CHAPTER 2

GROWTH PERFORMANCE OF WEANLING PIGS FED SPRAY-DRIED ANIMAL PLASMA: A REVIEW

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Abstract

Spray-dried animal plasma (SDAP), mostly of porcine origin, is frequently used as an ingredient of weanling piglets diets in order to improve feed intake and to reduce post-weaning diarrhoea. On the basis of 15 published studies it is concluded that dietary SDAP levels up to 6 % raise both average daily gain (ADG) and feed intake (ADFI) in the first two weeks after weaning in a dose-dependent fashion. Up to 6 % SDAP also reduces feed conversion ratio (FCR). The positive effect of SDAP on ADG and ADFI is much more pronounced in the first than the second week after weaning. There is no positive carry-over effect of SDAP feeding during the period of two weeks after weaning on growth performance thereafter. SDAP is an expensive protein source and an economic evaluation should be made before including SDAP in weanling piglets diets. Multiple regression analysis indicated that, apart from SDAP dose, baseline growth rate is an important determinant of the effect of SDAP on ADG, with high baseline growth rate being associated with small effects of SDAP. It should be stressed that SDAP is a non-sterilised product that might spread certain diseases after feeding it to pigs. Porcine plasma has more beneficial effects than bovine plasma. Possible modes of action are discussed. It is suggested that, in addition to improving feed

palatability, SDAP reduces post-weaning intestinal disease by preventing attachment of pathogens.

Introduction

Weanling piglets often suffer from post-weaning diarrhoea and oedema disease. In the pathogenesis of these diseases, enteropathogenic *E. coli* strains play a major role (Van Beers-Schreurs et al. 1992, Nabuurs et al. 1993, Pluske et al. 1997, Nabuurs 1998). Low feed intake and post-weaning diarrhoea, which both occur during the first two weeks after weaning, have a negative impact on growth performance. Various measures are taken to improve feed intake and health after weaning. Amongst these measures is the addition of specified substances to the weanling piglet diet. One of these substances is spray dried animal plasma (SDAP), which usually is of porcine origin (SDPP) as a by-product of slaughter plants. An anticoagulant is added, usually sodium citrate, to the blood from slaughtered pigs and the erythrocytes are removed by centrifugation. The plasma obtained is subsequently spray-dried and used for the production of both human foodstuffs and animal feeds (Howell and Lawrie 1983, Gatnau 1990).

The type of protein in the diet of weanling piglets has consequences for feed intake, weight gain, nitrogen digestibility and pancreatic enzyme activity (Makkink et al. 1994a, Makkink et al. 1994b, Peiniau et al. 1996). The typical composition of SDAP is given in Tables 1 and 2.

Table 1

Composition (% of product) of various spray-dried animal plasma (SDAP) preparations in comparison with that of casein and soybean protein concentrate

Component	SDAP [a]	SDPP*[b]	Freeze dried porcine plasma[c]	Dried porcine plasma[c]	Dried bovine plasma[c]	Casein [a]	Soybean [a] protein concentrate
Dry matter	91	94.6	90.8	91.1	91.6	91	90
Crude protein	78	87.5	68	70	70	89	64
Crude fat	2	1	2	1.5	1.5	0.8	3
Ash	n.g.	5	11.5	11.8	10.3	n.g.	n.g.
Calcium	0.15	0.09	n.g.	n.g.	n.g.	0.61	0.35
Phosphorus	1.71	0.13	n.g.	n.g.	n.g.	0.82	0.81
Sodium	3.02	3.4	5.2	5.1	5	0.01	0.05
Chloride	1.5	n.g.	n.g.	n.g.	n.g.	0.04	n.g.
Potassium	0.2	0.13	n.g.	n.g.	n.g.	0.01	2.2
Magnesium	0.34	n.g.	n.g.	n.g.	n.g.	0.01	0.32

* Spray-dried porcine plasma [a] National Research Council (1998). [b]Delaney (1975)
[c]Howell and Lawrie (1983) n.g. = not given

Table 2

Amino acid composition and apparent ileal digestibilities of various spray-dried plasma (SDAP) preparations in comparison with casein and soybean meal

	Content (% of product)					Apparent ileal digestibility (%)		
	SDAP[a]	SDPP[b*]	SDBP[b+]	Casein[c]	Soybean meal[c]	SDAP[a]	Casein[c]	Soybean meal[c]
Alanine	n.g.	4.19	3.95	2.69	2.05	n.g.	95	85
Asparagine	n.g.	7.58	8.48	6.13	5.42	n.g.	96	87
Arginine	4.55	4.47	4.70	3.02	3.46	90	94	94
Glutamine	n.g.	11.18	11.39	18.48	8.45	n.g.	96	90
Glycine	n.g.	2.80	2.91	1.68	2.01	n.g.	94	83
Histidine	2.55	2.51	2.45	2.60	1.26	91	98	89
Isoleucine	2.71	2.79	2.53	4.37	2.15	85	95	87
Leucine	7.61	7.44	7.63	8.15	3.60	84	98	87
Lysine	6.84	6.84	7.43	6.72	2.90	87	98	89
Methionine	0.75	0.62	0.95	2.52	0.65	64	98	90
Cystine	2.63	3.03	3.16	0.34	0.70	n.g.	86	82
Phenylalanine	4.42	4.43	4.25	4.37	2.38	88	99	88
Proline	n.g.	5.90	5.71	9.41	2.38	n.g.	98	89
Serine	n.g.	4.52	5.59	4.79	2.43	n.g.	91	87
Tyrosine	3.53	3.79	3.89	4.70	1.73	n.g.	99	88
Threonine	4.72	4.54	5.54	3.61	1.82	82	94	84
Tryptophan	1.36	1.36	1.45	1.09	0.61	92	97	87
Valine	4.94	5.07	5.64	5.63	2.24	86	95	86

* Spray-dried porcine plasma

[+] Spray-dried bovine plasma

[a] National Research Council (1998)

[b] Van der Peet-Schwering and Binnendijk (1997)

[c] CVB (1999)

n.g. = not given

The protein content of SDAP is lower than that of casein and has low apparent ileal digestibilities of amino acids. However, with respect to the contents of essential amino acids, SDAP is superior to soybean protein. The provision of essential amino acids from SDAP and the requirements of piglets (National Research Council 1998) are in good agreement except for methionine, which has a relatively low level in SDAP.

