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Effect of plasma and/or yeast extract on performance and intestinal morphology of piglets from 7 to 63 days of age

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ABSTRACT - The objective of this study was to evaluate the effect of diets supplemented with plasma and/or yeast extract on performance (daily weight gain [DWG], daily feed intake [DFI] and feed conversion [FC]) and intestinal morphology of piglets from 7 to 63 days of age. A total of 288 piglets aged 7 days and weighing 2.57±0.05 kg were studied. A randomized block design consisting of four experimental diets, six repetitions and 12 piglets per experimental unit was adopted. The pre-starter I (7 to 21 days), pre-starter II (22 to 35 days) and starter I (36 to 49 days) diets were supplemented as follows: control diet (CD): no plasma or yeast extract; plasma (PL) diet: addition of 6%, 4% and 2% plasma; yeast extract (YE) diet: addition of 6%, 4% and 2% yeast extract; plasma + yeast extract (PL+YE) diet: addition of 3%, 2% and 1% plasma and yeast extract each. From 50 to 63 days of age all piglets received the same diet. No difference in performance was observed from 7 to 21 days and from 7 to 28 days of age, whereas DWG was higher from 7 to 35 days in piglets receiving the PL+YE diet (268, 278, 271 and 288 g/day for CD, PL, YE and PL+YE, respectively). From 7 to 49 days and from 7 to 63 days, DWG (330 and 519 g/day, respectively) and DFI (307 and 647 g/day) were higher in animals receiving the PL-YE diet when compared with those consuming CD (DWG: 295 and 486 g/day; DFI: 266 and 594 g/day). No significant differences in intestinal morphology were observed between piglets receiving the different diets. The combination of plasma and yeast extract elevates DWG, but does not affect the intestinal morphology of piglets from 7 to 63 days of age.

Key Words: feed conversion, feed intake, swine, villi, weight gain

Introduction

At birth, the gastrointestinal tract of piglets is completely adapted to the digestion and utilization of the milk of their sow, with an apparent fat digestion of 96% during this phase (Jensen et al., 1997). However, important changes in the composition of the diet occur at weaning and require the presence of appropriate enzymes in the stomach, pancreas and intestine, which are usually not produced during the suckling period. As a consequence, weaning is associated with physiological and nutritional stress, which reduces feed intake and weight gain (Makkink et al., 1994).

The milk meets the energy requirements of piglets only until three weeks of age, a time when milk production by the sow reaches its peak and declines thereafter. In contrast, the energy requirements of piglets increase rapidly and supplementation is required to meet these demands. In this respect, two aspects need to be taken into account: the first concerns the variation in the quality and quantity of milk produced by the sow, and the second, particularities of the digestive system of piglets (Roppa, 1998).

When piglets are weaned at approximately three weeks of age, they no longer receive the immunoglobulins present in maternal milk that protect the small intestine (Wilson, 1974). This loss might be responsible for the growth delay normally seen in piglets that are weaned early, since the immune system only reaches its maturity at approximately six weeks of age (Stein, 1996).

In the small intestine, nutrients and water are absorbed by villus enterocytes, which are derived from crypt cells. A reduction in villous height (VH) and an increase in crypt depth (CD) are related to changes in the number of enterocytes. Therefore, the shortening of villi predisposes to poor digestion and absorption, which may be involved in the pathogenesis of post-weaning diarrhea (Hampson, 1986).

The greater the villus size, the higher the capacity of nutrient digestion and absorption since various digestive

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enzymes are produced in the villous borders. However, a major reduction in villous size is observed at weaning, which seriously affects the villous structure; this reduction reaches 63% within the first days (Roppa, 1998).

Dietary alternatives, as well as alternative ingredients or protein combinations, have been studied in an attempt to increase the feed intake of piglets before weaning and to improve diet quality and consequently animal performance (Ferreira, 1992).

The objective of the present study was to evaluate performance and intestinal morphology of piglets fed diets supplemented with plasma and/or yeast extract from 7 to 63 days of age.

Material and Methods

The experiment was conducted at the facilities of Granja Paraíso pig farm, located in Patos de Minas, Minas Gerais, Brazil. A total of 288 castrated male piglets (Agroceres PIC® genetics) were used. The animals were fed a dry diet throughout the experiment and were subjected to two periods of management: the first in the maternity unit and the second in the nursery after weaning.

At seven days of age with a starter body weight of 2.57±0.05 kg, piglets were equally allocated to the experimental diets and maintained in maternity cages with sows of third and fourth production cycles until weaning at 21 days of age. At that time, the piglets were transferred to nursing pens (1.60 × 1.25 × 1.65 m) with a partially slatted floor and equipped with semi-automatic feeders and nipple drinkers. A randomized block design was used to control starter differences in body weight, consisting of four experimental diets, six repetitions and 12 piglets per experimental unit. The experiment was conducted over a period of eight weeks, including two weeks in the maternity unit and the last 6 weeks in the nursery.

