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Spray Dried Animal Plasma as an Alternative to Antibiotics in Weanling Pigs* - A Review -

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ABSTRACT : Piglet health at weaning is compromised due to several stress factors. Following the ban of antibiotic growth promoters new alternatives are required to control these problems. This paper reviews the evidence available for the use of spray dried animal plasma (SDAP) as an alternative to antibiotics in weaning pigs. Data from 75 trials in 43 publications involving over 12,000 piglets (mean values) have been used to calculate the performance responses of piglets according to several factors including SDAP origin, protein source from the control diet being replaced, dose of inclusion, age and weight of the piglets at weaning, sanitary conditions and simultaneous use or not of medication. Although the use of SDAP of all origins results in positive responses, it appears that plasma from porcine origin has the highest efficacy. This could be explained by the specificity of its IgG against porcine pathogens. During the first week post-weaning the response to plasma appears to increase with the inclusion dose, although over the two-week pre-starter period an optimal inclusion level of 4-8% is suggested. SDAP improves feed efficiency more markedly when the piglets are challenged with an experimental infection or when feed does not contain medication, which could be indicative of a lower expenditure of energy and nutrients to build an immune response against the challenge. There is evidence supporting that SDAP IgG and other bioactive substances therein prevent the binding of pathogens to the gut wall and reduce the incidence of diarrhoea in the post-weaning phase. Overall, plasma can be postulated as an excellent alternative to in-feed antimicrobials for piglets in the post-weaning phase. (**Key Words :** Spray Dried Animal Plasma, Pigs, Antibiotic Alternatives)

INTRODUCTION

Weaning is the most critical stage in pig production. Pigs at weaning are suddenly removed from the sow into a new environment where they have to change from suckling to eating dry feed from a hopper and drinking water from a drinker. Additionally at the same time they are mixed with pigs from other litters and fighting to establish new hierarchies occurs. As a result piglets go through a period of anorexia that compromises the functionality and integrity of the intestinal mucosa (van Beers-Schreurs et al., 1998). Once this period of starvation is over, the hungry piglet eats more feed than its gastrointestinal tract can cope with. The mucosa has lost its integrity and has not yet adapted to producing enzymes for digesting feed of vegetable origin (Miller et al., 1986). All this may increase the amount of undigested feed in the gut and increase the animal's susceptibility to pathological disorders. These problems have been traditionally controlled with the use of antibiotics at subtherapeutical doses as growth promoters. However the use of antimicrobial growth promoters has been banned in the European Union due to concerns about the development of antimicrobial resistance that could be transferred to human pathogenic bacteria. However as observed the Danish antibiotic use monitoring programme (DANMAP, 2004), since their ban antimicrobial growth promoters have increasingly been replaced by prescribed therapeutic antibiotics. Veterinary prescription of antibiotics in Denmark has increased continously from 48 tonnes in 1996 to 112.5 tonnes in 2004. In the case of pigs in particular, it increased by 10% between 2003 and 2004. Thus several products, including spray dried animal plasma (SDAP), have been postulated as alternatives. The effect of SDAP on piglet performance has been previously reviewed (Coffey and Cromwell, 2001; van Dijk et al., 2001a). The objective of this paper is to review the evidence available to support the use of spray dried animal plasma as an alternative to antibiotics in weaning pigs.

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WEANING

At weaning, the supply of the beneficial factors provided by sow's milk to the piglet is suddenly stopped. Among these epidermal growth factor, polyamines, insulin and insulin like growth factor have been reported to contribute to the development of the intestinal tract (Pluske et al., 1997). Sow's milk also contains protective antibodies, the main immunoglobulin in milk being IgA (Husband and Bennell, 1980).

After the first days of age, the IgA and other milk immunoglobulins are not absorbed at the intestinal level; they provide continuous defence throughout the intestinal lumen against infectious organisms to which the sow is resistant (Svendsen and Larsen, 1977). This protection is essential while the piglet's own IgA production has not completely developed; this does not occur until 6-8 weeks of age (Svendsen and Brown, 1973). Therefore piglets weaned at 3-4 weeks of age lose the protection from maternal antibodies and cannot efficiently fight infections. It has been estimated that by 3 to 4 weeks of age the piglet receives approximately 1.6 g of IgA/d (Svendsen and Brown, 1973). Ideally the piglet should be offered sow's milk for the first days post-weaning. Unfortunately this is not possible, but an attempt to use ingredients with similar characteristics is feasible. The sow's mammary epithelium transforms precursors from blood or interstitial fluid into milk constituents by different processes. Among these transcytosis is of special interest; by this mechanism, intact proteins, immumoglobulins, hormones and growth factors can cross the mammary epithelium and be secreted intact in the milk (Hunziker and Kraehenbuhl, 1998; Monks and Neville, 2004). Many of the components in sow's milk may also be present in SDPP, and therefore SDPP may be a good substitute for sow's milk.

At weaning, piglets are producing enzymes that are adapted to the digestion of the nutrients contained in sow's milk. Appreciable quantities of lipase, amylase and other enzymes required to digest the nutrients in dry feed are not produced until 3-4 weeks of age and an adequate production is not achieved until 8 weeks of age (Kidder and Manners, 1980; Jensen et al., 1997). In addition, the piglet's ability to produce hydrochloric acid in the stomach at weaning is limited (Easter, 1988). During lactation, the pH of the stomach is kept low due to conversion of lactose to lactic acid by the lactic acid bacteria (Lactobacillus and Bifidobacteria). At weaning, the lactose supply is suddently reduced and a feed with high buffer capacity is provided, which results in an increased pH of stomach digestive contents. The increased pH causes the loss of the acidic protective barrier against the entry of germs into the small intestine, and an inefficient protein digestion may occur (Easter, 1988). Furthermore, at weaning the piglet has to learn to eat a new dry feed and to drink water. As a result piglets take on average about 15 h to initiate feed intake, but in some cases they may take up to 48 hours (Bruininx et al., 2001). The use of highly palatable ingredients may reduce the time to initiation to eating and ameliorate many of the problems associated with post-weaning anorexia. The poor feed intake associated with weaning results in a reduction of the height of the intestinal villi to almost half of their height before weaning. The mitotic activity in the crypts increases to compensate for this loss of enterocytes, their depth increases and the maturity of the enterocytes is reduced (Hampson, 1986; Miller et al., 1986; Kelly et al., 1991; Pluske et al., 1991). As well as the reduction in the small intestinal absorption area, the high proportion of immature enterocytes also compromises the enzymatic activity at the tips of the villi (Miller et al., 1986). The longer the piglet takes to iniciate eating, the hungrier it is and so eats in excess. As enzyme production is not appropiate due to the previous low feed intake (Makkink et al., 1994) feed cannot be properly digested and it may give undesirable microflora the chance to proliferate and cause GIT disorders.