After weaning, the transition from sow milk to solid feed has important nutritional consequences like a switch from fat to carbohydrates as the main source of digestible energy and a shift from highly digestible animal protein to less digestible protein of plant origin (Everts et al. 1999). Addition of SDAP instead of plant protein to diets of weaned piglets as a protein source may improve post weaning performance because the amino acid composition and protein digestibility of SDAP are more similar to those of the proteins in sow's milk (Darragh and Moughan 1998).

New-born piglets rely on colostrum as their sole source of serum antibodies and milk provides intestinal antibodies during most of the postnatal period (Bourne 1976, Blecha 1998). Coffey and Cromwell (1995) have proposed that SDPP may enhance piglet performance after weaning by improving immunocompetence due to the immunoglobulins present in SDPP.

As described below, the incorporation of SDAP into the diet can have positive effects on average daily gain (ADG), average daily feed intake (ADFI) and feed conversion ratio (FCR) in weanling piglets. SDAP is a relatively expensive protein source and experiments have therefore been carried out to determine the optimum dose. This paper presents a review of those studies. The main objective was to establish SDAP dose-response relationships on the basis of a meta analysis and to identify additional independent variables related to the response variables ADG, ADFI and FCR. In addition, an attempt is made to describe possible mechanisms by which SDAP influences growth performance.

Multiple regression analysis.

Table 3 summarises the design and outcome of published studies on the influence of feeding SDAP on growth performance in weanling piglets. The overall, mean SDAP-induced change in ADG, ADFI and FCR in the first two weeks after weaning is +26.8 % (n=68, SEM=3), +24.5 % (n=68, SEM=2.3) and –3.2 % (n=68, SEM=1.3), respectively.

Table 3
Summary of published experiments with piglets fed spray-dried animal plasma (SDAP) during the first two weeks after weaning

			Initial		Performance			Percentage difference vs. SDAP-free control		
Reference	Inclusion (% of diet)	n	Age (days)	Weight (kg)	ADG[$]	ADFI[+]	FCR[#]	ADG	ADFI	FCR
A	0	80	17	4.9	310	497	1.60			
A	3[x]	"	"	"	313	488	1.56	1	-1.8	-2.5*
A	6[x]	"	"	"	287	512	1.79	-7.4	3	11.9*
A	9[x]	"	"	"	289	532	1.85	-6.8	7	15.6*
A	12[x]	"	"	"	268	500	1.87	-13.5	0.6	16.9*
A	0	"	18	5.3	263	402	1.53			
A	8.33[x]	"	"	"	277	470	1.70	5.3	16.9*	11.1*
A	0	"	"	"	214	251	1.18			
A	8.33[x]	"	"	"	300	399	1.34	40.2*	59.0*	13.6*
A	0	"	"	"	304	419	1.39			
A	8.33[x]	"	"	"	323	496	1.54	6.3	18.4*	10.8
A	0	"	"	"	192	269	1.43			
A	8.33[x]	"	"	"	238	352	1.48	24.0*	30.9*	3.5
A	0	120	30	7.3	155	249	1.61			
A	5[x]	"	"	"	237	391	1.65	52.9*	57.0*	2.5
A	0	"	"	"	244	363	1.49			
A	5[x]	"	"	"	343	488	1.42	40.6*	34.4*	-4.7
A	0	"	"	"	203	317	1.57			
A	5[x]	"	"	"	343	488	1.42	69.0*	53.9*	-9.6
B	0	534	21	6.4	165	206	1.27			
B	2[x]	"	"	"	206	244	1.19	24.8*	18.4*	-6.3
B	4[x]	"	"	"	217	256	1.18	31.5*	24.3*	-7.1
B	6[x]	"	"	"	240	290	1.22	45.5*	40.8*	-3.9
B	8[x]	"	"	"	247	302	1.23	49.7*	46.6*	-3.1
B	10[x]	"	"	"	255	300	1.19	54.5*	45.6*	-6.3
C	0	96	25	6.1	151	387	2.66			
C	2[x]	"	"	"	150	447	2.94	-0.7	15.5	10.5
C	4[x]	"	"	"	236	526	2.25	56.3	35.9	-15.4
C	6[x]	"	"	"	254	528	2.07	68.2	36.4	-22.2
C	8[x]	"	"	"	269	547	2.03	78.1	41.3	-23.7
C	10[x]	"	"	"	188	445	2.44	24.5	15.0	-8.3
D	0	144	24	7.2	280	330	1.12			
D	4[x]	"	"	"	360	410	1.11	28.6*	24.2*	-0.9
D	0	18	19.5	6.1	280	420	1.59			
D	14[x]	"	"	"	360	510	1.45	28.6*	21.4*	-8.8
E	0	36	n.g.	6.9	247	292	1.18			
E	10[x]	"	"	"	261	350	1.34	5.7	19.9*	13.6
E	0	"	"	"	139	213	1.46			
E	10[x]	"	"	"	261	350	1.34	87.8*	64.3*	-8.2
E	0	"	"	"	153	204	1.47			

