

Effect of source of starch on net portal flux of glucose, lactate, volatile fatty acids and amino acids in the pig

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The ileal digestibilities of maize starch and native pea starch do not differ. However maize starch is digested faster than pea starch and the ileal amino acid digestibility of a diet containing pea starch is lower. In the present study, the net portal fluxes of glucose, lactate, volatile fatty acids (VFA) and amino acids were measured for diets including 650 g maize starch or pea starch/kg. The diets were fed at a level 870 kJ digestible energy/kg^{0.75} twice daily (06.00 and 18.00 hours) to four female pigs in a crossover design. Portal vein blood flow did not differ between maize and pea starches (1620 and 1484 ml/min respectively; SED 100; $P = 0.23$). For maize starch portal glucose flux was significantly higher during the first 6 h after feeding, was not different 8 h after feeding and was significantly lower thereafter. Net portal glucose flux was higher for maize starch than for pea starch (1759 and 1265 mmol/12 h respectively; SED 182; $P = 0.054$). Net portal lactate flux was not significantly different between maize and pea starches (36.5 and 67.2 mmol/12 h respectively; SED 24.1; $P = 0.27$) and net portal VFA flux was lower for maize starch than for pea starch (169 and 218 mmol/12 h respectively; SED 18; $P = 0.054$). Net portal fluxes of valine, isoleucine, phenylalanine, tryptophan, arginine, serine, cystine, tyrosine, lysine, histidine and the sum of essential amino acids tended to be or were higher ($P < 0.1$ or $P < 0.05$) and net portal flux of aspartic acid tended to be lower for pea starch ($P < 0.1$). It can be concluded that, although ileal digestibility of both starches is equal, the rate of appearance of glucose in the portal vein was higher for maize starch, influencing the net portal flux of amino acids.

Starch: Net portal flux: Amino acids

Enzymic digestion of starch in the small intestine may be incomplete. *In vitro* studies demonstrate large differences in the degree of degradation of starchy feedstuffs (Heaton *et al.* 1988; Cone & Vlot, 1990). In men 0–30 % of starch is resistant to digestion in the small intestine (Faisant *et al.* 1993). Also, ileal starch digestibility in pigs does not always equal 100 % and is related to the source and processing of the starch (Wünsche *et al.* 1987; Graham *et al.* 1989; van der Poel *et al.* 1992). Starch which is not digested in the small intestine will enter the large intestine and will be fermented (resistant starch; Cummings & Englyst, 1995).

Non-resistant starch is digested completely in the small intestine. However the rate of digestion of non-resistant starch in the small intestine may differ depending on the physical form of the food (Leclere *et al.* 1993; Cummings & Englyst, 1995). Even the intestinal digestion rates of ground purified non-resistant starches may differ as was shown for maize and native pea starches by Everts *et al.* (1996). The rate of disappearance from the small intestine in pigs was faster for maize starch than for native pea starch. Moreover, ileal

digestibility of N was positively affected after feeding maize starch (Everts *et al.* 1996). A decrease in the rate of starch digestion may reduce or delay the postprandial glucose and insulin responses (Cummings & Englyst, 1995), and a difference in the rate of digestion between carbohydrates and proteins may have nutritional consequences (R erat, 1985).

In the present study the net portal fluxes of nutrients (glucose, lactate, volatile fatty acids (VFA) and amino acids) after feeding maize starch and native pea starch were measured, in order to obtain a picture of the process and dynamics of carbohydrate digestion of these two non-resistant starches with different digestion rates.

MATERIALS AND METHODS

Animals

Four female (Dutch Landrace \times Yorkshire \times Finnish Landrace) pigs (weight 33.3 (SD 1.5 kg) were fitted, under general anaesthesia, with catheters in the portal vein and mesenteric vein and artery, according to the procedure described by Huntington *et al.* (1989) for cattle. After 1 week of recovery from surgery the pigs were housed in metabolism cages and adapted to the experimental diets. The mean weight of the pigs was 39.0 (SD 2.4) kg at the start of the experiment and 44.0 (SD 3.5) kg at the end of the experiment.