SPRAY DRIED ANIMAL PLASMA AS A PROTEIN SOURCE

Animal plasma is a by-product from the abattoir, obtained from animal blood. The cellular fraction of blood is separated by centrifugation with the use of an anticoagulant. Plasma is then concentrated by vacuum evaporation or by filtration with inverse osmotic membranes or ultrafiltration and is finally dried by the spray technique, thus obtaining the so-called "spray dried animal plasma" (SDAP). During spray drying, plasma proteins are exposed to high temperatures for a very short period of time, and this has the advantage over conventional drying that the proteins are not denaturalised and preserve their biological activity (Gatnau et al., 1989; Borg et al., 2002). According to its origin we can classify SDAP into "spray dried porcine plasma" (SDPP) and "spray dried bovine plasma" (SDBP), which are of porcine and bovine origin, respectively. It has been suggested that the beneficial effects of spray dried plasma are related to its immunoglobulin content (Gatnau and Zimmerman, 1991), and for this reason, some SDAP sources have an standardised IgG content. In addition, sources of plasma that are enriched for some specific immunoglobulins, have also been obtained from pigs that have been vaccinated against specific pathogens for this purpose. The plasma obtained with this procedure is known as spray dried immune porcine plasma (SDIPP). Plasma sources can also differ according to the use of technological processes (e.g.

Table 1. Essential amino acid composition and apparent ileal digestibility of different spray dried plasma sources

	AA content (%)			SDPP Ileal digestibility for piglets (%)[3]	
	SDAP[1]	SDPP[2]	SDBP[2]	Apparent	True
Arginine	4.55	4.47	4.70	73	87
Histidine	2.55	2.51	2.45	77	88
Isoleucine	2.71	2.79	2.53	77	88
Leucine	7.61	7.44	7.63	77	87
Lysine	6.84	6.84	7.43	76	88
Methionine	0.75	0.62	0.95	72	82
Cystine	2.63	3.03	3.16	-	-
Phenylalanine	4.42	4.43	4.25	75	86
Tyrosine	3.53	3.79	3.89	-	-
Threonine	4.72	4.54	5.54	71	84
Tryptophan	1.36	1.36	1.45	-	-
Valine	4.94	5.07	5.64	72	84

[1] NRC (1988). [2] van der Peet-Schwering and Binnnendijk (1997). [3] Yun et al. (2005).

ultrafiltration) to reduce the salt content before spray drying. Studies comparing plasma with high and low ash content have not found differences (Gatnau and Zimmerman, 1994; Rantanen et al., 1994; Russell, 1994). However these plasma sources have been tested at inclusion levels between 2-7.5%. It is possible that the high ash content could be detrimental at higher plasma inclusion levels.

A hygienic collection and processing of the blood is essential to ensure a good quality of plasma. Irradiation or antibacterial chemical treatment with formaldehyde of plasma has been shown to improve the efficacy of feed grade plasma (DeRouchey et al., 2004). However the same authors could not find an effect in plasma of low bacterial contamination (food grade). The safety of plasma as possible vector for transmissible diseases of pigs must be also taken into consideration (van Dijk et al., 2001a). Polo et al. (2005) have demonstrated that the spray drying process is effective in inactivating pseudorabies and porcine respiratory and reproductive syndrome viruses. The same authors have also shown that functional antibodies against porcine parvovirus in SDAP fed to naïve pigs did not promote their seroconversion.

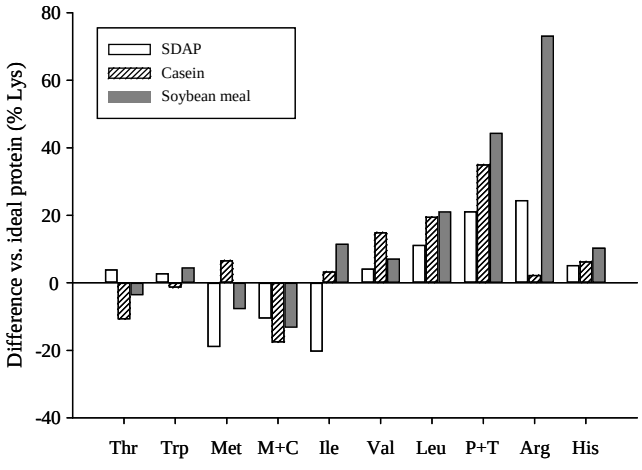

Figure 1. Deviation of the amino acid profiles of spray dried plasma, casein and soybean meal from the piglet's ideal protein profile (calculated after NRC, 1998).

Plasma is composed of protein, minerals and water. Proteins constitute the most important fraction; 95% of these are albumins and globulins (Tumbleson et al., 1986). The albumins are proteins whose function is the maintenance of plasma osmotic pressure and provision of the buffering capacity of the blood. Within the globulins, the gamma globulins have an immune function, of which IgG are the most important functional fraction of blood plasma. The other types, IgM, IgA, IgD and IgE are minor in blood plasma. The protein content in plasma ranges between 70 and 80% depending on the technological processes applied during its production. High protein levels are usually related to low ash contents and vice versa. Plasma sources concentrated by ultrafiltration have a higher protein concentration than those concentrated by reverse osmosis or vacuum drying. The amino acid composition of different spray dried plasma sources and their amino acid ileal digestibilities for weaning piglets are reported in Table 1. There are no substantial differences in amino acid composition between the plasma from porcine or bovine origin. Relative to the requirements of weaning pigs, the amino acid composition of plasma protein is well balanced, except for methionine and isoleucine which are limiting (Figure 1; NRC, 1998). The nutritive value of SDAP is similar to that of other high quality proteins, and cannot explain on its own the positive effects observed on the performance of weaning pigs. For example Kim and Easter (2001) did not find differences in lysine availability between SDAP and fishmeal, and Chae et al. (1999) observed that SDAP had a lower ileal protein digestibility than dried skim milk, isolated soy protein, and wheat gluten.

EFFECTS OF SDAP ON THE GROWTH PERFORMANCE OF NURSERY PIGS

A large amount of work on the efficacy of SDAP has been published since it was first proposed as a protein source for piglets in the late eighties (Zimmerman, 1987; Gatnau and Zimmerman, 1990). Table 2 summarises the results of 75 trials in 43 publications involving over 12,000

Table 2. Summary of trials testing spray dried plasma as a protein source for piglets at weaning