Table 3. Continued

			Initial		Performance			Percentage difference vs. SDAP-free control		
Reference	Inclusion (% of diet)	n	Age (days)	Weight (kg)	ADG[$]	ADFI[+]	FCR[#]	ADG	ADFI	FCR
E	10[x]	"	"	"	261	350	1.34	70.6*	71.6*	-8.8
E	0	"	"	"	191	267	1.44			
E	10[x]	"	"	"	345	462	1.35	80.6*	73.0*	-6.2
E	0	"	"	"	230	300	1.74			
E	10[x]	"	"	"	345	462	1.35	50.0*	54.0*	-22.4
E	0	96	"	7.1	63	119	1.85			
E	10[x]	"	"	"	127	209	1.65	101.6*	75.6*	-10.8
F	0	236	24	7.5	262	305	1.16			
F	10[x]	"	"	"	266	302	1.12	1.5	-1.0	-3.4
F	0	204	21	5.9	315	389	1.23			
F	10.35[x]	"	"	"	444	537	1.20	41.0*	38.0*	-2.4
F	10.35[x]	"	"	"	420	487	1.16	33.3*	25.2*	-5.7
F	13.4[x]	"	"	"	413	482	1.16	31.1*	23.9*	-5.7
F	13.4[x]	"	"	"	378	437	1.15	20.0*	12.3*	-6.5
F	0	120	"	5.3	328	390	1.18			
F	10.28[x]	"	"	"	378	499	1.32	15.2	27.9	11.9
F	6.96[y]	"	"	"	327	422	1.28	-0.3	8.2	8.5
G	0	180	22	6.2	190	253	1.34			
G	3[y]	"	"	"	220	293	1.32	15.8*	15.8*	-1.5
G	6[y]	"	"	"	263	338	1.29	38.4*	33.6*	-3.7
H	0	720	28	7.9	215	270	1.30			
H	5[x]	"	"	"	250	290	1.20	16.3*	7.4*	-7.7*
H	0	"	"	"	196	260	1.33			
H	5[x]	"	"	"	249	310	1.26	27.0*	19.2*	-5.3*
I	0	960	"	7.5	192	250	1.30			
I	5[x]	"	"	"	235	290	1.23	22.4*	16.0*	-5.4*
I	5[y]	"	"	"	224	270	1.23	16.7*	8.0*	-5.4
I	3.33[x]	"	"	"	223	280	1.27	16.1*	12.0*	-2.3
I	1.66[x]	"	"	"	227	270	1.18	18.2*	8.0*	-9.2*
J	0	626	13.2	4.1	163	186	2.50			
J	2[x]	"	"	"	195	217	2.44	19.6*	16.7*	-2.4
J	4[x]	"	"	"	204	234	2.56	25.2*	25.8*	2.4
J	6[x]	"	"	"	212	236	2.44	30.1*	26.9*	-2.4
J	2[x]	"	"	"	195	222	2.50	19.6*	19.4*	0
J	4[x]	"	"	"	215	237	2.44	31.9*	27.4*	-2.4
J	6[x]	"	"	"	209	241	2.56	28.2*	29.6*	2.4
J	2[y]	"	"	"	182	204	2.50	11.7*	9.7*	0
J	4[y]	"	"	"	204	219	2.38	25.2*	17.7*	-4.8
J	6[y]	"	"	"	200	277	2.50	22.7*	48.9*	0
K	0	180	17	5	227	299	1.32			
K	2.5[z]	"	"	"	262	316	1.20	15.4*	5.7*	-9.1*
K	5[z]	"	"	"	290	341	1.18	27.8*	14.0*	-10.6*
L	0	416	15	4.3	191	248	1.30			

Table 3. Continued

			Initial		Performance			Percentage difference vs. SDAP-free control		
Reference	Inclusion (% of diet)	n	Age (days)	Weight (kg)	ADG[$]	ADFI[+]	FCR[#]	ADG	ADFI	FCR
L	5[y]	"	"	"	209	265	1.27	9.4	6.9	-2.3
L	5[x]	"	"	"	232	267	1.15	21.5*	7.7	-11.5*
L	5[x]	"	"	"	232	267	1.15	21.5*	7.7	-11.5*
M	0	360	19	5.3	311	296	0.95			
M	7.5[z]	"	"	"	333	321	0.96	7.1*	8.4*	1.0
M	0	"	"	"	329	298	0.91			
M	7.5[z]	"	"	"	337	326	0.96	2.4*	9.4*	5.8
M	0	"	"	"	295	289	0.98			
M	7.5[z]	"	"	"	313	301	0.96	6.1*	4.2*	-1.9
M	0	"	"	"	341	291	0.84			
M	7.5[z]	"	"	"	339	321	0.94	-0.6*	10.3*	12.3
M	0	"	"	"	272	259	0.95			
M	7.5[z]	"	"	"	295	293	0.99	8.5*	13.1*	4.0
M	0	"	"	"	345	304	0.88			
M	7.5[z]	"	"	"	375	342	0.91	8.7*	12.5*	3.6
N	0	45	28	7.1	138	243	2.10			
N	2[x]	"	"	"	176	276	2.34	27.5*	13.6	11.4*
N	4[x]	"	"	"	203	294	1.49	47.1*	21.0	-29.0*
N	6[x]	"	"	"	251	326	1.32	81.9*	34.2	-37.1*
N	8[x]	"	"	"	188	290	1.63	36.2*	19.3	-22.4*

A = Coffey and Cromwell (1995), B = Kats et al. (1994), C = Gatnau and Zimmerman (1992), D = de Rodas et al. (1995), E = Gatnau (1990), F = Hansen et al. (1993), G = Angulo and Cubilo (1998), H = Van der Peet-Schwering and Binnendijk (1995), I = Van der Peet-Schwering and Binnendijk (1997), J = Rantanen et al. (1994), K = Grinstead et al. (1998), L = Smith II et al. (1995), M = Nessmith et al. (1997), N = Gatnau et al. (1991)

* = statistically significant difference ($P < 0.05$)

[x] porcine plasma

[y] bovine plasma

[z] plasma of unknown origin

n.g. = not given

n = number of piglets in the experiment

[$] = average daily gain

[+] = average daily feed intake

[#] = feed conversion ratio

The data were subjected to multiple linear regression (SAS, 1988) to disclose relationships between the independent and response variables. Figure 1 shows the dose-response effects for the percentage of SDAP in the diet and percentage change in ADG, ADFI and FCR for all studies combined.