Surgery

Animal preparation. Before surgery animals were denied food for 24 h and water for 12 h. Anaesthesia was induced by intramuscular injection of 2 mg azaperone/kg (Stresnil; Janssen, Tilburg, The Netherlands) followed within 30 min by intravenous injection of 15 mg Nesdonal/kg (Rh one M erieux, Lyon, France). The pig was intubated and general anaesthesia was maintained by inhalation anaesthesia with O₂, N₂O and halothane. After shaving and disinfecting the surgical sites, the pig was placed in dorsal recumbency. The abdomen was opened by a midline incision of approximately 250 mm. During surgery intestines in the surgical field were rinsed frequently with physiological saline (9 g NaCl/l) containing 7500 U heparin/l (Leo, Weesp, The Netherlands) and 100 000 U procaine penicillin/l (Combiotic; Pfizer, Rotterdam, The Netherlands).

Catheterization of mesenteric vein and artery. Mesenteric vein and artery were cleared of surrounding tissue by blunt dissection. A catheter (Tygon, i.d. 1.02 mm, o.d. 1.78 mm, length 1 m; Norton, Akron, Ohio, USA) was inserted in the vein and advanced for 100 mm. After patency was confirmed by flushing with physiological saline containing 5 U heparin/ml, the catheter was sutured. An identical catheter was placed in the mesenteric artery. Two mesenteric vein and two mesenteric artery catheters were inserted, to provide optimal mixing of the indicator for blood flow measurement and as insurance in case of loss of patency.

Catheterization of the portal vein. The portal vein was lifted towards the incision. The lymph node lying posterior to the gastroduodenal vein was used to locate the place of insertion. The portal vein was punctured anterior to the gastroduodenal vein with a needle (18 gauge) and a 1 mm wire guide was inserted into the vein. The needle was removed from the guide and the catheter (Tygon, i.d. 1.27 mm, o.d. 2.29 mm, length 1 m) was inserted into the vein by threading over the guide, after which the guide was removed. Location of the tip of the catheter in the vein towards the left lateral lobe of the liver was checked by palpation. Patency of the catheter was checked before the catheter was anchored.

Exteriorization of the catheters and closure. The pig was placed in left lateral recumbency. The catheters were individually exteriorized dorsally in a line parallel to the spine and secured using a velcro system. The pig was replaced in dorsal recumbency and after a final rinse of 100 ml physiological saline containing 5000 U heparin, 150 000 U procaine benzyl penicillin G (Procpen; AUV, Cuijk, The Netherlands) and 2.4 mg dexamethasone (Alfasan, Woerden, The Netherlands), peritoneum, muscle layers and skin were closed. After surgery and between sampling sessions the catheters were filled with physiological saline containing 250 IU heparin, 3000 U procaine benzyl penicillin G and 0.01 ml benzyl alcohol/ml. Physiological saline containing 5 U heparin/ml was used for flushing catheters during surgery and sampling sessions.

Post-surgery care. Antibiotic (400 mg Ampicillin; AUV) and anodyne (Antipyranal; Alfasan) were given intramuscularly for 3 d after surgery. The day after surgery the pig was given one-third of its pre-surgery daily feed intake, and was returned to its preoperative intake in 3 d. The catheters were checked weekly for their patency.

Diets

Diets contained 650 g maize starch or native pea starch/kg and the remaining 350 g/kg supplied all amino acids, fat, fibre, minerals and vitamins (Table 1). The diets were mixed with water at a ratio of 1:4.5 (w/v) and fed twice daily (06.00 and 18.00 hours) at a feeding level of 870 kJ digestible energy/kg^{0.75}

Table 1. *Composition and chemical analysis of the diets*

	Diet M	Diet P
Ingredients (g/kg)		
Maize starch	649.7	–
Native pea starch*	–	669.2
Lucerne (<i>Medicago sativa</i>) meal	136.8	129.1
Potato protein	149.1	140.8
Soyabean oil	10.0	9.4
Cane molasses	35.0	33.1
DL-Methionine	0.8	0.8
L-Tryptophan	0.3	0.3
Mono calcium phosphate	9.1	8.6
Limestone	4.6	4.3
Salt	2.5	2.4
Mineral-vitamin premix†	1.7	1.7
Component (g/kg DM)		
DM (g/kg)	914	885
Crude protein	146	146
Ash	35	32
Crude fibre	45	46
Starch	634	639
Sugar	21	18

* Nastar (Cosucra, Momalle, Belgium).