Ref.	Plasma	Dose	Ref. Protein	Alternative Product	Medication	Challenge	Pigs/tr	Age	Weight	First week				Pre-starter phase			
										d	ADG	ADFI	FGR	d	ADG	ADFI	FGR
Torrallardona et al. (2007)		-	FM	-	-	yes	12	21	6.2	-	-	-	-	14	150	225	1.56
	SDAP	6	FM	-	-	yes	12	21	6.2	-	-	-	-	14	223	301	1.35
		-	FM	Ca formate	-	yes	12	21	6.2	-	-	-	-	14	141	202	1.47
		-	FM	Colistin	yes	yes	12	21	6.2	-	-	-	-	14	173	236	1.37
Torrallardona et al. (2007)		-	FM	-	-	yes	11	21	7.4	-	-	-	-	10	112	192	1.78
	SDAP	6	FM	-	-	yes	11	21	7.4	-	-	-	-	10	142	230	2.01
		-	FM	Ca formate	-	yes	11	21	7.4	-	-	-	-	10	106	172	1.65
		-	FM	Colistin	-	yes	11	21	7.4	-	-	-	-	10	128	196	1.52
Nofrarias et al. (2006)		-	SPC+WG	-	no	-	8	20	6.0	7	40	139	3.33	14	125	239	1.89
	SDPP	6	SPC+WG	-	no	-	8	20	6.0	7	75	141	1.96	14	150	241	1.59
		-	SPC+WG	Plant extract	no	-	8	20	6.0	7	74	192	2.78	14	166	301	1.82
Conde (2005)		-	FM	-	-	yes	15	21	7.3	7	123	181	1.47	14	182	263	1.47
	SDAP	6	FM	-	-	yes	15	21	7.3	7	175	217	1.26	14	245	312	1.28
	SDAP	6	FM	-	-	yes	15	21	7.3	7	133	186	1.44	14	199	275	1.37
		-	FM	Colistin	-	yes	15	21	7.3	7	176	207	1.23	14	252	312	1.26
Conde (2005)		-	FM	-	-	yes	12	21	5.7	7	-25	134	.	14	7	171	-
	SDIPP	6	FM	-	-	yes	12	21	5.7	7	-9	104	.	14	72	172	-
	SDPP	6	FM	-	-	yes	12	21	5.7	7	15	145	.	14	56	188	-
Pierce et al. (2005)		-	SPC	-	-	-	19	15	5.3	7	117	178	1.57	14	170	243	1.44
	SDPP	8	SPC	-	-	-	19	15	5.3	7	102	187	1.99	14	228	356	1.57
		-	SPC	IgG 64%	-	-	19	15	5.3	7	146	196	1.45	14	228	325	1.45
		-	SPC	IgG 128%	-	-	19	15	5.3	7	180	225	1.29	14	264	373	1.41
		-	SPC	IgG 192%	-	-	19	15	5.3	7	167	204	1.24	14	258	356	1.39
Pierce et al. (2005)		-	SPC	-	-	-	19	20	5.6	7	99	209	2.14	14	174	285	1.65
	SDPP	8	SPC	-	-	-	19	20	5.6	7	206	352	1.73	14	267	451	1.69
	SDBP	8	SPC	-	-	-	19	20	5.6	7	141	264	1.93	14	194	336	1.76
		-	SPC	Bov IgG 50%	-	-	19	20	5.6	7	182	270	1.52	14	223	352	1.60
		-	SPC	Bov IgG 100%	-	-	19	20	5.6	7	202	296	1.49	14	254	391	1.54
Pierce et al. (2005)		-	SPC	-	-	-	19	23	6.4	7	87	175	2.25	14	228	333	1.47
	SDPP	8	SPC	-	-	-	19	23	6.4	7	183	287	1.60	14	265	425	1.62
	SDBP	8	SPC	-	-	-	19	23	6.4	7	157	256	1.75	14	268	404	1.53
		-	SPC	Bov IgG 50%	-	-	19	23	6.4	7	162	235	1.46	14	287	389	1.35
		-	SPC	Bov IgG 100%	-	-	19	23	6.4	7	150	229	1.66	14	271	380	1.43
Pierce et al. (2005)		-	SPC	-	-	-	16	21	5.6	7	141	311	2.35	14	252	438	1.74
	SDPP	8	SPC	-	-	-	16	21	5.6	7	229	462	2.10	14	281	500	1.81
		-	SPC	IgG	-	-	16	21	5.6	7	241	410	1.99	14	262	443	1.74
		-	SPC	Albumin	-	-	16	21	5.6	7	150	297	2.16	14	228	359	1.74
		-	SPC	LMW	-	-	16	21	5.6	7	119	300	2.77	14	223	416	1.88
Pierce et al. (2005)		-	SPC	-	-	-	16	21	6.3	7	162	216	1.37	14	274	386	1.43
	SDPP	8	SPC	-	-	-	16	21	6.3	7	272	376	1.42	14	334	461	1.40
		-	SPC	IgG 40%	-	-	16	21	6.3	7	228	291	1.27	14	334	461	1.40
		-	SPC	IgG 80%	-	-	16	21	6.3	7	272	347	1.30	14	333	471	1.42
		-	SPC	IgG 120%	-	-	16	21	6.3	7	273	317	1.18	14	349	470	1.38
Bikker et al. (2004)		-	FM+PP	-	no	-	72	26	8.0	7	176	194	1.13	14	249	303	1.22
		-	FM+PP	Avilamycin	yes	-	72	26	8.0	7	187	196	1.06	14	266	317	1.20
	SDAP	4	FM+PP	-	no	-	72	26	8.0	7	231	228	0.99	14	295	339	1.15
	SDAP	4	FM+PP	Avilamycin	yes	-	72	26	8.0	7	222	215	0.97	14	288	328	1.14
Bikker et al. (2004)		-	FM+PP	-	no	-	110	26	8.3	7	121	152	1.27	14	182	230	1.27
		-	FM+PP	-	no	-	110	26	8.3	7	124	155	1.32	14	171	230	1.37
	SDAP	4	FM+PP	-	no	-	110	26	8.3	7	149	167	1.14	14	186	231	1.25
	SDAP	4	FM+PP	-	no	-	110	26	8.3	7	141	160	1.18	14	191	238	1.26
Bosi et al. (2004)		-	FM	-	no	yes	10	21	4.9	-	-	-	-	15	128	175	1.81
	SDAP	6	FM	-	no	yes	12	21	4.9	-	-	-	-	15	148	186	1.48
		-	FM	Antibiotics	yes	yes	12	21	4.9	-	-	-	-	15	164	197	1.30
	SDAP	6	FM	Antibiotics	yes	yes	12	21	4.9	-	-	-	-	15	186	214	1.30
DeRouchey et al. (2004)		-	SBM46	-	-	-	30	17	5.9	5	223	209	0.93	10	239	281	1.18
	$SDAP_1$	5	SBM46	-	-	-	30	17	5.9	5	268	215	0.79	10	295	328	1.11
	$irSDAP_1$	5	SBM46	-	-	-	30	17	5.9	5	321	284	0.87	10	330	364	1.10
	$SDAP_2$	5	SBM46	-	-	-	30	17	5.9	5	223	212	0.96	10	253	293	1.16
	$irSDAP_2$	5	SBM46	-	-	-	30	17	5.9	5	280	238	0.84	10	297	325	1.09
	FDAP	5	SBM46	-	-	-	30	17	5.9	5	273	220	0.80	10	288	307	1.06
DeRouchey et al. (2004)		-	SBM46	-	-	-	40	17	6.3	7	191	169	0.91	14	258	255	0.99
	$SDAP_1$	5	SBM46	-	-	-	40	17	6.3	7	233	205	0.88	14	281	279	0.99
	$irSDAP_1$	5	SBM46	-	-	-	40	17	6.3	7	253	215	0.85	14	292	285	0.97
	$SDAP_2$	5	SBM46	-	-	-	40	17	6.3	7	242	203	0.84	14	290	284	0.98
	$irSDAP_2$	5	SBM46	-	-	-	40	17	6.3	7	239	202	0.84	14	280	277	0.99
	$SDAP_3$	5	SBM46	-	-	-	40	17	6.3	7	255	219	0.85	14	299	293	0.98
	$irSDAP_3$	5	SBM46	-	-	-	40	17	6.3	7	262	226	0.86	14	288	287	0.99
	$SDAP_4$	5	SBM46	-	-	-	40	17	6.3	7	273	233	0.85	14	303	302	1.00
	$irSDAP_4$	5	SBM46	-	-	-	40	17	6.3	7	263	216	0.83	14	288	281	0.98

Table 2. Summary of trials testing spray dried plasma as a protein source for piglets at weaning (Continued)