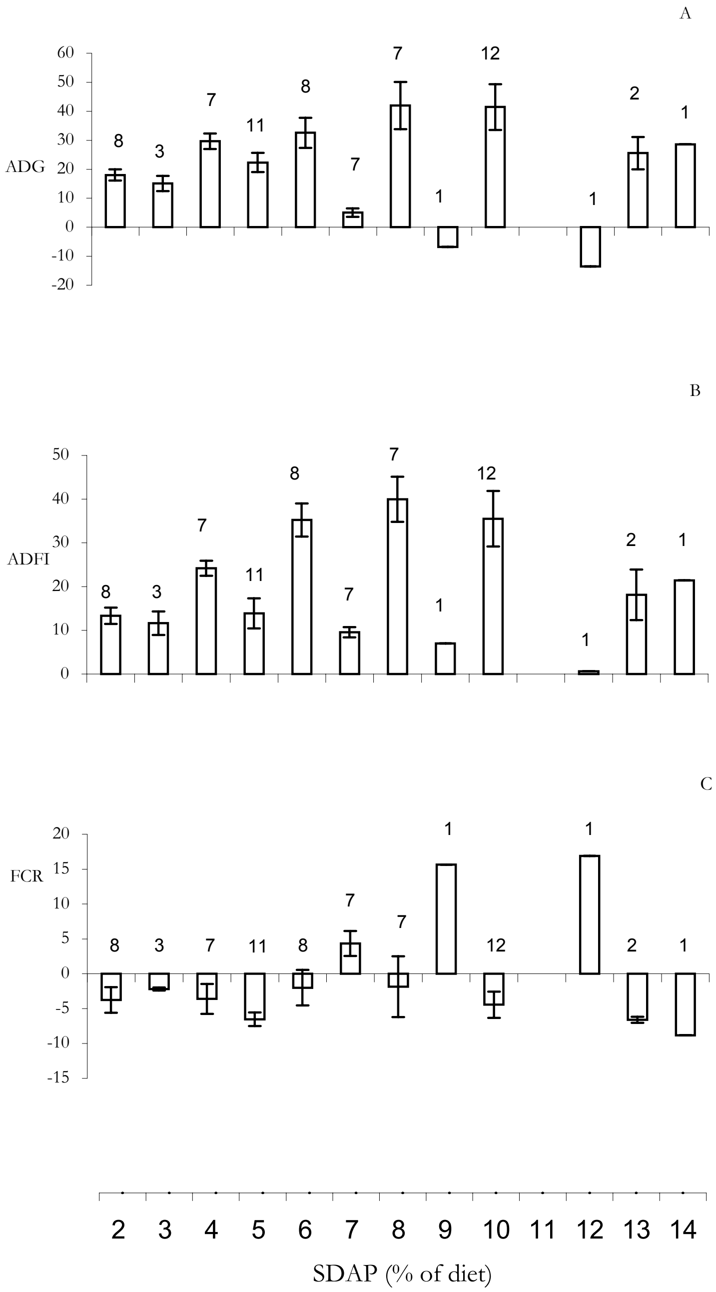

Fig. 1. Percentage change in average daily gain (ADG) (panel A), average daily feed intake (ADFI) (panel B) and feed conversion ratio (FCR) (panel C) in piglets fed spray-dried animal plasma (SDAP) during the first two weeks after weaning. SDAP dose classes were defined as the value indicated on the x axis ± 0.5 %. For the selected ranges of SDAP dose, expressed as percentage of diet, the percentage changes versus SDAP-free controls were calculated as weighted means; the SEM is given. The number of observations is indicated above the bars.

For this analysis the data were weighed according to the number of piglets studied. The response of both ADG and ADFI is more or less consistent up to 6 % SDAP in the diet, whereas the responses to higher levels of inclusion were not clear. As to FCR, the response to SDAP seems beneficial at levels below 6 %. Again, at higher levels, the response was variable.

Regression analyses for all studies combined showed that there are no significant relationships between the dose of SDAP and the response of either ADG, ADFI or FCR. When more independent variables were included in the regression model the variance in some response variables could be correlated significantly although the explained variance was not substantial (Table 4).

Table 4
Relationships between independent variables and response variables (percentage SDAP-induced change in ADG) for the first week (subscript 1) and for the period of two weeks after weaning (subscript 1+2)*

Response variable	Model[a]	R^2	P value
% Δ ADG_1	55.7 + 2.73*%SDAP - 0.24*$ADG_{1\ control}$	0.73	0.0001
% Δ ADG_{1+2}	65.22 + 3.77*%SDAP - 0.29*$ADG_{1+2\ control}$	0.54	0.0001

[*] SDAP = spray-dried animal plasma, ADG = average daily gain
[a] Models were selected by using the linear regression procedure of SAS (SAS, 1988).

As to ADG, there is a strong influence of the performance of the control group, with high values of ADG in the control group being associated with small effects of SDAP. This is illustrated in Figure 2 for ADG in the first week after weaning. It would appear that the feeding of SDAP improves ADG only when the piglets show suboptimal performance.

In general, the response of ADG to SDAP during the first two weeks after weaning is quite impressive. The beneficial effect of SDAP on ADG is associated with an increase in ADFI. As a consequence, the improvement of FCR is generally modest.

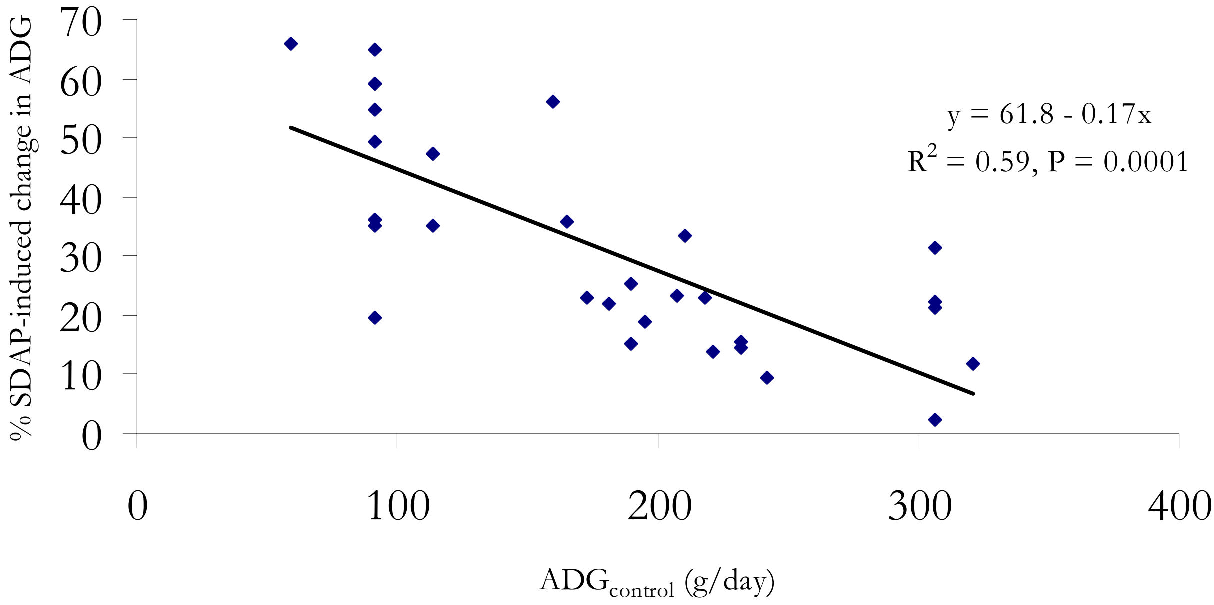

Fig. 2. Relationship between average daily gain (ADG) in control piglets and the percentage change in ADG of piglets fed spray-dried amimal plasma (SDAP) during the first week after weaning.