† Supplied (mg/kg diet): retinol 13, cholecalciferol 3, α -tocopherol 16, riboflavin 5, cyanocobalamin 20, nicotinic acid 20, pantothenic acid 17, antioxidant 125, $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ 40, $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ 430, MnO 50, $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ 155, KI 2, $\text{Na}_2\text{SeO}_3 \cdot 5\text{H}_2\text{O}$ 0.07 and choline chloride 300.

Experimental design

Pigs were randomly allocated to one of four treatment combinations in a crossover design comprising the two diets and three periods (Jones & Kenward, 1989). Each of these three periods comprised an adaptation period of 6 d while on day 7 blood samples were taken simultaneously from the portal vein and the mesenteric artery at 05.55 hours (just before feeding) and 0.5, 1, 1.5, 2, 3, 4, 6, 8, 10 and 12 h after feeding.

Measuring portal blood flow and nutrient flux

p-Aminohippuric acid (PAH) infusion. Portal vein blood flow was measured by the continuous infusion indicator-dilution technique employing PAH (Fluka Chemie, Buchs, Switzerland) as indicator (Yen & Killefer, 1987). PAH (15 mg/ml) was dissolved in water and NaOH (pH 7.4). A priming dose of PAH was infused into the mesenteric veins. After priming, PAH was infused continuously (16–21 mg/min), starting 1 h before the first blood sampling and continuing throughout the sampling session.

The required PAH priming dose and infusion rate were determined for each pig several days before the actual experiment started. PAH (300 mg) was administered through a mesenteric vein catheter and arterial plasma PAH concentrations were measured every 5 min over a period of 1 h. By means of the pharmacokinetic computer program PKCALC (Shumaker, 1986) the clearance and distribution volume of PAH were determined, and these were used to calculate the priming dose and infusion rate to attain arterial PAH concentrations of 20 mg/l.

Calculating portal vein blood flow. Portal vein blood flow (PVBF) was calculated by the following equation (Yen & Killefer, 1987):

$$\text{PVB} = C_i \times \text{IR} / [\text{PAH}_p(100 - \text{PCV}_p)/100 - \text{PAH}_a(100 - \text{PCV}_a)/100],$$

where C_i is the concentration of the PAH infusion solution (mg/ml), IR is the infusion rate of PAH (ml/min), PAH_p and PAH_a are PAH concentrations in portal and arterial blood plasma respectively (mg/l) and PCV_p and PCV_a are packed cell volumes of portal and arterial blood respectively (%).

Calculating net portal flux of nutrients. Net portal-drained viscera (PDV) flux was calculated by the following equation (Deutz *et al.* 1992):

$$\text{PDVflux} = \text{PVPF} \times (N_p - N_a),$$

where PVPF is the portal vein plasma flow and N_p and N_a are nutrient concentrations in portal and arterial plasma respectively.

Analysis

Blood samples were collected in cooled heparinized syringes and placed on ice. After the packed cell volume (PCV) was determined, blood samples were centrifuged (2500 g, 10 min, 4°). Within 24 h plasma was analysed enzymically for lactate and for glucose (Boehringer Mannheim GmbH, Mannheim, Germany). A portion of the plasma was stored at –80° until it was analysed for PAH (Eisemann *et al.* 1987) and VFA (Reynolds *et al.* 1986) and a portion was deproteinized and stored until it was analysed for amino acids (de Jonge & Breuer, 1994).

Statistics

The crossover design allowed the possibility of testing carry-over effects, and if necessary correction of these effects. Data were subjected to ANOVA for a crossover design, using the ANOVA procedure of Genstat (Payne *et al.* 1987) according to the following model: $Y_{ijk} = \mu + A_i + P_j + T_k + e_{ijk}$, where μ is overall mean, A_i is effect of animal, P_j is effect of period, T_k is effect of treatment, e_{ijk} is residual error with $i = 1 \dots 4$, $j = 1 \dots 3$, $k = 1 \dots 2$. The results are given as estimated means corrected for period- and animal-effects from the observations on each treatment.