Ref.	Plasma	Dose	Ref. protein	Alternative product	Medication	Challenge	Pigs/tr	Age	Weight	First week				Pre-starter phase			
										d	ADG	ADFI	FGR	d	ADG	ADFI	FGR
DeRouchey et al. (2004)		-	SBM46	-	-	-	35	17	6.1	7	102	105	1.02	14	226	235	1.04
	$SDAP_1$	5	SBM46	-	-	-	35	17	6.1	7	144	116	0.80	14	236	230	0.97
	$irSDAP_1$	5	SBM46	-	-	-	35	17	6.1	7	169	138	0.82	14	269	259	0.96
	$SDAP_2$	5	SBM46	-	-	-	35	17	6.1	7	183	158	0.85	14	261	256	0.98
	$irSDAP_2$	5	SBM46	-	-	-	35	17	6.1	7	195	161	0.83	14	270	265	0.98
Lawrence et al. (2004)		-	SBM46	-	yes	-	42	21	6.2	-	-	-	-	14	312	319	1.14
		-	WG	-	yes	-	42	21	6.2	-	-	-	-	14	330	341	0.99
	SDAP	1.25	WG	-	yes	-	42	21	6.2	-	-	-	-	14	318	322	0.97
	SDAP	2.5	WG	-	yes	-	42	21	6.2	-	-	-	-	14	305	313	0.98
	SDAP	3.75	WG	-	yes	-	42	21	6.2	-	-	-	-	14	319	327	0.95
	SDAP	5	WG & SBM46	-	yes	-	42	21	6.2	-	-	-	-	14	294	301	0.95
Lawrence et al. (2004)		-	SBM46	-	yes	-	40	21	7.0	-	-	-	-	14	319	325	0.93
		-	$SBM46+WG_1$	-	yes	-	40	21	7.0	-	-	-	-	14	320	315	0.88
		-	$SBM46+WG_2$	-	yes	-	40	21	7.0	-	-	-	-	14	303	306	0.93
		-	WG	-	yes	-	40	21	7.0	-	-	-	-	14	302	291	0.89
	SDAP	5	SBM46 & WG	-	yes	-	40	21	7.0	-	-	-	-	14	331	333	0.92
Lawrence et al. (2004)		-	SBM46	-	yes	-	40	21	6.0	-	-	-	-	14	259	271	1.00
		-	hWG_1	-	yes	-	40	21	6.0	-	-	-	-	14	263	266	0.97
		-	hWG_2	-	yes	-	40	21	6.0	-	-	-	-	14	248	254	0.97
	SDAP	2.5	SBM46 & hWG_1	-	yes	-	40	21	6.0	-	-	-	-	14	288	290	0.94
	SDAP	5	SBM46 & hWG_2	-	yes	-	40	21	6.0	-	-	-	-	14	298	309	0.97
Lawrence et al. (2004)	SDAP	6	WG_1 & WG_2	-	yes	-	44	21	6.1	-	-	-	-	21	413	468	1.08
	SDAP	3	WG_1	-	yes	-	44	21	6.1	-	-	-	-	21	377	419	1.06
		-	WG_1	-	yes	-	44	21	6.1	-	-	-	-	21	353	383	1.04
	SDAP	3	WG_2	-	yes	-	44	21	6.1	-	-	-	-	21	394	439	1.06
		-	WG_2	-	yes	-	44	21	6.1	-	-	-	-	21	363	392	1.03
Owusu-Asiedu et al. (2003a)		-	PPI	-	-	yes	18	10	3.5	7	46	64	1.39	14	85	114	1.35
		-	PPI	Egg yolk AB	-	yes	18	10	3.5	7	72	95	1.31	14	123	157	1.27
	SDPP	10	PPI	-	-	yes	18	10	3.5	7	78	102	1.31	14	127	167	1.31
	SDPP	10	PPI	Egg yolk AB	-	yes	18	10	3.5	7	78	103	1.32	14	130	174	1.34
	SDPP	5	PPI	-	-	yes	24	10	3.5	7	83	109	1.31	14	132	173	1.31
Owusu-Asiedu et al. (2003b)	SDPP	10	PPI	-	-	yes	15	10	3.8	7	138	187	1.36	14	157	213	1.36
		-	PPI	-	-	yes	15	10	3.8	7	100	147	1.47	14	101	141	1.40
		-	PPI	Egg yolk AB	-	yes	15	10	3.8	7	134	186	1.39	14	151	208	1.38
		-	PPI	ZnO	-	yes	15	10	3.8	7	129	173	1.34	14	159	215	1.35
		-	PPI	Fumaric acid	-	yes	15	10	3.8	7	126	177	1.40	14	155	212	1.36
		-	PPI	Carbadox	-	yes	15	10	3.8	7	128	184	1.44	14	153	222	1.46
Torrallardona et al. (2003)		-	FM	-	no	yes	12	24	7.1	7	24	164	7.69	14	101	227	2.33
		-	FM	Colistin	yes	yes	12	24	7.1	7	122	198	1.67	14	214	298	1.41
	SDAP	7	FM	-	no	yes	12	24	7.1	7	142	212	1.47	14	193	268	1.39
	SDAP	7	FM	Colistin	yes	yes	12	24	7.1	7	140	232	1.64	14	230	286	1.23
Owusu-Asiedu et al. (2002)	SDPP	10	SDPPa	-	no	-	24	10	3.2	7	66	100	1.51	14	127	185	1.46
	SDPP	10	SDPPa	Egg yolk AB	no	-	24	10	3.2	7	81	119	1.48	14	140	198	1.41
		-	SDPPa	-	no	-	24	10	3.2	7	61	90	1.48	14	102	152	1.48
		-	SDPPa	Egg yolk AB	no	-	24	10	3.2	7	72	104	1.44	14	121	178	1.46
Owusu-Asiedu et al. (2002)		-	SDAP	-	no	yes	18	10	3.5	7	74	107	1.45	14	146	192	1.31
		-	SDAP	Egg yolk AB	no	yes	18	10	3.5	7	84	122	1.45	14	175	230	1.31
	SDPP	10	SDAP	-	no	yes	18	10	3.5	7	91	136	1.48	14	176	235	1.33
	SDPP	10	SDAP	Egg yolk AB	no	yes	18	10	3.5	7	97	143	1.47	14	180	237	1.32
Torrallardona et al. (2002)		-	FM	-	no	-	16	22	4.8	-	-	-	-	14	206	273	1.33
	SDAP	5	FM	-	no	-	16	22	4.8	-	-	-	-	14	227	272	1.20
		-	FM	Colistin	yes	-	16	22	4.8	-	-	-	-	14	216	271	1.27
	SDAP	5	FM	Colistin	yes	-	16	22	4.8	-	-	-	-	14	212	260	1.23
		-	FM	-	no	-	16	32	6.4	-	-	-	-	14	334	423	1.26
	SDAP	5	FM	-	no	-	16	32	6.4	-	-	-	-	14	336	420	1.26
		-	FM	Colistin	yes	-	16	32	6.4	-	-	-	-	14	360	442	1.23
	SDAP	5	FM	Colistin	yes	-	16	32	6.4	-	-	-	-	14	368	446	1.21
Torrallardona et al. (2002)		-	FM	-	no	-	24	21	5.7	-	-	-	-	14	151	226	1.44
	SDAP	5	FM	-	no	-	24	21	5.7	-	-	-	-	14	202	254	1.31
		-	FM	Colistin	yes	-	24	21	5.7	-	-	-	-	14	178	234	1.31
	SDAP	5	FM	Colistin	yes	-	24	21	5.7	-	-	-	-	14	210	243	1.19
Van Dijk et al. (2002a)		-	SBM+WHY	-	no	yes	10	19	6.6	6	-46	-	-	14	-47	-	-
	SDPP	8	SBM+WHY	-	no	yes	10	19	7.2	6	-1	-	-	14	42	-	-
Van Dijk et al. (2002b)		-	FM+DSM	-	no	-	80	26	8.0	7	176	185	1.06	21	339	421	1.24
	SDPP	3	FM+DSM	-	no	-	80	26	8.0	7	196	194	1.02	21	361	434	1.20
Van Dijk et al. (2002b)		-	FM+WHY	-	no	-	88	26	8.0	-	-	-	-	21	316	409	1.30
	SDPP	3	WHY	-	no	-	88	26	8.0	-	-	-	-	21	314	416	1.32
	SDPP	3	FM	-	no	-	88	26	8.0	-	-	-	-	21	331	421	1.27