The pre-starter I (7 to 21 days), pre-starter II (22 to 35 days) and starter I (36 to 49 days) diets were supplemented as follows: control diet: no plasma or yeast extract; plasma (PL) diet: addition of 6%, 4% and 2% plasma; yeast extract (YE) diet: addition of 6%, 4% and 2% yeast extract; plasma + yeast extract (PL+YE) diet: addition of 3%, 2% and 1% plasma and yeast extract each. From 50 to 63 days of age, all piglets received the same diet based on corn and soybean meal, which consisted of 3,260 kcal/kg metabolizable energy (ME), 20% crude protein (CP), 0.80% Ca, 0.61% Pt, 1.23% lysine, 0.35% methionine, 0.81% threonine, and 0.23% tryptophan. The diets tested were formulated to meet the minimum nutritional requirements of piglets according to Rostagno et al. (2005) (Tables 1, 2 and 3).

Both piglets and sows (which were fed the routine farm ration) received feed and water *ad libitum* throughout the experiment. Maximum and minimum temperatures and relative air humidity were recorded twice a day, at 8h00 and 17h00 (Table 4). The piglets were weighed at 7, 21, 28, 35, 49, and 63 days of age. Feed leftovers were weighed on the same occasions and used for the calculation of daily feed intake, daily weight gain and feed conversion.

For structural and ultrastructural analysis of duodenal and jejunal mucosa, 48 piglets with a live weight close the mean of each repetition were slaughtered at 28 and 49 days of age (7 and 28 days postweaning), corresponding to six

Table 1 - Percentage, nutritional and energetic compositions of pre-starter diets I supplied to piglets from 7 to 21 days of age

Ingredients	Experimental diets			
	Control diet	Plasma	Yeast extract	Plasma + yeast extract
Corn, 7.8% CP	26.982	33.785	27.730	30.740
Soybean flour, 52% CP	12.000	-	6.000	3.650
Soybean meal, 45% CP	9.000	9.000	9.000	9.000
Yeast extract	-	-	6.000	3.000
Cracker meal	10.000	10.00	10.000	10.000
Bovine plasma	-	6.000	-	3.000
Whey	17.900	17.900	17.900	17.900
Bone meal, 16% CP	0.850	0.350	0.250	0.300
Sugar	5.000	5.000	5.000	5.000
Pre-starter supplement I[1]	10.000	10.000	10.000	10.000
Pre-starter supplement II[1]	5.000	5.000	5.000	5.000
Sodium bentonite	0.300	0.300	0.300	0.300
Degummed soybean oil	2.950	2.650	2.800	2.100
DL-methionine 99-MI	-	-	0.005	-
L-lysine 80-MI	0.015	0.015	0.015	0.010
L-threonine 98%	0.003	-	-	-
Total, kg	100.000	100.000	100.000	100.000
Nutritional levels[2]				
Metabolizable energy, kcal/kg	3,500	3,500	3,500	3,500
Crude protein, %	19.53	18.10	19.50	18.91
Total lactose, %	16.00	16.00	16.00	16.00
Fat, %	7.11	6.25	6.91	6.35
Crude fiber, %	1.81	1.59	1.67	1.75
Calcium, %	0.85	0.64	0.68	0.67
Total phosphorus, %	0.65	0.62	0.62	0.62
Available phosphorus, %	0.52	0.52	0.52	0.52
Sodium, %	0.39	0.55	0.40	0.48
Total lysine, %	1.63	1.61	1.64	1.63
Digestible lysine, %	1.50	1.50	1.50	1.50
Total methionine, %	0.61	0.60	0.61	0.60
Digestible methionine, %	0.58	0.58	0.58	0.58
Total methionine + cystine, %	0.92	0.94	0.90	0.92
Digestible methionine + cystine, %	0.85	0.87	0.86	0.85
Total threonine, %	1.05	1.06	1.06	1.07
Digestible threonine, %	0.96	0.96	0.95	0.95
Total tryptophan, %	0.26	0.25	0.25	0.25
Digestible tryptophan, %	0.22	0.22	0.22	0.22

[1] Guaranteed levels per kg of diet: vit. A - 4,000 IU; vit. D3 - 220 IU; vit. E - 22 mg; vit. K - 0.5 mg; vit B2 - 3.75 mg; vit. B12 - 20 mcg; calcium pantothenate - 12 mg; niacin - 20 mg; choline - 60 mg; iodine - 140 mg; selenium - 300 mg; manganese - 10 mg; zinc - 100 mg; copper - 10 mg; iron - 99 mg.
[2] Nutritional values of ingredients, as proposed by Rostagno et al. (2005).
CP - crude protein.

animals per treatment/slaughter. For slaughter, the animals were stunned electrically and then subjected to cardiac perfusion and bleeding. Next, the viscera were removed and two segments of 1 cm each were collected from the two parts of the small intestine (duodenum and jejunum).