RESULTS

Portal vein blood flow rate

Portal vein blood flow rate was elevated for a period of 6 h after feeding. Average portal vein blood flow did not differ between maize and pea starches (1620 and 1484 ml/min respectively; SED 100; $P = 0.23$).

Glucose

Portal and arterial glucose concentrations relative to the time of feeding are shown in Fig. 1. The highest portal glucose concentration was observed 0.5 h after feeding for maize starch and 1 h after feeding for pea starch. Maize starch showed a second peak in portal glucose concentration 3 h after feeding. Portal glucose concentration was higher for maize starch up to 8 h after feeding, but after that it was higher for pea starch. Net portal glucose flux for maize starch was significantly higher during the first 6 h and significantly lower

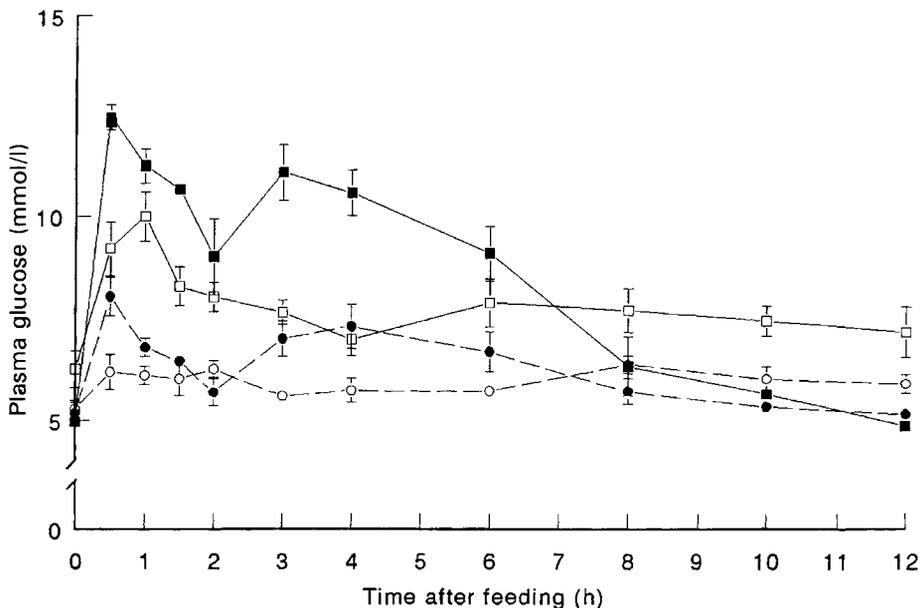


Fig. 1. Portal (□, ■) and arterial (○, ●) plasma glucose concentrations in pigs after consumption of a meal containing maize starch (■, ●) or pea starch (□, ○). Values are means for four pigs, with their standard errors represented by vertical bars.