Table 2. Summary of trials testing spray dried plasma as a protein source for piglets at weaning (Continued)

Ref.	Plasma	Dose	Ref. protein	Alternative product	Medication	Challenge	Pigs/tr	Age	Weight	First week				Pre-starter phase			
										d	ADG	ADFI	FGR	d	ADG	ADFI	FGR
Bosi et al. (2001)		-	CAS	-	no	yes	12	19	4.9	-	-	-	-	15	101	226	2.25
	SDPP	25	CAS	-	no	yes	12	19	4.9	-	-	-	-	15	100	251	2.52
	SDAP	25	CAS	-	no	yes	12	19	4.9	-	-	-	-	15	139	251	1.80
	SDAP	25	CAS	-	no	yes	12	19	4.9	-	-	-	-	15	169	252	1.49
Bosi et al. (2001)		-	CAS	-	no	yes	12	13	4.2	-	-	-	-	14	100	197	1.96
	SDPP	25	CAS	-	no	yes	12	13	4.2	-	-	-	-	14	118	208	1.78
	SDAP	25	CAS	-	no	yes	12	13	4.2	-	-	-	-	14	107	208	1.96
	SDAP	25	CAS	-	no	yes	12	13	4.2	-	-	-	-	14	140	215	1.53
Grinstead et al. (2000)		-	SBM48	-	yes	-	36	17	5.1	7	173	223	1.30	14	228	301	1.32
	SDAP	2.5	SBM48 & WHY_1	-	yes	-	36	17	5.1	7	214	238	1.11	14	262	316	1.20
	SDAP	5	SBM48 & WHY_2	-	yes	-	36	17	5.1	7	243	267	1.10	14	290	341	1.18
		-	WHY_1	-	yes	-	36	17	5.1	7	223	235	1.05	14	267	316	1.18
		-	WHY_2	-	yes	-	36	17	5.1	7	225	237	1.04	14	277	305	1.11
Grinstead et al. (2000)	SDAP	6.7	WHY	-	yes	-	62	12	4.2	7	116	131	1.12	14	163	193	1.18
	SDAP	5	WHY	-	yes	-	62	12	4.2	7	127	144	1.14	14	178	210	1.19
	SDAP	3.35	WHY	-	yes	-	62	12	4.2	7	130	137	1.05	14	182	195	1.08
	SDAP	1.7	WHY	-	yes	-	62	12	4.2	7	122	137	1.06	14	183	215	1.18
		-	WHY	-	yes	-	62	12	4.2	7	112	123	1.16	14	169	197	1.16
Grinstead et al. (2000)		-	DSM	-	yes	-	36	19	5.8	7	190	173	0.91	14	277	278	1.01
	SDAP	2.5	DSM & WHY_1	-	yes	-	36	19	5.8	7	219	203	0.93	14	289	280	0.96
	SDAP	5	DSM & WHY_2	-	yes	-	36	19	5.8	7	239	222	0.93	14	278	290	1.04
		-	WHY_1	-	yes	-	36	19	5.8	7	196	190	0.96	14	281	279	0.99
		-	WHY_2	-	yes	-	36	19	5.8	7	195	185	0.95	14	289	281	0.97
Chae et al. (1999)		-	SBM48	-	yes	-	30	22	6.7	7	103	176	1.76	7	103	176	1.76
		-	DSM	-	yes	-	30	22	6.7	7	160	217	1.30	7	160	217	1.30
		-	iSP	-	yes	-	30	22	6.7	7	113	208	1.82	7	113	208	1.82
	SDAP	18.86	All others	-	yes	-	30	22	6.7	7	255	313	1.23	7	255	313	1.23
		-	WG	-	yes	-	30	22	6.7	7	180	248	1.39	7	180	248	1.39
Angulo and Cubiló (1998)	SDPP	6	SBM55	-	yes	-	60	22	6.2	7	-	300	-	14	263	338	1.29
	SDPP	3	SBM55	-	yes	-	60	22	6.2	7	-	266	-	14	220	293	1.32
		-	SBM55	-	yes	-	60	22	6.2	7	-	211	-	14	190	253	1.34
Kerr et al. (1998)	SDAP	7	PP	-	yes	-	36	20	5.9	7	245	263	1.10	14	290	349	1.20
	SDAP	5.25	PP	-	yes	-	36	20	5.9	7	308	308	1.00	14	349	386	1.12
	SDAP	3.5	PP	-	yes	-	36	20	5.9	7	295	277	0.94	14	322	349	1.09
	SDAP	1.75	PP	-	yes	-	36	20	5.9	7	308	299	0.98	14	336	376	1.12
		-	PP	-	yes	-	36	20	5.9	7	263	254	0.99	14	331	340	1.03
Kerr et al. (1998)		-	DSM	-	yes	-	35	20	5.5	7	286	240	1.18	14	376	386	1.02
	SDAP	3.5	DSM & PP_1	-	yes	-	35	20	5.5	7	304	277	1.09	14	367	376	1.03
	SDAP	7	DSM & PP_2	-	yes	-	35	20	5.5	7	331	304	1.10	14	376	395	1.05
		-	PP_1	-	yes	-	35	20	5.5	7	295	272	1.08	14	390	403	1.03
		-	PP_2	-	yes	-	35	20	5.5	7	240	240	1.00	14	349	372	1.06
Cain and Zimmerman (1997)		-	CAS	-	no	-	8	12	5.0	-	-	-	-	14	175	330	1.51
	SDAP	6	CAS	-	no	-	8	12	5.0	-	-	-	-	14	164	360	1.62
Nessmith et al. (1997)		-	FM+CAS	-	-	-	180	19	5.3	7	225	190	0.84	14	316	290	0.92
	SDAP	7.5	FM+CAS	-	-	-	180	19	5.3	7	262	227	0.87	14	332	317	0.95
Nessmith et al. (1997)		-	SPC	-	-	-	162	10	3.7	5	106	95	0.88	10	165	160	0.98
	SDAP	7	SPC	-	-	-	162	10	3.7	5	129	105	0.83	10	182	182	1.00
Peet Schwering et al. (1997)		-	FM	-	no	-	360	28	7.6	8	195	230	1.23	8	195	230	1.23
	SDAP	5	FM	-	no	-	360	28	7.6	8	232	250	1.11	8	232	250	1.11
Woodgate et al. (1997)	SDAP	6	UP1673	-	-	-	36	19	5.5	-	-	-	-	21	276	359	1.30
		-	UP1673	-	-	-	36	19	5.5	-	-	-	-	21	276	369	1.34
Burnham et al. (1995)	SDPP	8	WG	-	-	-	30	-	5.6	-	-	-	-	14	412	433	1.05
	SDPP	6	WG	-	-	-	30	-	5.6	-	-	-	-	14	427	457	1.07
	SDPP	4	WG	-	-	-	30	-	5.6	-	-	-	-	14	426	458	1.07
	SDPP	2	WG	-	-	-	30	-	5.6	-	-	-	-	14	393	435	1.11
		-	WG	-	-	-	30	-	5.6	-	-	-	-	14	357	393	1.09
Coffey and Cromwell (1995)		-	DSM	-	yes	-	16	17	4.9	-	-	-	-	14	310	497	1.60
	SDPP	3	DSM	-	yes	-	16	17	4.9	-	-	-	-	14	313	488	1.56
	SDPP	6	DSM	-	yes	-	16	17	4.9	-	-	-	-	14	287	512	1.79
	SDPP	9	DSM	-	yes	-	16	17	4.9	-	-	-	-	14	289	532	1.85
	SDPP	12	DSM	-	yes	-	16	17	4.9	-	-	-	-	14	268	500	1.87
Coffey and Cromwell (1995)		-	DSM	-	yes	-	20	18	5.4	-	-	-	-	14	263	402	1.53
	SDPP	8.3	DSM	-	yes	-	20	18	5.4	-	-	-	-	14	277	470	1.70
		-	DSM	-	yes	yes	20	18	5.4	-	-	-	-	14	214	251	1.18
	SDPP	8.3	DSM	-	yes	yes	20	18	5.4	-	-	-	-	14	300	399	1.34
Coffey and Cromwell (1995)		-	DSM	-	yes	-	20	18	5.4	-	-	-	-	14	304	419	1.39
	SDPP	8.3	DSM	-	yes	-	20	18	5.4	-	-	-	-	14	323	496	1.54
		-	DSM	-	yes	yes	20	18	5.4	-	-	-	-	14	192	269	1.43
	SDPP	8.3	DSM	-	yes	yes	20	18	5.4	-	-	-	-	14	238	352	1.48