Effective feeding period

Most papers on SDAP feeding in piglets report ADG and ADFI for the combined first two weeks after weaning, but not for the first and second week separately. The available percentage changes in ADG, ADFI and FCR for both weeks 1 and 2 are given in Table 5. It appears that the beneficial effect of SDAP on performance is much more pronounced in the first week than in the second week after weaning.

The percentage SDAP-induced changes in ADG, ADFI and FCR in the first two weeks after weaning and during the following period, when the control and SDAP-fed piglets received identical feeds, are presented in Table 5. It can be concluded that there is no positive carry-over effect of SDAP.

Table 5

Comparison of the mean percentage spray-dried animal plasma (SDAP)-induced change in average daily gain (ADG), average daily feed intake (ADFI) and feed conversion ratio (FCR) in the first and second week after weaning (upper part) and of the first two weeks after weaning and the following weeks when the control and SDAP-fed piglets received identical feeds (lower part). For the comparisons within each row, only experiments were used in which the data from both periods were given.

	Week after weaning						
	Week 1			Week 2			
	n	Mean	SEM	n	Mean	SEM	P value[a]
% Δ ADG	29	31.1	3.4	29	13.9	2.8	0.0002
% Δ ADFI	6	26.5	4.2	6	18.3	3.4	0.16
% Δ FCR	4	-24.5	7.4	4	1.1	1.7	0.01

	Week after weaning					
	Week 1+2			Week > 3 + 4/5		
	n	Mean	SEM	n	Mean	SEM
% Δ ADG	39	21	3	39	2.4	1.9
% Δ ADFI	39	20.9	2.6	39	0.9	1
% Δ FCR	39	0.3	1.2	39	-0.8	1.3

Data derived from experiments mentioned in Table 3.
n = number of control-SDAP comparisons
[a] Model used in t-test: y = mean + week + error

Diet composition of control group

The response to SDAP may be dependent on the kind of protein used in the control diet. In most experiments, dairy proteins were used for the control feed, but soy proteins were also used. Table 6 documents that the responses of FCR and ADG to SDAP are greater when soy protein was used in the control feed instead of dairy protein. Milk proteins are generally considered to be of high value in piglet feeding. Therefore, it is surprising that in most experiments SDAP improves piglet performance even when compared with milk proteins.

Table 6

Mean percentage spray-dried animal plasma (SDAP)-induced change in average daily gain (ADG), average daily feed intake (ADFI) and feed conversion ratio (FCR) during the first two weeks after weaning as determined by the kind of protein in the control feed (upper part), source of the SDAP (middle part) and form of the diet (lower part)

	Protein in the control feed						
	Milk protein			Soy protein			
	n	Mean	SEM	n	Mean	SEM	P value[a]
% Δ ADG	38	23.9	3.1	14	38.1	7.3	0.04
% Δ ADFI	38	24.5	2.8	14	28.8	5.7	0.45
% Δ FCR	38	-0.1	1.4	14	-7.9	2.3	0.006
	Source						
	Porcine SDP			Bovine SDP			
	n[d]	Mean	SEM	n[d]	Mean	SEM	P value[b]
% Δ ADG	5	24.2	2	6	17.1	3	0.07
% Δ ADFI	5	17.9	3.9	6	18.2	7.9	0.97
% Δ FCR	5	-4.7	2.4	6	-2.5	1.1	0.45
	Form						
	Meal diet			Pelleted diet			
	n	Mean	SEM	n	Mean	SEM	P value[c]
% Δ ADG	12	26.1	10.3	24	21.2	2.9	0.55
% Δ ADFI	12	29.6	7.6	24	16.3	2.5	0.05
% Δ FCR	12	4.9	2.8	24	-3.8	1.2	0.002

Data derived from experiments mentioned in Table 3.
n = number of control-SDAP comparisons
[a] Model used in t-test: $y = \text{mean} + \text{protein}_{\text{control feed}} + \text{error}$
[b] Model used in t-test : y = mean + source + error
[c] Model used in t-test : y = mean + form + error
[d] Data derived from Rantanen et al. (1994), Smith et al. (1995), and Van der Peet-Schwering and Binnendijk (1997)

SDAP is lower in methionine than is casein (Table 2). In the published experiments, the diets were usually formulated on an iso-lysine basis and only occasionally on an iso-methionine basis. Hansen et al. (1993), Kats et al. (1994) and Owen et al. (1995) have suggested that insufficient absolute intake of methionine could have been the cause of the low response to SDPP in certain experiments. Low responses to dietary SDAP could also result from low intakes of other essential amino acids such as cystine, threonine and tryptophan. To exclude any effects of amino acid intake, the experimental diets should be formulated so that the amounts of apparent, ileal-digestible amino acids are identical. Sodium citrate is frequently used as an anticoagulant. Thus, SDAP preparations may contain 2 % citrate and diets containing 10 % SDAP may contain up to 0.2 % citrate. Because citric acid might be considered as a growth promoter in swine, it could be argued that, in studies on the effects of SDAP, the control diets should be enriched with sodium citrate. However, it is unlikely that dietary citrate concentrations as low as 0.2 % would influence piglet performance.

Porcine versus bovine spray dried plasma

Hansen et al. (1993) found no response to spray dried bovine plasma (SDBP) in the first two weeks after weaning. In three other experiments, a direct comparison between SDPP and SDBP was made. The results are presented in Table 6. It can be concluded that both SDPP and SDBP improve piglet performance post weaning, but the response of ADG to SDPP is greater than that to SDBP.