For structural analysis of the small intestine, samples (±3 cm) from the duodenum and mid-portion of the jejunum were opened along the mesenteric border and collected. The specimens were fixed in Bouin fixative for 24 hours. After this period, the specimens were washed in running water and in 70% ethanol for removal of the fixative, dehydrated in an increasing alcohol series (70 to 100%), cleared in xylene and embedded in paraffin. The blocks were cut into 5 µm thick sections with a microtome, generating 12 to 14 semi-serial sections of each segment per animal. The sections were stained with hematoxylin-eosin.

The histological slides were examined under an Olympus BX41 light microscope equipped with an Olympus DP11-N digital camera. The images were analyzed with the Image Pro-Plus® 4.1 program at a magnification of 125× for the evaluation of villus height (VH) and crypt depth (CD). Thirty measurements of each variable were made per sample and the mean was used for analysis. Based on these results, the VH/CD ratio was calculated.

Table 2 - Percentage, nutritional and energetic compositions of pre-starter diets II supplied to piglets from 22 to 35 days of age

Ingredients	Experimental diets			
	Control diet	Plasma	Yeast extract	Plasma + yeast extract
Corn, 7.8% CP	39.943	42.915	41.130	40.870
Soybean flour, 52% CP	8.280	2.5000	3.300	3.975
Soybean meal, 45% CP	12.000	12.000	12.000	12.000
Yeast extract	-	-	4.000	2.000
Cracker meal	7.000	7.000	7.000	7.000
Bovine plasma	-	4.000	-	2.000
Whey	14.140	14.150	14.100	14.150
Bone meal, 16% CP	0.850	0.700	0.600	0.650
Sugar	5.000	5.000	5.000	5.000
Pre-starter supplement II[1]	10.000	10.000	10.000	10.000
Sodium bentonite	0.300	0.300	0.300	0.300
Degummed soybean oil	2.320	1.420	2.300	2.975
DL-methionine 99-MI	0.022	-	0.050	0.010
L-lysine 80-MI	0.095	0.015	0.150	0.050
L-threonine 98%	0.050	-	0.070	0.020
Total, kg	100.000	100.000	100.000	100.000
Nutritional levels[2]				
Metabolizable energy, kcal/kg	3,450	3,450	3,450	3,450
Crude protein, %	18.00	18.00	17.37	18.00
Total lactose, %	12.00	12.00	12.00	12.00
Fat, %	6.44	5.65	6.39	6.12
Crude fiber, %	2.02	1.91	2.00	2.02
Calcium, %	0.76	0.70	0.70	0.70
Total phosphorus, %	0.64	0.66	0.64	0.65
Available phosphorus, %	0.50	0.53	0.52	0.52
Sodium, %	0.31	0.43	0.32	0.37
Total lysine, %	1.52	1.52	1.52	1.52
Digestible lysine, %	1.40	1.40	1.40	1.40
Total methionine, %	0.59	0.58	0.60	0.59
Digestible methionine, %	0.56	0.56	0.57	0.56
Total methionine + cystine, %	0.88	0.89	0.88	0.88
Digestible methionine + cystine, %	0.81	0.82	0.81	0.81
Total threonine, %	0.99	1.00	0.99	0.99
Digestible threonine, %	0.88	0.89	0.88	0.88
Total tryptophan, %	0.20	0.20	0.20	0.20
Digestible tryptophan, %	0.18	0.18	0.18	0.18

[1] Guaranteed levels per kg of diet: vit. A - 4,000 IU; vit. D3 - 220 IU; vit. E - 22 mg; vit. K - 0.5 mg; vit B2 - 3.75 mg; vit. B12 - 20 mcg; calcium pantothenate - 12 mg; niacin - 20 mg; choline - 60 mg; iodine - 140 mg; selenium - 300 mg; manganese - 10 mg; zinc - 100 mg; copper - 10 mg; iron - 99 mg.
[2] Nutritional values of ingredients, as proposed by Rostagno et al. (2005).
CP - crude protein.