Table 2. Summary of trials testing spray dried plasma as a protein source for piglets at weaning (Continued)

Ref.	Plasma	Dose	Ref. protein	Alternative product	Medication	Challenge	Pigs/tr	Age	Weight	First week				Pre-starter phase			
										d	ADG	ADFI	FGR	d	ADG	ADFI	FGR
Coffey and Cromwell (1995)		-	SBM48	Cu + Antibiotics	yes	-	24	30	7.3	-	-	-	-	14	203	317	1.57
		-	DSM	-	no	-	24	30	7.3	-	-	-	-	14	155	249	1.61
		-	DSM	Cu + Antibiotics	yes	-	24	30	7.3	-	-	-	-	14	244	363	1.49
	SDPP	5	DSM	-	no	-	24	30	7.3	-	-	-	-	14	237	391	1.65
	SDPP	5	SBM48 & DSM	Cu + Antibiotics	yes	-	24	30	7.3	-	-	-	-	14	343	488	1.42
de Rodas et al. (1995)		-	DSM	-	-	-	48	24	7.2	7	210	210	1.03	14	280	330	1.12
	SDPP	4	SDBM & DSM	-	-	-	48	24	7.2	7	280	270	0.98	14	360	410	1.11
		-	SDBM	-	-	-	48	24	7.2	7	250	240	0.97	14	320	370	1.10
de Rodas et al. (1995)		-	SBM44	-	-	-	9	20	6.1	7	160	310	2.04	14	280	420	1.59
	SDPP	14	SBM44	-	-	-	9	20	6.1	7	250	390	1.56	14	360	510	1.45
Gatnau et al. (1995)		-	CAS	-	no	yes	27	19	6.0	-	-	-	-	15	19	181	7.75
	SDPP	8	CAS	-	no	yes	27	19	6.0	-	-	-	-	15	134	262	3.11
		-	CAS	Albumin	no	yes	27	19	6.0	-	-	-	-	15	78	244	4.61
		-	CAS	IgG	no	yes	27	19	6.0	-	-	-	-	15	158	273	2.93
		-	CAS	LMW	no	yes	27	19	6.0	-	-	-	-	15	50	191	4.69
Nessmith Jr et al. (1995)	SDAP	7	SDEP	-	-	-	54	14	4.3	-	-	-	-	14	209	-	1.19
	SDAP	5.25	SDEP	-	-	-	54	14	4.3	-	-	-	-	14	203	-	1.19
	SDAP	3.5	SDEP	-	-	-	54	14	4.3	-	-	-	-	14	209	-	1.23
	SDAP	1.75	SDEP	-	-	-	54	14	4.3	-	-	-	-	14	187	-	1.30
		-	SDEP	-	-	-	54	14	4.3	-	-	-	-	14	192	-	1.30
Owen et al. (1995)		-	DSM	-	-	-	36	21	4.5	-	-	-	-	14	237	-	1.03
	SDPP	7.5	DSM	-	-	-	36	21	4.5	-	-	-	-	14	278	-	1.15
		-	DSM	LMW	-	-	36	21	4.5	-	-	-	-	14	251	-	1.01
		-	DSM	IgG	-	-	36	21	4.5	-	-	-	-	14	299	-	1.05
		-	DSM	Albumin	-	-	36	21	4.5	-	-	-	-	14	261	-	1.09
Owen et al. (1995)		-	DSM	-	-	-	42	10	3.2	-	-	-	-	21	204	-	1.23
	SDPP	10	DSM	-	-	-	42	10	3.2	-	-	-	-	21	227	-	1.19
		-	DSM	IgG	-	-	42	10	3.2	-	-	-	-	21	254	-	1.14
		-	DSM	Albumin	-	-	42	10	3.2	-	-	-	-	21	231	-	1.15
Smith II et al. (1995)		-	DSM	-	-	-	104	15	4.3	-	-	-	-	14	191	248	1.30
	SDBP	5	DSM	-	-	-	104	15	4.3	-	-	-	-	14	209	265	1.27
	SDPP	5	DSM	-	-	-	104	15	4.3	-	-	-	-	14	232	267	1.15
Stahly et al. (1995)	SDAP	6	SBM	-	-	yes	20	19	5.9	-	-	-	-	20	536	327	1.66
		-	SBM	-	-	yes	20	19	5.9	-	-	-	-	20	450	245	1.88
	SDAP	6	SBM	-	-	-	20	19	5.9	-	-	-	-	20	582	409	1.42
		-	SBM	-	-	-	20	19	5.9	-	-	-	-	20	573	400	1.44
Stahly et al. (1995)	SDIPP	4	CAS	-	-	-	10	20	6.0	-	-	-	-	15	227	311	1.36
	SDPP	4	CAS	-	-	-	10	20	6.0	-	-	-	-	15	241	321	1.33
		-	CAS	-	-	-	10	20	6.0	-	-	-	-	20	178	304	1.69
Weaver et al. (1995)		-	CAS	-	-	-	20	-	6.7	7	51	118	2.27	14	198	247	1.22
	SDAP	8	CAS	-	-	-	20	-	6.7	7	115	184	1.61	14	223	300	1.37
		-	CAS	LMW	-	-	20	-	6.7	7	49	119	2.44	14	117	185	1.61
		-	CAS	Albumin	-	-	20	-	6.7	7	103	170	1.67	14	212	294	1.39
		-	CAS	IgG	-	-	20	-	6.7	7	111	175	1.59	14	218	284	1.32
Kats et al. (1994)		-	DSM	-	yes	-	89	21	6.4	-	-	-	-	14	165	206	1.27
	SDPP	2	DSM	-	yes	-	89	21	6.4	-	-	-	-	14	206	244	1.19
	SDPP	4	DSM	-	yes	-	89	21	6.4	-	-	-	-	14	217	256	1.18
	SDPP	6	DSM	-	yes	-	89	21	6.4	-	-	-	-	14	240	290	1.22
	SDPP	8	DSM	-	yes	-	89	21	6.4	-	-	-	-	14	247	302	1.23
	SDPP	10	DSM	-	yes	-	89	21	6.4	-	-	-	-	14	255	300	1.19
Kats et al. (1994)	SDPP	10	SDBM	-	yes	-	60	19	5.5	-	-	-	-	14	231	286	1.23
	SDPP	7.5	SDBM	-	yes	-	60	19	5.5	-	-	-	-	14	258	304	1.16
	SDPP	5	SDBM	-	yes	-	60	19	5.5	-	-	-	-	14	240	290	1.20
	SDPP	2.5	SDBM	-	yes	-	60	19	5.5	-	-	-	-	14	245	281	1.15
		-	SDBM	-	yes	-	60	19	5.5	-	-	-	-	14	231	281	1.22
Rantanen et al. (1994)		-	DSM	-	-	-	63	13	4.1	7	91	150	3.57	14	163	186	2.50
	$SDPP_1$	2	DSM	-	-	-	63	13	4.1	7	124	175	2.94	14	195	217	2.44
	$SDPP_1$	4	DSM	-	-	-	63	13	4.1	7	123	176	3.13	14	204	234	2.56
	$SDPP_1$	6	DSM	-	-	-	63	13	4.1	7	145	200	2.94	14	212	236	2.44
	$SDPP_2$	2	DSM	-	-	-	63	13	4.1	7	124	177	3.03	14	195	222	2.50
	$SDPP_2$	4	DSM	-	-	-	63	13	4.1	7	136	186	2.86	14	215	237	2.44
	$SDPP_2$	6	DSM	-	-	-	63	13	4.1	7	150	195	2.86	14	209	241	2.56
	SDBP	2	DSM	-	-	-	63	13	4.1	7	109	173	3.23	14	182	204	2.50
	SDBP	4	DSM	-	-	-	63	13	4.1	7	141	186	2.86	14	204	219	2.38
	SDBP	6	DSM	-	-	-	63	13	4.1	7	145	182	2.5	14	200	227	2.50
Rojas et al. (1994)		-	SBM48	-	no	-	20	21	5.9	-	-	-	-	14	64	218	3.45
	SDPP	10	SBM48	-	no	-	20	21	5.9	-	-	-	-	14	218	358	1.64
		-	SBM48	Cu+Antibiotics	yes	-	20	21	5.9	-	-	-	-	14	145	277	1.92
	SDPP	10	SBM48	Cu+Antibiotics	yes	-	20	21	5.9	-	-	-	-	14	304	449	1.47

