, mmol	20	11.3[a]	47.3[a]	81.6[b]	209.3[c]
	55	32.6[a]	51.6[a]	69.0[ab]	75.0[b]
NH_3, mmol	20	11.4	24.3	30.1	53.3
	55	41.6	50.8	51.1	53.3

a, b, c, d, e – means within comparison groups bearing the same letter are not significantly different ($P < 0.05$)

TABLE 5

Analysis of variance for faecal indices

	Source of variation: diet	body weight, kg	D x W	error
Degree of freedom	3	1	3	56
Mean square				
faecal indices				
dry matter	69.29***	28.25+	14.72	8.02
pH	10.45***	6.74*	0.35	0.17
SCFA	7325.75***	5617.13*	4277.52**	1024.41
NH_3	64.43***	2925.46***	242.18	100.96
Daily faecal output				
fresh faeces	1892205***	3579	300771***	46905
water	1474771***	13470	237625***	37496
SCFA	45435***	13855*	17228**	3127
NH_3	2410***	5741***	410	267

+ $P<0.10$; * $P<0.05$; ** $P<0.01$; *** $P<0.001$

concentration was not affected by diet. On the other hand, body weight markedly influenced the faecal concentration of these metabolites ($P<0.001$); this effect was least significant for faecal pH and SCFA concentration ($P<0.05$). In fact, faecal pH and ammonia concentration increased from 6.38 and 24.4 mmol/100 g DM at 20 kg to 6.61 and 36.8 mmol/100 g DM at 55 kg. The reverse was evident for SCFA concentration in faeces (from 61.4 to 42.6 mmol/100 g DM respectively). The interaction diet x body weight was only significant ($P<0.001$) for faecal SCFA concentration.

The effect of diet showed a highly significant influence ($P<0.001$) on either fresh faecal and water flow, or SCFA and ammonia. The general trend was toward an increased daily faecal flow in direct association with increased levels of Jerusalem artichokes in the diet. The effect of body weight was significant for daily faecal flow of ammonia ($P<0.001$) or SCFA ($P<0.05$), respectively, which either increased from 29.8 to 49.2 or was depressed from 87.4 to 57.1 mmol/day per kg DM intake, respectively. A significant diet x body weight interaction was found for daily faecal fresh material and water ($P<0.001$) and SCFA ($P<0.01$) flows, respectively.

A significant correlation ($r = -0.772$; $P<0.05$) existed for organic matter digestibility (x, %) and daily faecal flow of SCFA (Y, mmol/kg DM intake per day), with the regression equation:

$$Y = 1200.27 - 12.69\,x \pm 4.26$$

DISCUSSION

The animals fed on either sugar cane molasses or Jerusalem artichokes did not develop diarrhoea defined as profuse unformed faeces, despite the low faecal dry matter concentration observed throughout the experiment. However, the introduction of Jerusalem artichokes into a sugar cane molasses diet led to a considerable increase in faecal bulk, in agreement with previous observations by Ly et al. (1995). In this connection, microbial digestion of fructans rather than that of cell wall or non-starch polysaccharides contained in Jerusalem artichokes could be responsible for this phenomenon. This hypothesis arises from results of Graham and Åman (1986) who found that precaecal and faecal DM digestibility in Jerusalem artichokes was 40 and 90%, respectively. Comparable values have been obtained for artichoke tubers (Ly et al., 1995). Therefore, fructans from Jerusalem artichokes degraded in the large intestine may largely increase faecal bulk and produce softer faeces, similarly as is the case with soluble dietary fibre in humans (Stephen and Cumming, 1980), rats (Nyman and Asp, 1982) and pigs (Graham and Åman, 1987; Bach Knudsen and Hansen, 1991).

In this study the increase in faecal bulk was evident when pigs were fed diets with increasing proportions of Jerusalem artichokes. Furthermore, an inverse relationship appeared to exist between high levels of dietary Jerusalem artichokes and nutrients and energy digestibility. In this connection the excretion of soft faeces with a relatively low dry matter content by pigs has been related to reduced retention time of feed residues in the digestive tract (Cherbut and Ruckebusch, 1985; Metz and Dekker, 1985). On the other hand, a low retention time of undigested matter has been shown to be directly responsible for lowering the digestibility of several dietary components under variable circumstances in the pig (Kass et al., 1980; Metz and Dekker, 1985; Mroz et al., 1986). Therefore it can be assumed that this was the case in the present experiment.