Table 3 - Percentage, nutritional and energetic compositions of starter diets I supplied to piglets from 36 to 49 days of age

Ingredients	Experimental diets			
	Control diet	Plasma	Yeast extract	Plasma + yeast extract
Corn, 7.8% CP	48.160	49.585	47.910	48.530
Soybean flour, 52% CP	6.250	3.200	4.500	4.000
Soybean meal, 45% CP	18.000	18.000	18.000	18.000
Yeast extract	-	-	2.000	1.000
Cracker meal	7.000	7.000	7.000	7.000
Bovine plasma	-	2.000	-	1.000
Whey	9.720	9.720	9.700	9.650
Bone meal, 16% CP	0.550	0.550	0.500	0.500
Sugar	2.000	2.000	2.000	2.000
Starter supplement I[1]	5.000	5.000	5.000	5.000
Sodium bentonite	0.300	0.300	0.300	0.300
Degummed soybean oil	2.900	2.480	2.980	3.015
DL-methionine 99-MI	0.040	0.025	0.050	0.002
L-lysine 80-MI	0.010	0.100	-	-
L-threonine 98%	0.070	0.040	0.060	0.003
Total, kg	100.000	100.000	100.000	100.000
Nutritional levels[2]				
Metabolizable energy, kcal/kg	3,400	3,400	3,400	3,400
Crude protein, %	18.00	18.00	18.06	19.01
Total lactose, %	7.00	7.00	7.00	7.00
Fat, %	6.36	6.00	6.41	6.44
Crude fiber, %	2.44	2.38	2.39	2.49
Calcium, %	0.70	0.70	0.70	0.70
Total phosphorus, %	0.59	0.61	0.60	0.61
Available phosphorus, %	0.42	0.44	0.44	0.44
Sodium, %	0.28	0.34	0.28	0.31
Total lysine, %	1.42	1.42	1.42	1.42
Digestible lysine, %	1.30	1.30	1.29	1.29
Total methionine, %	0.55	0.54	0.55	0.54
Digestible methionine, %	0.52	0.51	0.52	0.51
Total methionine + cystine, %	0.84	0.84	0.84	0.84
Digestible methionine + cystine, %	0.77	0.77	0.77	0.77
Total threonine, %	0.94	0.94	0.94	0.95
Digestible threonine, %	0.83	0.83	0.83	0.83
Total tryptophan, %	0.20	0.21	0.20	0.21
Digestible tryptophan, %	0.17	0.18	0.17	0.18

[1] Guaranteed levels per kg of diet: vit. A - 4,000 IU; vit. D3 - 220 IU; vit. E - 22 mg; vit. K - 0.5 mg; vit B2 - 3.75 mg; vit. B12 - 20 mcg; calcium pantothenate - 12 mg; niacin - 20 mg; choline - 60 mg; iodine - 140 mg; selenium - 300 mg; manganese - 10 mg; zinc - 100 mg; copper - 10 mg; iron - 99 mg.
[2] Nutritional values of ingredients, as proposed by Rostagno et al. (2005).
CP - crude protein.

Table 4 - Average maximum and minimum temperature and relative humidity and their respective standard deviations recorded during the experimental period

Period	Temperatures (ºC)		Relative humidity (%)
	Maximum	Minimum	
08h00	27.3±3.5	14.7±2.8	64.8±9.2
17h00	30.5±3.6	21.4±2.5	38.1±17.3

Samples (±1 cm) were also collected from the duodenum and mid-portion of the jejunum for ultrastructural analysis of the small intestine, immediately washed in phosphate buffer (0.1 M, pH 7.4) and fixed in glutaraldehyde. Next, the specimens were dehydrated in an increasing ethanol series, critical point dried with CO_2, mounted, coated with gold-palladium and examined under a JEOL JSM scanning electron microscope operated at 15 kV. Electron micrographs were obtained from five areas per sample for the estimation of villus density (number of villi/μm^2). The microscopic analyses were performed at the laboratories of the Department of Morphology and Animal Physiology, Faculty of Agricultural and Veterinary Sciences, Unesp, Campus Jaboticabal, Brazil.

Statistical analysis was performed using the SAEG (Sistema para Análises Estatísticas e Genéticas, version 8.0) software. The data were analyzed by analysis of variance and treatment means were compared by the Student-Newman-Keuls test, adopting a significance level of 5%. The assumptions for analysis of variance were tested.

Results and Discussion

No significant effects (P>0.05) of the different experimental diets on daily weight gain, daily feed intake or feed conversion of piglets were observed between 7 and 21 days of age (Table 5). These results agree with Carlson & Veum (2000), who also found no effect of the addition of plasma (5%) and yeast extract (5%) on these variables in piglets from 7 to 21 days of age. In contrast, Ferreira et al. (1992) showed that offering complex diets by day 7 or day 10 after birth stimulates the development of the digestive enzyme system, improving utilization of the diets.