Table 2. Summary of trials testing spray dried plasma as a protein source for piglets at weaning (Continued)

Ref.	Plasma	Dose	Ref. Protein	Alternative Product	Medication	Challenge	Pigs/tr	Age	Weight	First week				Pre-starter phase			
										d	ADG	ADFI	FGR	d	ADG	ADFI	FGR
Hansen et al. (1993)		-	DSM	-	yes	-	30	21	5.9	7	306	299	0.97	14	315	389	1.23
	SDPP	10.35	DSM & SBM48	-	yes	-	30	21	5.9	7	402	398	0.99	14	444	537	1.20
	SDPP	10.35	DSM & SBM48	-	yes	-	30	21	5.9	7	374	346	0.92	14	420	487	1.16
	SDPP	13.4	DSM+WHY$_1$	-	yes	-	30	21	5.9	7	371	362	0.97	14	413	482	1.16
	SDPP	13.4	DSM+WHY$_2$	-	yes	-	30	21	5.9	7	313	302	0.96	14	378	437	1.15
		-	SBM48	-	yes	-	30	21	5.9	7	260	281	1.06	14	327	416	1.27
Hansen et al. (1993)		-	DSM	-	yes	-	30	21	5.3	7	321	309	0.95	14	328	390	1.18
	SDPP	10.28	All others	-	yes	-	30	21	5.3	7	359	374	1.04	14	378	499	1.32
		-	SDB	-	yes	-	30	21	5.3	7	287	293	1.01	14	341	405	1.19
		-	MEX	-	yes	-	30	21	5.3	7	224	290	1.28	14	263	408	1.52
	SDBP	6.96	All others	-	yes	-	30	21	5.3	7	311	325	1.03	14	327	422	1.28
Hansen et al. (1993)		-	DSM+WHY	-	yes	-	118	24	7.4	7	181	175	0.96	14	262	305	1.16
	SDPP	10	DSM+WHY	-	yes	-	118	24	7.4	7	221	217	0.98	14	266	302	1.12
Gatnau and Zimmerman (1992)		-	SBM	-	-	-	16	25	6.1	-	-	-	-	14	151	387	2.66
	SDPP	2	SBM	-	-	-	16	25	6.1	-	-	-	-	14	150	447	2.95
	SDPP	4	SBM	-	-	-	16	25	6.1	-	-	-	-	14	236	526	2.25
	SDPP	6	SBM	-	-	-	16	25	6.1	-	-	-	-	14	254	528	2.07
	SDPP	8	SBM	-	-	-	16	25	6.1	-	-	-	-	14	269	547	2.04
	SDPP	10	SBM	-	-	-	16	25	6.1	-	-	-	-	14	188	445	2.44
Kats et al. (1992)		-	eSPC	-	-	-	234	21	6.0	9	74	134	2.08	9	74	134	2.08
	SDPP	10	eSPC	-	-	-	234	21	6.0	9	138	183	1.35	9	138	183	1.35
Gatnau and Zimmerman (1991)	SDPP	10	BM	-	-	-	9	-	7.1	-	-	-	-	14	284	365	1.29
	SDPP	5	BM	-	-	-	9	-	7.1	-	-	-	-	14	279	348	1.24
		-	BM	-	-	-	9	-	7.1	-	-	-	-	14	244	321	1.33
Gatnau and Zimmerman (1991)		-	SBM	-	-	-	24	-	7.1	-	-	-	-	14	63	119	1.85
	SDPP	10	SBM & BM	-	-	-	24	-	7.1	-	-	-	-	14	127	209	1.65
	SDPP	5	BM	-	-	-	24	-	7.1	-	-	-	-	14	97	165	1.66
		-	BM	-	-	-	24	-	7.1	-	-	-	-	14	58	130	2.37
Gatnau et al. (1991)		-	SBM	-	-	-	9	28	7.1	-	-	-	-	14	138	243	2.10
	SDPP	2	SBM	-	-	-	9	28	7.1	-	-	-	-	14	176	276	2.34
	SDPP	4	SBM	-	-	-	9	28	7.1	-	-	-	-	14	203	294	1.49
	SDPP	6	SBM	-	-	-	9	28	7.1	-	-	-	-	14	251	326	1.32
	SDPP	8	SBM	-	-	-	9	28	7.1	-	-	-	-	14	188	290	1.63
Sohn et al. (1991)		-	DSM	-	-	-	48	24	-	7	210	210	1.03	14	280	330	1.16
	SDAP	4	DSM & SDB	-	-	-	48	24	-	7	280	270	0.99	14	360	410	1.15
		-	SDB	-	-	-	48	24	-	7	250	240	0.97	14	320	370	1.15
Gatnau and Zimmerman (1990)		-	CAS	-	-	-	9	-	6.9	-	-	-	-	14	247	292	1.18
		-	MEX	-	-	-	9	-	6.9	-	-	-	-	14	139	213	1.46
		-	iSP	-	-	-	9	-	6.9	-	-	-	-	14	153	204	1.47
	SDPP	10	All others	-	-	-	9	-	6.9	-	-	-	-	14	261	350	1.34
Gatnau and Zimmerman (1990)		-	SBM	-	-	-	12	-	6.9	-	-	-	-	14	191	267	1.44
		-	DSM	-	-	-	12	-	6.9	-	-	-	-	14	230	300	1.74
	SDPP	10	SBM & DSM	-	-	-	12	-	6.9	-	-	-	-	14	345	462	1.35