The decrease in apparent digestibility of nutrients with increasing Jerusalem artichokes in the diet, except for the crude fibre and NDF fractions, is in agreement with previous observations related to growing pigs (Ly et al., 1995). Nevertheless, a slight increase in nutrient digestibility with increasing body weight of pigs fed Jerusalem artichokes as the only energy source in the diet is in accordance with experimental data indicating a positive influence of age or body weight on digestibility of nutrients from conventional diets in the growing pig (Fernández et al., 1984; Everts et al., 1986; Shi and Noblet, 1993). However a reduction in nutrient digestibility with increasing body weight of pigs fed sugar cane molasses was unexpected, taking into account the data of Jentsch et al. (1991). It appears that additional research is needed to identify mechanisms by which body weight or age influence nutrient digestion by pigs fed sugar cane molasses.

A substantial change in concentration and daily flow of end-products of microbial metabolism, along with a modification in faecal pH in pigs fed either sugar cane molasses or Jerusalem artichokes was found in the present study. Moreover, the effect of body weight on faecal SCFA, ammonia and pH was also evident, thus implying a long-term adaptation of the animals to the type of diet fed. The nature of the dietary source of carbohydrates was obviously responsible for such changes. In this connection, Bach Knudsen et al. (1991) showed that caecal and colonic pH decreased as a consequence of fermentation of the carbohydrates and amount of feed residues reaching the large intestine. Furthermore Ehle et al. (1982) and Varel et al. (1984) found differences in faecal concentration of SCFA in pigs fed high and low fibre diets. The same differences were observed in caecal and colonic digesta by Varel et al. (1984). Nevertheless, attempts to achieve changes in faecal SCFA caused by Jerusalem artichokes in very young pigs have not been consistent (Farnworth, 1994; Farnworth et al., 1995), probably due to the low level of fructans included in the diet.

High faecal ammonia excretion caused by Jerusalem artichokes has previously been observed by Ly et al. (1995). In this connection Bolduan et al. (1986) have suggested that a straight relation between SCFA and ammonia concentrations does exist in the colonic digesta and faeces of pigs, whilst Varel et al. (1984) observed high faecal ammonia concentrations in pigs fed diets high in fibre. The correlation was more apparent in the present study for daily faecal flow of both types of metabolites, perhaps as a function of retention time of digesta in the large intestine of the animals.

In conclusion, a decrease in digestibility of nutrients from diets containing Jerusalem artichokes depends on the level at which the tubers are introduced into the diet. On the other hand, significant adaptation to high amounts of Jerusalem artichokes with age of pigs may also be expected.

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STRESZCZENIE

Wpływ udziału topinamburu i masy ciała świń na strawność składników pokarmowych dawek z dużym udziałem melasy z trzciny cukrowej

Mieszańce – wieprzki o średniej masie ciała 15 kg, podzielono na 4 grupy po 8, w doświadczeniu o układzie czynnikowym 2 x 4 (20 lub 55 kg, udział topinamburu w dawce 0, 205, 410 lub 760/kg). Pozorna strawność suchej masy, substancji organicznej, energii i białka ogólnego obniżała się stopniowo, a strawność włókna i NDF zwiększała się w miarę zwiększania udziału topinamburu w dawce. Mniejsza zawartość suchej masy w kale i związana z tym większa ilość kału u świń otrzymujących topinambur mogły być wynikiem gorszej strawności składników pokarmowych i energii dawek zawierających dużą ilość topinamburu. Z wyjątkiem energii, pozorna strawność składników pokarmowych dawek była istotnie większa u świń 55 niż 20 kg, gdy główne źródło energii w dawkach stanowił topinambur, a mniejsza gdy źródłem energii była melasa z trzciny cukrowej. Zwiększenie ilości skarmianego topinamburu zwiększało dzienne wydalanie krótkołańcuchowych kwasów tłuszczowych i amoniaku w kale oraz obniżało pH kału. Stwierdzono, że wraz z wiekiem zwierzęta przystosowują się do dużych ilości topinamburu w diecie.