Feed intake shows marked individual variations during the suckling period as a result of competition between piglets with their littermates for sow milk (Appleby et al., 1991). Pajor et al. (1991) reported variations in preweaning feed intake of 13 to 191 g/piglet between day 10 and day 28 of age when the animals were weaned. The feed intake of piglets until 21 days of age might be a limiting factor for subsequent performance. In a literature review of studies on animals fed solid diets, Lopes et al. (1986) found a feed intake of less than 10 g/piglet/day during the suckling period.

The different experimental diets did not affect (P>0.05) daily weight gain, daily feed intake or feed conversion of piglets between 7 and 28 days of age (Table 5). The low feed intake after weaning is one of the main factors associated with intestinal atrophy. Any component included in the starter diets that improves consumption during this period will also improve digestion and intestinal absorption. Daily weight gain and feed intake tended to increase in animals receiving diets containing plasma and/or yeast extract, but this difference was not significant (P>0.05) (Table 5).

Piglets receiving the PL+YE diet showed higher daily weight gain than animals fed the control and YE diets between 7 and 35 days of age (P<0.05) (Table 5). These results disagree with those reported by Costa (2006), who found no effect of complex diets on the daily weight gain of piglets at 35 days of age. Neither daily feed intake nor feed conversion was affected by the experimental diets during this period (P>0.05). In contrast, Hansen et al. (1993) and Kats et al. (1994) observed higher daily feed intake by piglets consuming complex diets when compared with animals receiving the control diet.

Table 5 - Average daily weight gain (DWG), daily feed intake (DFI) and feed conversion (FC) of piglets in different periods fed different experimental diets

	Experimental diets				P	CV (%)
	Control diet	Plasma	Yeast extract	Plasma + yeast extract		
Period 1						
DWG (g)	317	322	326	324	0.1893	9.84
DFI (g)	44	45	46	46	0.3665	6.00
FC	0.14	0.14	0.14	0.14	0.4893	5.43
Period 2						
DWG (g)	238	249	250	251	0.3626	5.90
DFI (g)	65	69	69	71	0.3993	9.36
FC	0.27	0.28	0.28	0.28	0.4156	10.49
Period 3						
DWG (g)	268b	278ab	271b	288a	0.0129	3.46
DFI (g)	154	167	156	169	0.2163	9.34
FC	0.57	0.60	0.57	0.59	0.3452	7.82
Period 4						
DWG (g)	295c	319ab	310b	330a	0.0002	3.46
DFI (g)	266c	295ab	283bc	307a	0.0029	5.70
FC	0.90	0.92	0.91	0.93	0.3962	4.23
Period 5						
DWG (g)	486c	502b	501b	519a	0.0006	2.14
DFI (g)	594b	627ab	622ab	647a	0.0170	4.11
FC	1.22	1.25	1.24	1.24	0.3526	3.34

Means followed by the same letter within the row are similar by the SNK test (5 %).
Period 1 – from 7 to 21 days of age; Period 2 – from 7 to 28 days of age; Period 3 – from 7 to 35 days of age; Period 4 – from 7 to 49 days of age; Period 5 – from 7 to 63 days of age.
CV - coefficient of variation.

From 7 to 49 days of age, daily weight gain was higher in piglets receiving the PL+YE diet (P<0.05) and lower in those receiving the control diet (P<0.05). Daily feed intake was higher in piglets fed the PL+YE diet as compared with those receiving the control and YE diets (P<0.05). Piglets fed the YE and PL diets presented similar daily feed intake. The lowest daily feed intake, in absolute values, was observed in piglets fed the control diet, which did not differ from animals consuming the YE diet. Feed conversion was not affected by the different experimental diets (P>0.05) (Table 5). These results disagree with Costa (2006), who observed higher daily weight gain and feed intake during this period in piglets fed plasma-supplemented diets compared with those receiving diets containing yeast extract. The author also found no effects of the diets on feed conversion.

Daily weight gain from 7 to 63 days of age was higher in piglets receiving the PL+YE diet than in those fed the PL and YE diets (P<0.05) and the lowest gain was observed in animals fed the control diet (P<0.05). Daily feed intake was higher in piglets receiving the PL+YE diet (P<0.05) in relation to animals fed the control diet. No significant difference in daily feed intake was observed between piglets fed the YE or PL diets and those receiving the control diet, although feed intake was 5.26% and 4.5% lower in the latter as compared with piglets fed the PL and YE diets, respectively. Feed conversion was not affected by the experimental diets (P>0.05).

The results of this experiment agree with those reported by Carlson & Veum (2000), who evaluated the effects of the addition of plasma (5%) and/or yeast extract (5%) to piglet diets during the starter phase and observed better performance of animals fed the diet containing both additives. In addition, the authors reported that weight gain, feed intake and feed conversion efficiency were similar in animals receiving the plasma- or yeast extract-supplemented diets.