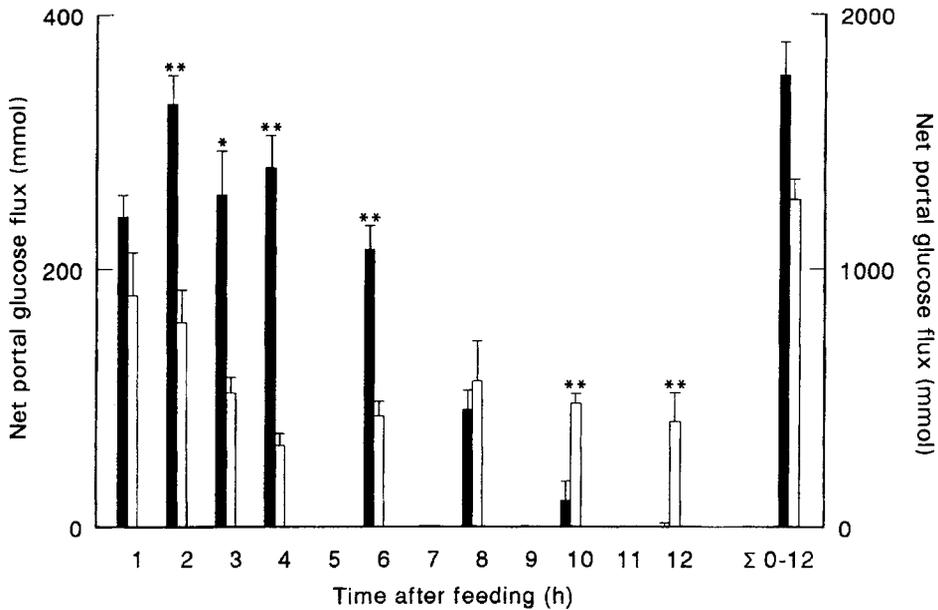


Fig. 2. Net portal flux of glucose in pigs after consumption of a meal containing maize starch (■) or pea starch (□). Values are means for four pigs, with their standard errors represented by vertical bars. Values for the two diets were significantly different: * $P < 0.05$, ** $P < 0.01$.

during the last 4 h after feeding (Fig. 2). The net portal glucose flux over 12 h was higher for maize starch than for pea starch (1759 and 1265 mmol respectively; SED 182; $P = 0.054$; Fig. 2) and accounted for 97 % and 72 % respectively of ileal digested glucose.

Lactate

Portal lactate concentration relative to the time of feeding (Fig. 3) resembled portal glucose concentration, especially for maize starch (correlations between portal glucose and lactate concentration for maize and pea starches, $r = 0.79$; $P < 0.01$ and $r = 0.45$; $P < 0.01$ respectively). Average portal lactate concentrations did not differ between the two diets. However, arterial lactate concentration tended to be higher for maize starch (Fig. 3). Net portal lactate flux relative to the time of feeding (Fig. 4) resembled net portal flux of glucose, except in the hour before and after feeding. Moreover, net portal lactate flux was not significantly different between maize and pea starches (36.5 and 67.2 mmol respectively; SED 24.1; $P = 0.27$; Fig. 4).

Volatile fatty acids

Neither portal and arterial VFA concentrations, nor the proportions of VFA changed appreciably after feeding. The proportions of VFA were the same for both diets (Table 2). Portal vein contained acetate, propionate, and butyrate in the proportions 76:14:3 and traces of isobutyrate, valerate, isovalerate and caproate. In the artery the proportions were 86:6:1. Portal VFA concentrations was similar for both diets and were always higher than the arterial concentrations. Arterial VFA concentration was higher for maize starch than for

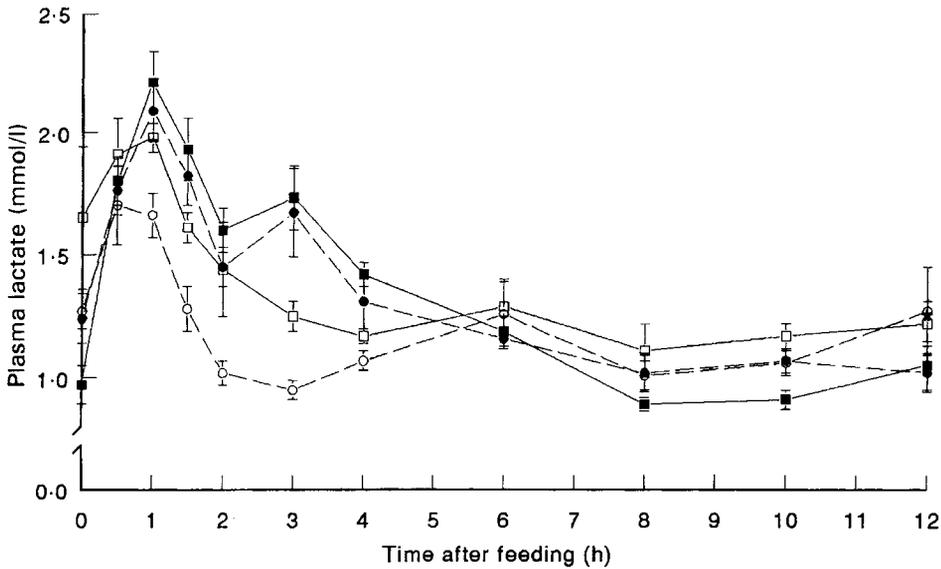


Fig. 3. Portal (□, ■) and arterial (○, ●) plasma lactate concentrations in pigs after consumption of a meal containing maize starch (■, ●) or pea starch (□, ○). Values are means for four pigs, with their standard errors represented by vertical bars.