Feed processing and effect of SDAP

Weanling piglets can be fed diets in either pellet or meal form. It could be suggested that the process of pelleting, during which high temperatures are reached, may damage specific bioactive components, such as immunoglobulins, in the SDAP which in turn would diminish the positive effect on performance. It appears that both meal and pelleted feed containing SDAP have a positive effect on piglet post-weaning performance (Table 6). The response of ADFI to SDAP in meal was greater than that to SDAP incorporated in pellets. FCR appears to react more favourably to SDAP in pelleted feed.

Effect on piglet health

It has been hypothesised that the feeding of SDAP reduces the incidence and/or severity of post-weaning diarrhoea. Unfortunately, health parameters were not registered in most published experiments. In two experiments, less diarrhoea was found in piglets fed SDPP during the first two weeks after weaning (Gatnau 1990, Van der Peet-Schwering and Binnendijk 1995). In one experiment, piglets given feeds with SDPP required less treatment against gastro-intestinal disorders during the first two weeks after weaning than did piglets that were fed diets without SDPP (Van der Peet-Schwering and Binnendijk 1995).

Between-experiment variation in response to SDAP

Between experiments, the response to SDAP can vary considerably (Table 3). Various factors determining the effect of SDAP, such as baseline growth and composition of the control diet, have been discussed above. It has been suggested that the response also depends on health and hygiene status (Coffey and Cromwell 1995, Bergström et al. 1997), but this suggestion is not well substantiated other than indirectly by the negative association between SDAP effect and growth of the control group (Figure 2).

Coffey and Cromwell (1995) demonstrated that the growth-enhancing properties of SDPP are unrelated to the response to antimicrobial agents, indicating that the health status of the piglets is not an important determinant of the SDAP effect.

Possible mode of action of SDAP

As to the mechanism by which SDAP enhances growth of weanling piglets, only speculative theories have been put forward. Knowledge about the mode of action could assist in identifying and/or developing feedstuffs less expensive than SDAP, but with the same properties. It is unclear whether the beneficial effects of SDAP on post-weaning ADG are caused by directly increasing feed intake or indirectly by specific bioactive components. It is likely that factors present in SDAP influence systemic and/or intestinal functions controlling growth and/or immunity.

Feed intake and digestibility

Ermer et al. (1994) performed a preference test in which weanling piglets could choose between diets containing either SDPP or dried skim milk. ADFI was higher for the feed containing SDPP and thus it has been suggested that the higher intake was associated with a greater palatability.

The higher ADFI by itself can explain most of the SDAP-induced increase in ADG. The latter increase is generally greater than the increase in ADFI, resulting in an improvement in the FCR. Hansen et al. (1993) found lower dry matter and nitrogen digestibilities for piglets consuming diets containing SDPP instead of dairy proteins. Knabe (1994) found lower apparent ileal amino acid digestibilities for SDPP than for blood meal. However, the impact of the lower digestibility of SDPP must be small because the feeding of diets with up to 6 % SDAP actually improves the ADG and FCR (Fig. 1).

Immunoglobulins (Ig) and insulin-like growth factor-I (IGF-I)

Coffey and Cromwell (1995) have proposed that SDPP may enhance piglet performance by improving immunocompetence through Ig present in SDPP. The Ig would prevent viruses and bacteria from damaging the gut wall, resulting in a more functional intestinal wall. However, there is no evidence that SDPP is more effective in environments with a greater load of pathogenic organisms. Dritz et al. (1996) have hypothesised that the Ig fraction decreases exposure of the immune system to antigens, leading to decreased production of inflammatory cytokines and, in turn, to increased feed intake. There is only indirect evidence for these ideas. Ig derived from processed blood and orally administered to colostrum-deprived new-born piglets have beneficial effects on health and performance (Drew and Owen 1988, Gatnau 1990, Gomez et al. 1998). Extrapolating these effects to non-colostrum-deprived weanling piglets is not justified, but it is clear that Ig in SDAP can have an effect on piglet health. The response to SDPP is higher than that to SDBP (Table 6) suggesting that a specific Ig effect could be involved. De Rodas et al. (1995) did not find a difference in piglet performance for two different sources of SDPP. Thus, this provides no evidence to support the hypothesis that the effect of SDPP is based on its Ig moiety.

De Rodas et al. (1995) reported that SDPP contains high levels of immunoreactive IGF-I (0.8 ng/mg), a peptide hormone in the somatotrophic axis that is involved in the regulation of growth. However, SDPP-fed piglets showed superior performance but no change in plasma IGF-I concentrations. The authors suggested that dietary IGF-I might have influenced intestinal mucosal function and gastrointestinal growth.

Glycoproteins

Andersen et al. (1980) described that binding of purified K88 antigen to porcine intestinal brush border membranes was inhibited by glycoproteins derived from porcine submaxillari mucins. In vitro studies have demonstrated that the oligosaccharide chains of glycoproteins obtained from plasma can act as binding sites for the fimbrial adhesins of *E. coli* (Sanchez et al. 1993). In this way, it may be possible that attachment of F-17 expressing *E. coli* strains to bovine mucus and brush border membranes can be prevented by glycoproteins. These authors state that this inhibition is not due to Ig present in the plasma because neither heat denaturation, nor proteolytic digestion nor removal of the antibodies from the plasma affected this inhibitory capacity. Mouricout et al. (1990) treated diarrhoea in calves due to infection by enteropathogenic *E. coli* by administration of glycoprotein glycans derived from bovine plasma. The glycan moieties of the non-Ig fraction of plasma mimicked the oligosaccharide moiety of the intestinal receptors recognised by K99 pili. The glycoprotein glycans inhibited adhesion of bacteria to the intestine and protected colostrum-deprived calves against lethal doses of enterotoxigenic *E. coli*. There is some evidence that the feeding of large amounts of SDPP to weaned piglets offers protection against pathogenic *E. coli* (Nollet et al. 1999).