The present results suggest that the combined administration of protein sources (YE and PL) favor the daily feed intake of piglets during the postweaning period, with a positive effect on daily weight gain. Since the diets were isonutrient, the beneficial effects observed for the diets supplemented with PL and YE alone or in combination were related to factors present in these ingredients that are not essential nutrients for the formulation of a diet. No disease or death of piglets was observed during the experimental period. In addition, the animals presented no diarrhea or loose stool and no signs or symptoms of enteritis.

No significant differences (P>0.05) in VH, CD or VH/CD ratio in the duodenum and jejunum were observed between piglets receiving the different experimental diets and slaughtered at 28 days of age (Table 6). These results agree with the study of Bertol (2000) and Castillo (2004), who found no effects of different protein sources on VH, CD or VH/CD ratio. Jiang et al. (2000) also observed no effect of diets supplemented with plasma on the same jejunal variables in piglets slaughtered at 8 days postweaning. Similarly, the addition of 15% plasma or casein exerted no effect on jejunal VH or CD in piglets slaughtered at 28 days of age (Dijk et al., 2001). Carlson & Veum (2000) also found no effect of the addition of plasma or yeast extract on duodenal or jejunal VH in piglets slaughtered at 28 days of age. However, in that study CD was lower and the VH/CD ratio tended to be higher in piglets fed diets supplemented with plasma and yeast extract as compared with those receiving the control diets without either ingredient. The present results disagree with those reported by Domeneghini et al. (2004), who evaluated diets supplemented with 0.05% nucleotides and observed a higher VH and VH/CD ratio and lower CD in piglets slaughtered at 28 days of age.

According to Hancock (1990), CD is an indicator of the degree of epithelial cell hyperplasia, which is related to antigenicity of the diet, among other factors. A lower CD indicates less aggression of the diet to the morphology of the intestinal wall (Li et al., 1991). In addition, a higher VH/CD ratio indicates a greater capacity of digestion and absorption by intestinal villi, thus demonstrating the positive effect of plasma and yeast extract on the intestinal wall of piglets.

Experimental diets did not affect (P>0.05) VH, CD or VH/CD ratio of piglets slaughtered at 49 days of age (Table 6). These results disagree with those reported by Cera et al. (1988), Makkink et al. (1994), McCracken et al. (1999) and Klurfeld (2002), who demonstrated a significant effect of total nutrient intake on gastrointestinal tract development; VH was directly related to dry matter and energy intake.

Immunoglobulins, peptides and specific amino acids present in plasma are among the nutrients that stimulate the development of intestinal villi; immunoglobulins are the main component responsible for the beneficial effects of plasma. However, the absorption of intact protein after weaning is unlikely and the favorable effects of plasma seem to be more related to peptides released by hydrolysis of proteins present in the immunoglobulin fraction and/or specific amino acids released by total protein hydrolysis, which stimulate intestinal enterocytes.

Dietary nucleotides enhance the growth and maturation of intestinal epithelial cells as demonstrated by an increase in mucosal protein and DNA synthesis, increased VH in the small intestine, and increased activity of maltase and lactase (Uauy et al., 1990; Carver, 1994). In addition, dietary nucleotides also stimulate cell differentiation (Sanderson & He, 1994) and dietary supplementation with nucleic acid stimulates mucosal cell proliferation (Kishibuchi et al., 1997; Tsujinaka et al., 1999). The development of the gastrointestinal tract directly affects the digestion and absorption of nutrients and, consequently, animal performance. In view of the effects of nucleotides on the maintenance and maturation of the intestinal mucosa, their presence in the diet seems to be important for structural maintenance and growth of the gastrointestinal tract, particularly after weaning.

According to Hall & Byrne (1989), the decrease in the rate of crypt cell production and consequent villous atrophy is the result of deficient energy and protein intake. Hancock (1990) and Li et al. (1991) concluded that there is a positive correlation between VH in the small intestine and the growth rate of piglets.

At 28 days of age, villus density in the duodenum was not affected by the experimental diets (P>0.05) (Table 7), whereas in the jejunum this variable was higher in piglets receiving the PL+YE diet than in those fed the control diet (P<0.05). These results agree with Cera et al. (1988), who observed visible alterations in the intestinal villi of piglets after weaning, which were influenced by the nutrients and protein sources used in the diets.

No effects of the experimental diets were observed on duodenum or jejunum villus density in piglets slaughtered at 49 days of age (P>0.05) (Table 7). According to Argenzio (1984), the pleats or folds increase the absorption surface by 10 times, villi by 150 times, and microvilli by 600 times.