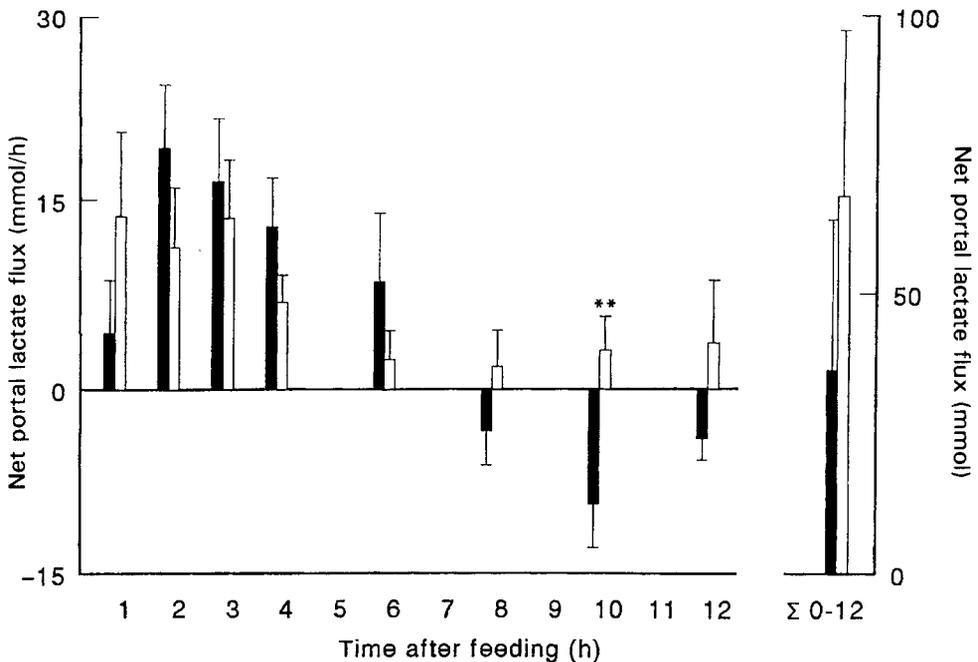


Fig. 4. Net portal flux of lactate in pigs after consumption of a meal containing maize starch (■) or pea starch (□). Values are means for four pigs, with their standard errors represented by vertical bars. ** Values for the two diets were significantly different, $P < 0.01$.

Table 2. Mean arterial and portal volatile fatty acid (VFA) concentrations and mean portal flux of VFA in pigs fed on diets containing maize starch or pea starch

		Diet			Statistical significance of difference: $P =$
		Maize starch	Pea starch	SED	
Artery (mmol/l)	VFA	0.236	0.162	0.050	0.220
	Acetate	0.206	0.136	0.045	0.195
	Propionate	0.012	0.010	0.002	0.476
	Butyrate	0.002	0.002	0.000	0.677
Portal vein (mmol/l)	VFA	0.459	0.454	0.049	0.920
	Acetate	0.357	0.341	0.047	0.349
	Propionate	0.058	0.070	0.006	0.131
	Butyrate	0.015	0.017	0.002	0.467
Net portal flux (mmol/h)	VFA	13.93	17.82	1.48	0.059
	Acetate	9.64	12.35	1.11	0.072
	Propionate	2.75	3.72	0.45	0.323
	Butyrate	0.79	0.97	0.16	0.883

pea starch, but this difference was not significant. The hourly net portal VFA flux tended to be higher for pea starch (Table 2). Acetate, propionate and butyrate contributed 69, 20 and 6 % respectively, to the net portal VFA flux. Net portal flux of VFA over 12 h was 29 % higher for pea starch (maize starch: 169 mmol; pea starch: 218 mmol; SED 18; $P = 0.054$).