Conclusions and further research

Dietary SDAP levels up to 6 % raise both ADG and ADFI in the first two weeks after weaning in a dose-dependent fashion. Up to 6 % SDAP also reduces the FCR. The positive effect of SDAP on ADG and ADFI is much more pronounced in the first than the second week after weaning. There is no positive carry-over effect of SDAP feeding during the period of two weeks after weaning on subsequent growth. In all studies with SDAP, performance is only considered during a very short period of the piglets life. Long term effects of this expensive protein source are unknown and an economic evaluation should be made before applying SDAP in weanling diets. Baseline growth rate is an important determinant of the effect of SDAP on ADG, with high values of baseline ADG being associated with small effects of SDAP. So, it should be considered to use SDAP in weanling piglets' diets only in farms with suboptimal post-weaning performance.

There are health risks associated with the use of non-sterilised products of animal origin as feed ingredients for the same species (Horst et al. 1997). Therefore, it must be considered that the use of dietary SDAP in pigs might spread certain diseases like Classical and African Swine Fever, and Foot and Mouth disease (Mann and Sellers 1989, Van Oirschot and Terpstra 1989, Wilkinson 1989). It is recommended to only use SDPP that originates from slaughter pigs that were approved after ante- and post-mortem veterinary inspection.

The growth-promoting action of SDAP could lie in the observed increase in ADFI due to increased palatability of SDAP-containing feed. Alternatively or additionally, SDAP could have direct effects on the intestine, leading to less intestinal disease and, in turn, higher ADFI and ADG. The Ig and glycoprotein fractions of SDAP might prevent attachment of pathogens and thus support functionality of the intestine. This possible mode of action should be put to the test in vivo. Piglets fed a diet containing SDAP should show enhanced colonisation resistance against enteropathogenic bacteria. SDAP may protect against the development of mucosa damage and thus should allow less passage of inert large molecules through the intestinal wall. Experiments have to be carried out in order to either support or refute these hypotheses.

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References

Andersen, M.J., Whitehead, J.S., Kim, Y.S., 1980. Interaction of *Escherichia coli* K88 antigen with porcine intestinal brush border membranes. Infect. Immun. 29: 897-901.

Angulo, E., Cubiló, D., 1998. Effect of different dietary concentrations of spray-dried porcine plasma and a modified soyprotein product on the growth performance of piglets weaned at 6 kg body weight. Anim. Feed Sci. Tech. 72: 71-79.

Bergström, J.R., Nelssen, J.L., Tokach, M.D., Goodband, R.D., Dritz, S.S., Owen, K.Q., Nessmith, W.B. Jr., 1997. Evaluation of spray-dried animal plasma and select menhaden fish meal in transition diets of pigs weaned at 12 to 14 days of age and reared in different production systems. J. Anim. Sci. 75: 3004-3009.

Bourne, F.J., 1976. Humoral immunity in the pig. Vet. Rec. 98: 499-501.

Blecha, F., 1998. Immunological aspects: comparison with other species. In: Verstegen, M.W.A., Moughan, P.J., Schrama, J.W. (Eds.), The Lactating Sow. Wagenigen Pers, Wageningen, pp. 23-45.

Coffey, R.D., Cromwell, G.L., 1995. The impact of environment and antimicrobial agents on the growth response of early weaned pigs to spray-dried porcine plasma. J. Anim. Sci. 73: 2532-2539.

CVB, 1999 [Data about chemical composition, digestibility and feedstuffs]. Veevoeder Tabel, Centraal Veevoeder Bureau, Lelystad.

Darragh, A.J., Moughan, P.J., 1998. The composition of colostrum and milk. In: Verstegen, M.W.A., Moughan, P.J., Schrama, J.W. (Eds.), The Lactating Sow. Wageningen Pers, Wageningen, pp. 3-21.

Delaney, R.A.M., 1975. The nutritive value of porcine blood plasma concentrates prepared by utrafiltration and spray drying. J. Sci. Food. Agric. 26: 303-310.

De Rodas, B.Z., Sohn, K.S., Maxwell, C.V., Spicer, L.J., 1995. Plasma protein for pigs weaned at 19 to 24 days of age. Effect on performance and plasma insulin-like growth factor-I, growth hormone, insulin and glucose concentrations. J. Anim. Sci. 73: 3657-3665.

Drew, M.D., Owen, B.D., 1988. The provision of passive immunity to colostrum-deprived piglets by bovine or porcine serum immunoglobulins. Can. J. Anim. Sci. 68: 1277-1284.

Dritz, S.S., Owen, K.Q., Goodband, R.D., Nelssen, J.L., Tokach, M.D., Chengappa, M.M., Blecha, F., 1996. Influence of lipopolysaccharide-induced immune challenge and diet complexity on growth performance and acute-phase protein production in segregated early-weaned pigs. J. Anim. Sci. 74: 1620-1628.

Ermer, P.M., Miller, P.S., Lewis, A.J., 1994. Diet preference and meal patterns of weanling pigs offered diets containing either spray-dried porcine plasma or dried skim milk. J. Anim. Sci. 72: 1548-1554.

Everts, H., Van Beers-Schreurs, H.M.G., Vellenga, L., 1999. Diet in relation to weaning problems in piglets. Tijdschr. Diergeneesk. 124: 44-47.

Gatnau, R., 1990. Spray dried porcine plasma as a source of protein and immunoglubulins for weanling pigs. M.S. Thesis, Iowa State University.

Gatnau, R., Zimmerman, D.R., 1992. Determination of optimum levels of inclusion of spray-dried porcine plasma (SDPP) in diets for weanling pigs fed in practical conditions. J. Anim. Sci. 70 (Suppl. 1): 60 (Abstr.).

Gatnau, R., Zimmerman, D.R, Diaz, T., Johns, J., 1991. Determination of optimum levels of spray-dried porcine plasma in diets for weanling pigs. J. Anim. Sci. 69 (Suppl.1): 369 (Abstr.).

Gomez, G.G., Phillips, O., Goforth, R.A., 1998. Effect of immunoglobulin source on survival, growth, and haematological and immunological variables in pigs. J. Anim. Sci. 76: 1-7.

Grinstead, G.S., Goodband, R.D., Nelssen, J.L., Tokach, M.C., Riebold, B., 1998. Effect of increasing high protein, whey protein concentrate and spray-dried animal plasma on growth performance of weanling pigs. J. Anim. Sci. 76 (Suppl. 1): 179 (Abstr.).