Analysis of the electron micrographs of the duodenum of piglets slaughtered at 28 days of age and fed the control diet showed slight villous flattening without uniformity (Figure 1), indicating that the dietary nutrients were poorly utilized by the animals as compared with the other groups. However, since the first week after weaning is considered to be critical for piglets, none of the animals presented perfect villi. In contrast, ultrastructural analysis revealed major villous alterations in the jejunum of piglets slaughtered at 28 days of age (Figure 2). The villi were slightly thinned at the tips and markedly damaged in animals receiving the control and PL diets, whereas intact and finger-like villi were observed in the intestinal mucosa of piglets fed the YE and PL+YE diets, demonstrating greater preservation and maintenance of the intestinal epithelium.

At 49 days of age, deformation of the villous surface of the duodenum characterized by tongue-shaped villi and the occurrence of fusions was noted mainly in piglets fed the control diet (Figure 3). Finger-like villi that were visually more intact were observed in piglets receiving the other diets, indicating the preservation of villous integrity and a greater capacity of digestion and absorption. Analysis of the jejunum of piglets slaughtered at 49 days of age (Figure 4) showed tongue-shaped and compressed villi in animals receiving the PL, YE and PL+YE diets, whereas shorter and more flattened villi were observed in animals fed the control diet, indicating poor utilization of dietary nutrients.

Taken together, the results regarding performance of piglets and structural and ultrastructural analysis of the duodenum and jejunum suggest that the PL+YE diet was the best, followed by the PL and YE diets, whereas the control diet exerted the worst effect on animal performance and intestinal morphology.

Table 6 - Average villus height (VH), crypt depth (CD) in µm, and VH/CD ratio in the duodenum and jejunum of piglets slaughtered at 28 and 49 days of age fed different experimental diets

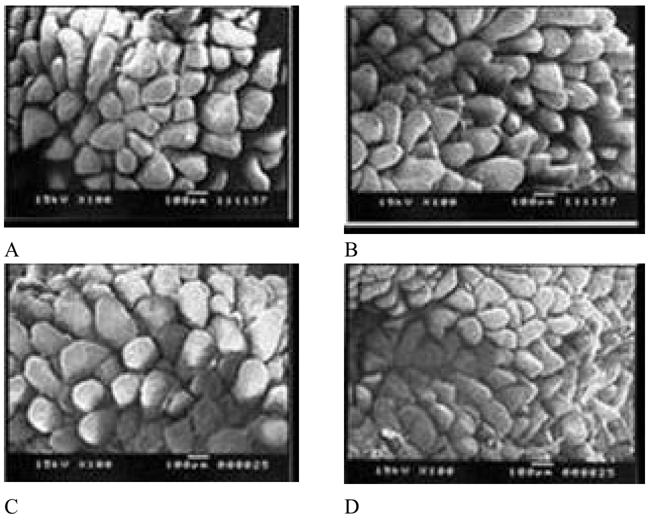
	Experimental diets				P	CV (%)
	Control diet	Plasma	Yeast extract	Plasma + yeast extract		
Duodenum, 28 days						
Villus height	450.65	480.35	474.15	489.35	0.0980	5.47
Crypt depth	196.65	210.50	201.35	201.15	0.1235	8.82
VH/CD	2.31	2.30	2.36	2.43	0.1198	9.90
Jejunum, 28 days						
Villus height	438.50	449.15	446.35	482.65	0.1052	6.85
Crypt depth	175.00	182.85	176.85	188.85	0.1458	14.98
VH/CD	2.59	2.50	2.54	2.61	0.1236	18.46
Duodenum, 49 days						
Villus height	510.35	548.35	542.00	550.15	0.1401	5.89
Crypt depth	175.15	183.50	181.00	187.00	0.1369	11.48
VH/CD	2.92	3.00	3.01	2.97	0.0985	6.09
Jejunum, 49 days						
Villus height	498.65	526.65	520.35	539.35	0.3316	7.24
Crypt depth	170.15	178.00	171.15	173.15	0.1856	13.16
VH/CD	2.95	3.00	3.06	3.15	0.1125	10.87

CV - coefficient of variation.