Amino acids

Portal and arterial amino acids concentrations tended to be higher for pea starch than for maize starch. Compared with pea starch, net portal amino acids flux for maize starch was higher between 2 and 4 h after feeding and otherwise lower, but these differences were not significant, except for 8 h after feeding. The net portal glutamine and glutamic acid flux was negative (Table 3), showing an uptake by PDV. Also net portal flux of the sum of non-essential amino acids sometimes showed an uptake by PDV particularly for maize starch at about the time of feeding. Net portal flux over 12 h of pea starch tended to be lower for aspartic acid, but was higher or tended to be higher for valine, isoleucine, phenylalanine, tryptophan, arginine, serine, cystine, tyrosine, lysine, histidine and the sum of essential amino acids ($P < 0.1$ or $P < 0.05$; Table 3). Portal appearance of ileal digested tyrosine, lysine, serine, valine, cystine, isoleucine, phenylalanine, arginine, histidine, tryptophan and the sum of essential amino acids tended to be or was lower for maize starch than for pea starch (Table 3).

DISCUSSION

The patterns of appearance of glucose in the portal vein from maize and pea starches were different. Compared with maize starch, the appearance of glucose from pea starch was slower but lasted longer. This agrees with the observation that maize starch is digested faster than pea starch (Everts *et al.* 1996). The ratio insoluble starch : water-soluble starch in the stomach and cranial part of the small intestine (Everts *et al.* 1996) indicates a difference in the rate of hydrolysis between maize starch and pea starch. This different

Table 3. Net portal flux of amino acids in pigs fed on diets containing maize starch or pea starch

Amino acid	Net portal flux (mmol)				Flux as % of ileally digested			
	Diet		SED	Statistical significance of difference: P=	Diet		SED	Statistical significance of difference: P=
	Maize starch	Pea starch			Maize starch	Pea starch		
Threonine	10.9	15.2	3.3	0.274	43.8	59.3	13.9	0.330
Valine	22.1	28.6	2.9	0.087	66.6	84.0	7.9	0.091
Cystine	1.9	2.8	0.3	0.050	77.2	108.1	14.4	0.099
Methionine	8.4	9.6	0.8	0.217	93.3	99.2	7.4	0.470
Isoleucine	19.8	24.0	1.6	0.066	83.3	97.7	5.7	0.066
Leucine	35.0	40.9	2.9	0.115	86.4	99.0	6.0	0.105
Tyrosine	13.5	16.7	0.6	0.008	85.6	100.2	2.7	0.006
Phenylalanine	19.5	22.8	1.3	0.068	94.5	106.8	5.0	0.071
Lysine	24.1	31.0	1.7	0.017	82.5	109.3	5.3	0.007
Histidine	7.2	8.6	0.5	0.054	107.5	127.4	7.3	0.052
Tryptophan	2.6	3.7	0.4	0.082	74.1	110.6	13.3	0.052
Arginine	17.1	20.1	1.1	0.066	109.2	123.9	6.5	0.086
EAA	182.6	224.4	12.7	0.030	79.9	96.0	4.2	0.019
Aspartic acid	3.7	2.6	0.4	0.071	49.1*	47.2*	2.3	0.478
Asparagine	22.3	23.3	1.1	0.452				
Glutamic acid	-7.4	-8.8	2.7	0.653	-187.0†	-178.3†	23.0	0.725
Glutamine	-66.2	-62.9	7.3	0.677				
Serine	25.8	28.8	1.3	0.084	94.2	102.4	3.8	0.105
Glycine	23.1	25.5	7.0	0.745	68.1	73.9	22.3	0.807
Alanine	57.2	65.4	4.7	0.160	193.3	215.8	14.8	0.205
Proline	12.7	14.6	2.6	0.512	48.1	56.6	17.0	0.643
NEAA	71.3	88.7	22.1	0.477	34.2	41.8	10.8	0.523
Taurine	-1.0	-0.8	1.0	0.832				
Citrulline	10.3	11.0	0.5	0.277				
Ornithine	2.8	3.6	0.5	0.208				
TAA	253.9	313.1	30.5	0.124	60.6	73.0	7.2	0.161

EAA, essential amino acids; NEAA, non-essential amino acids; TAA, total amino acids.

* Combined flux of asparagine plus aspartic acid.