Hansen, J.A., Nelssen, J.L., Goodband, R.D., Weeden, T.L., 1993. Evaluation of animal protein supplements in diets of early-weaned pigs. J. Anim. Sci. 71: 1853-1862.

Horst, H.S., Huirne, R.B.M., Dijkhuizen, A.A., 1997. Risks and economic consequences of introducing classical swine fever into the Netherlands by feeding swill to swine. Rev. Sci. Tech. Off. Int. Epiz. 16: 207-214.

Howell, N.K., Lawrie, R.A., 1983. Functional aspects of blood plasma proteins. I. Separation and characterisation. J. Food. Technol. 18: 747-762.

Kats, L.J., Nelssen, J.L., Tokach, M.D., Goodband, R.D., Hansen, J.A., Laurin, J.L., 1994. The effect of spray-dried porcine plasma on growth performance in the early-weaned pig. J. Anim. Sci. 72: 2075-2081.

Knabe, D.A., 1994. Apparent ileal digestibility of protein and amino acids in dried blood products. Research Report Texas A&M University, Animal Science Department.

Makkink, C.A., Berntsen, P.J., op den Kamp, B.M., Kemp, B., Verstegen, M.W., 1994a. Gastric protein breakdown and pancreatic enzyme activities in response to two different dietary protein sources in newly weaned pigs. J. Anim. Sci. 72: 2843-2850.

Makkink, C.A., Negulescu, G.P. Qin, G., Verstegen, M.W., 1994b. Effect of dietary protein source on feed intake, growth, pancreatic enzyme activities and jejunal morphology in newly weaned piglets. Br. J. Nutr. 72: 353-368.

Mann, J.A., Sellers, R.F., 1989. Foot and mouth disease virus. In: Pensaert, M.B. (Ed.), Virus infections of porcines. Elsevier Science Publishers, Amsterdam, pp. 251-258.

Mouricout, M., Petit, J.M., Carias, J.R., Julien, R., 1990. Glycoprotein glycans that inhibit adhesion of *Escherichia coli* mediated by K99 fimbriae. Treatment of experimental colibacilliosis. Infect. Immun. 58: 98-106.

Nabuurs, M.J.A., 1998. Weaning piglets as a model for studying pathophysiology of diarrhoea. Vet. Quarterly 20: 42-45.

Nabuurs, M.J.A., van Zijderveld, F.G., de Leeuw, P.W., 1993. Clinical and microbiological field studies in the Netherlands of diarrhoea in pigs at weaning. Res. Vet. Sci. 55: 70-77.

National Research Council, 1998. Nutrient Requirements of Swine. National Research Council, 10th revised edition. National Academy press, Washington, D.C.

Nessmith Jr., W.B., Nelssen, J.L., Tokach, M.D., Goodband, R.D., Bergström, J.R., Dritz, S.S., Richert, B.T., 1997. Evaluation of the interrelationships among lactose and protein sources in diets for segregated early-weaned pigs. J. Anim. Sci. 75: 3214-3221.

Nollet, H., Deprez, P., Van Driessche, E., Muylle, E., 1999. Protection of just weaned pigs against infection with F18+ *Escherichia coli* by non-immune plasma powder. Veterinary Microbiology 65: 37-45.

Owen, K.Q., Goodband, R.D., Nelssen, J.L., Tokach, M.D., Dritz, S.S., 1995. The effect of dietary methionine and its relationship to lysine on growth performance of the segregated early weaned pig. J. Anim. Sci. 73: 3666-3672.

Peiniau, J., Aumaitre, A., Lebreton, Y., 1996. Effects of dietary protein sources differing in solubility on total tract and ileal apparent digestibility of nitrogen and pancreatic enzymes activity in early weaned pigs. Livest. Prod. Sci. 45: 197-208.

Pluske, J.R., Hampson, D.J., Williams I. H., 1997. Factors influencing the structure and function of the small intestine in the weaned pig, a review. Livest. Prod. Sci. 51: 215-236.

Rantanen, M.M., Smith II, J.W., Richert, B.T., Friesen, K.G., Nelssen, J.L., Goodband, R.D., Tokach, M.D., Russell, L.E., 1994. Influence of spray-dried porcine plasma source on growth performance of weanling pigs. J. Anim. Sci. 72 (Suppl.1): 166 (Abstr.).

Sanchez, R., Kanarek, L., Koninkx, J., Hendriks, H., Lintermans, P., Vertels, A., Charlier, G., Van Driessche, E., 1993. Inhibition of adhesion of enterotoxigenic *Escherichia coli* cells expressing F17 fimbriae to small intestinal mucus and brush-border membranes of young calves. Microb. Path. 15: 407-419.

SAS, 1988. SAS/STAT User's Guide (Release 6.03 Ed.). SAS Inst. Inc., Cary, NC.

Smith II, J.W., Richert, B.T., Nessmith Jr., W.B., Nelssen, J.L., Goodband, R.D., Tokach, M.D., 1995. The effect of spray dried plasma source on starter pig performance. J. Anim. Sci. 73 (Suppl.1): 81 (Abstr.).

Van Beers-Schreurs, van H.M.G., Vellenga, L., Wensing, Th., Breukink, H.J., 1992. The pathogenesis of the post weaning syndrome in weaned pigs; a review. Vet. Quarterly 14: 29-34.

Van Oirschot, J.T., Terpstra, C., 1989. Hog cholera virus. In: Pensaert, M.B. (Ed.), Virus infections of porcines. Elsevier Science Publishers, Amsterdam, pp. 113-131.

Van der Peet-Schwering, C.M.C., Binnendijk, G.P., 1995. The effect of spray-dried porcine plasma in diets with different protein sources on the performance of weanling piglets. Report P1.137. Praktijkonderzoek varkenshouderij, Rosmalen, The Netherlands.

Van der Peet-Schwering, C.M.C., Binnendijk, G.P., 1997. Spray dried porcine and bovine plasma and animal and plant protein in diets of weaned piglets. Report P1.185. Praktijkonderzoek varkenshouderij, Rosmalen, The Netherlands.

Wilkinson, P.J., 1989. African swine fever virus. In: Pensaert, M.B. (Ed.), Virus infections of porcines. Elsevier Science Publishers, Amsterdam, pp. 17-37.