Table 7 - Means for the density of villi (no./µm^2) in duodenum and jejunum of piglets at 28 and 49 days of age fed different experimental diets

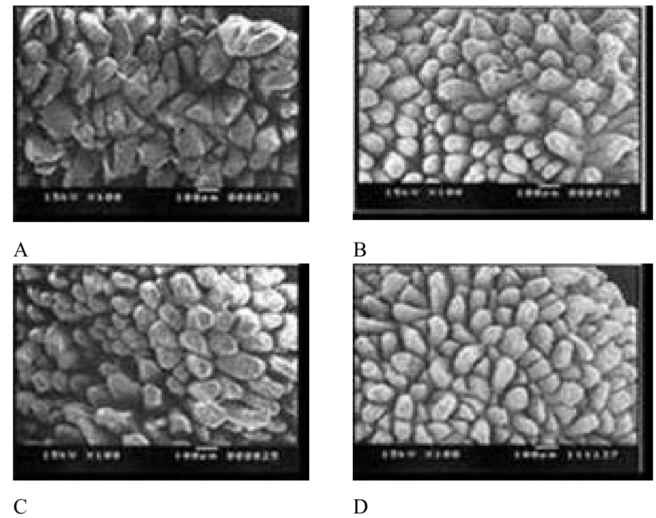
	Experimental diets				P	CV (%)
	Control diet	Plasma	Yeast extract	Plasma + yeast extract		
28 days						
Duodenum	79.00	76.95	65.85	77.65	0.1253	21.89
Jejunum	63.50b	76.35ab	73.15ab	88.35a	0.0493	18.69
49 days						
Duodenum	36.00	44.50	40.50	45.65	0.1433	15.52
Jejunum	50.85	54.50	54.15	56.35	0.1056	17.42

CV - coefficient of variation.



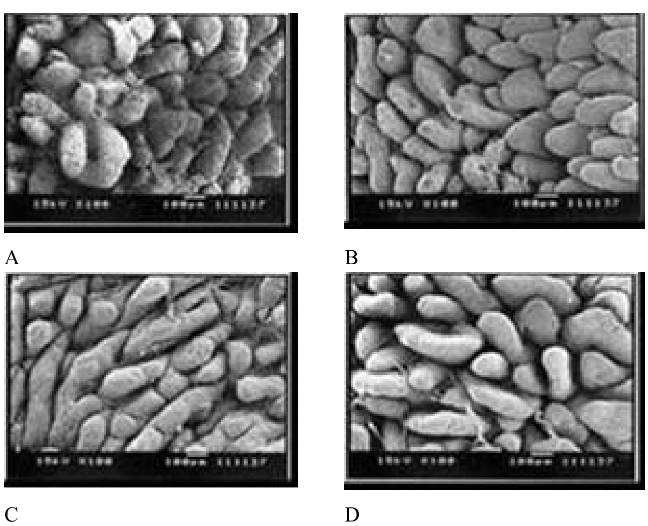
A = 150X.

Figure 1 - Electron-micrographs of duodenum of piglets slaughtered at 28 days of age and fed the control (A), plasma (B), yeast extract (C) and plasma + yeast extract (D) diets.



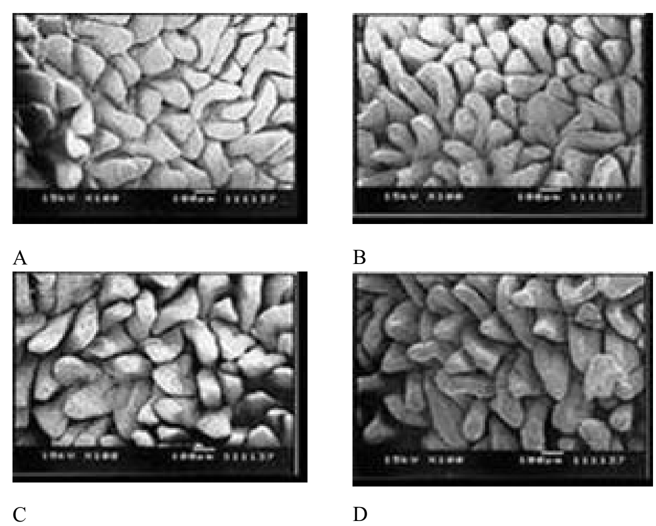
A = 150X.

Figure 2 - Electron-micrographs of jejunum of piglets slaughtered at 28 days of age and fed control (A), plasma (B), yeast extract (C) and plasma + yeast extract (D) diets.



A = 150X.

Figure 3 - Electron-micrographs of duodenum of piglets slaughtered at 49 days of age and fed control (A), plasma (B), yeast extract (C) and plasma + yeast extract (D) diets.



A = 150X.

Figure 4 - Electron-micrographs of jejunum of piglets slaughtered at 49 days of age and fed control (A), plasma (B), yeast extract (C) and plasma + yeast extract (D) diets.

Conclusions

The addition of plasma or yeast extract to pre- and postweaning diets has beneficial effects on the daily weight gain of piglets. Plasma and yeast extract exert a synergistic effect, favoring daily weight gain in piglets from 7 to 63 days of age. In general, the addition of plasma and/or yeast extract does not alter the structure and ultrastructure of the small intestine of piglets during the starter phase.

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