† Combined flux of glutamine plus glutamic acid.

hydrolysis rate may be responsible for the different pattern of appearance of glucose. Borgida & Laplace (1977) found that gastric emptying was 40% more rapid when hydrolysis of potato starch was made easier by extrusion. Also differences in ileal digestibility between non-resistant starch and resistant starch are attributed to differences in hydrolysis (Cummings & Englyst, 1995) and Rérat *et al.* (1984) suggested that the rate-limiting factor for appearance of glucose from maize starch in the portal vein is the rate of enzymic hydrolysis. The appearance of two peaks of glucose in the portal vein for maize starch has also been measured for a diet containing rapeseed concentrate but not for a diet containing casein (Galibois *et al.* 1989). Therefore the appearance of one or two peaks of glucose in the portal vein after feeding maize starch seems to depend, also, on diet components other than starch (Galibois *et al.* 1989).

The total amount of glucose absorbed over 12 h was lower for pea starch than for maize starch. However, ileal digestibility of pea starch is nearly 100% (Berggren *et al.*

1995; Everts *et al.* 1996), and is not different from ileal digestibility of maize starch (Everts *et al.* 1996). This implies that after feeding pea starch more glucose may be used as an oxidative substrate by the small-intestinal wall, or that part of the pea starch is fermented in the stomach or small intestine. Although microbial activity is low in the stomach and in the cranial two-thirds of the small intestine, it increases in the distal third of the small intestine (Jensen, 1988; Bach Knudsen *et al.* 1991) and a significant pre-caecal fermentation of NSP may occur (Bach Knudsen *et al.* 1991). Lactate and VFA are the end-products of fermentation in the stomach and small intestine, while in the large intestine VFA are the principal products (Argenzio & Southworth, 1974). The net portal flux of lactate was higher after feeding pea starch, but the difference with maize starch was not significant. However, lactate is not only an end-product of fermentation in the stomach and small intestine. Lactate may also be derived from metabolism of glutamine (Rérat & Corring, 1991) and glucose (Giusi-Perier *et al.* 1989) in the gut wall. The latter is supported by the correlation between the portal glucose and lactate concentration, although this correlation was not as high as that found by Giusi-Perier *et al.* (1989). The net portal VFA flux showed a higher fermentation for pea starch than for maize starch. However, increased fermentation in the large intestine, probably promoted by the higher N flow into the large intestine (Everts *et al.* 1996), may also have contributed to the higher net portal VFA flux. Acetate was the main component of this higher net portal VFA flux, as has been observed for fermentation of resistant starch in rats (Morand *et al.* 1991). Recently it has been suggested that VFA provoke the release of enteroglucan, which inhibits, among other things, gastric emptying (Gee *et al.* 1996). By inhibiting gastric emptying the higher fermentation for pea starch may contribute to the slower appearance of glucose from pea starch.

Net portal flux of glutamine was negative indicating an uptake of glutamine by the gastrointestinal wall. Glutamine is a major oxidative substrate for the small intestine (Rérat & Corring, 1991). Net portal flux of some amino acids was higher for pea starch than for maize starch, while the ileal amino acid digestibility is lower (Everts *et al.* 1996). The lower ileal amino acid digestibility for pea starch may have been caused by the reduced passage rate and the slower rate of starch digestion, resulting in a higher endogenous secretion (Everts *et al.* 1996). On the other hand, the slower rate of digestion of pea starch provided a more gradual supply of nutrients to the intestinal tissues, as can be seen from the net portal flux of glucose which approached zero 10 h after feeding maize starch but continued until the next feed for pea starch. A more gradual supply of glucose to the intestinal tissues also occurs for a diet containing maize starch compared with the same diet in which 35 % of maize starch is replaced by lactose, resulting in a 20 % higher net portal flux of amino-N for the diet with the more gradual supply of glucose (Giusi-Perier *et al.* 1989). The appearance of amino-N also differs when oligopeptides are infused into the duodenum in the presence of maltitol or maltose (Rérat *et al.* 1991).

A higher passage rate may reduce the contact time between feeds and enzymes and may result in incomplete hydrolysis of proteins (Giusi-Perier *et al.* 1989). On the other hand, a lower passage rate resulting in a more gradual supply of nutrients to the intestinal tissues, may have affected the mutual inhibition of sugars and amino acids during intestinal absorption (Vinardell, 1990; Rérat *et al.* 1991).

From the present study it may be concluded that, even though the ileal digestibilities of starches do not differ and approach 100 %, the rate of appearance of glucose in the portal vein and the net portal flux of glucose may be different. Moreover, the net portal flux of amino acids may be affected by the type of non-resistant starch in the diet.

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