Albumin = Albunim fraction of plasma; BM = Blood meal; Bov IgG = Immunoglobulins from bovine origin; CAS = Casein; DSM = Dried skimed milk; eSPC = Extruded soy protein concentrate; FDAP = Freeze dried animal plasma; FM = Fishmeal; hWG = Hydrolysed Wheat Gluten; IgG = Immunoglobulins from plasma (% relative to plasma source); irSDAP = Irradiated spray dried animal plasma; iSP = Isolated soy protein; LMW = Low molecular fraction of plasma; MEX = Meat extract; PP = Potato protein; PPI = Pea protein isolate; SBM = Soybean meal; SBM44 = Soybean meal-44%CP; SBM46 = Soybean meal-46%CP; SBM48 = Soybean meal-48%CP; SBM55 = Soybean meal-55%CP; SDAP = Spray dried animal plasma; SDB = Spray dried blood; SDBM = Spray dried blood meal; SDBP = Spray dried bovine plasma; SDEP = Spray dried egg protein; SDIPP = Immunised spray dried porcine plasma; SDPP = Spray dried porcine plasma; SDPPa = Autoclaved spray dried porcine plasma; SPC = Soy protrein concentrate; UP1673 = Ultimate protein 1673; WG = Wheat Gluten; WHY = Whey protein.

piglets that have been used to prepare this review. The mean differences (vs. control) in each trial for weight gain, feed intake and feed to gain due to the use of SDAP have been used to calculate the performance responses of piglets according to several factors using the GLM procedure of SAS. The mean improvements over control for each group considered were compared using Tukey's Studentized Range (Honestly Significant Difference) test and each mean value was compared to a value of zero (control) using a Student's *t*-test. Factors considered are: nature of protein being replaced by SDAP, source of spray dried plasma used, weaning age of the pigs, presence or absence of a pathogenic challenge and presence or absence medication in the feed, and the corresponding results are presented in Table 3 to 7.

To study a possible relationship between the positive effects observed for the diets containing SDAP and its nutritional value, it can be of interest to compare the magnitude of the responses according to the nature of the protein being replaced. A positive response should be expected if SDAP replaced a protein sources with poorer nutritive value whereas no response or a negative effect

Table 3. Performance improvement over the control diet of piglets fed with different sources of spray dried plasma for one or two weeks after weaning

Source	One week post-weaning				Two weeks post-weaning			
	n	ΔADG (g/d)	ΔADFI (g/d)	ΔFGR (g/g)	n	ΔADG (g/d)	ΔADFI (g/d)	ΔFGR (g/g)
SDPP	25	+62*	+60*	-0.15	54	+55*	+68[a, *]	-0.13*
SDBP	5	+43*	+44*	-0.17	5	+22	+37[ab, *]	+0.03
SDAP	52	+48*	+36*	-0.21*	84	+27*	+24[b, *]	-0.07
Pooled STD		37.7	36.2	0.730		38.5	38.5	0.449

[a, b] Values in same column with different letters are significantly different as analysed by Tukey's (HSD) test ($p<0.05$). n: Number of trials.

* $p<0.05$. Statistical significance of improvement over controls without plasma.

should be expected if the protein source being replaced had the same or a better nutritive value, respectively. Table 4 shows the productive response to plasma according to the nature of the protein being replaced. For all the protein sources being replaced, SDAP improved weight gain and feed intake which suggests that factors other than nutritive value may also be involved in the positive effects of SDAP. It is worth noting that feed to gain ratio changed very little for most protein sources. Only the replacement by SDAP of fishmeal (during the first week post-weaning) and casein (two weeks post-weaning) resulted in significant feed to gain ratio improvements. The feed intake mediated effect supports the hypothesis of an improved palatability of the feeds containing SDAP. Ermer et al. (1994) observed that piglets had a higher preference for SDPP than for dried skim milk containing feeds. This contrasts with the observations of Torrallardona and Solà-Oriol (2009), who evaluated the pig's preference for SDPP and another fourteen additional protein sources in relation to a common reference diet. SDPP preference was intermediate among the protein sources tested and did not differ significantly from them except for potato protein that had a significantly lower preference. Numerically, fishmeal, lupine, soybean meal-44, extruded soybeans, soybean meal-48, dried porcine solubles and dried skimmed milk at 10% of inclusion had higher preference values than SDPP. The higher feed intakes observed for the diets containing plasma could also result from an improved health status and higher body weight of the piglets (Torrallardona et al., 2003). In pair fed piglets plasma has also improved performance which suggests a specific biological effect independent of feed intake (Jiang et al., 2000b).

The response of weaning piglets to spray dried plasma from porcine (SDPP), bovine (SDBP), and mixed or unknown (SDAP) origin are presented in Table 3. All three sources significantly improve the performance of the piglets. It appears that plasma from porcine origin has a higher efficacy than the other sources, although statistically significant differences are only obtained for feed intake in the 0-14 d period. It is possible that the specific IgG against porcine pathogens in SDPP are advantageous. This is in good agreement with studies in which the direct comparison of the two sources resulted in higher productivities for SDPP than for SDBP (Hansen et al., 1993; Gatnau and Zimmerman, 1994; Rantanen et al., 1994; Smith II et al., 1995; Pierce et al., 2005). However, higher responses for SDBP have also been reported (Russell, 1994). It has also been suggested that SDPP is better than SDAP of mixed origin (Owusu-Asiedu et al., 2002). However, in a study in which SDPP was compared with two sources of SDAP

Table 4. Performance improvement over the control diet according to the protein being replaced of piglets fed spray dried plasma for one or two weeks after weaning

Source	One week post-weaning				Two weeks post-weaning			
	n	ΔADG (g/d)	ΔADFI (g/d)	ΔFGR (g/g)	n	ΔADG (g/d)	ΔADFI (g/d)	ΔFGR (g/g)
Meat extract	2	+111[a, *]	+60*	-0.25	2	+90[a, *]	+53†	-0.22
Soybean meal	25	+71[ab, *]	+50*	-0.14	32	+57[ab, *]	+52*	-0.14†
Soy protein concentrate	9	+74[ab, *]	+92*	-0.24	9	+55[ab, *]	+84*	-0.00
Dry skimmed milk	11	+47[ab, *]	+52*	-0.01	26	+42[ab, *]	+63*	+0.03
Pea protein isolate	3	+25[b]	+29	-0.06	3	+35[ab]	+47*	-0.00
Casein	1	+37[ab]	+37	+0.03	9	+32[ab, *]	+28*	-0.67*
Fishmeal	7	+42[ab, *]	+18	-1.32*	18	+34[ab, *]	+17†	-0.14
Whey protein	11	+22[b, *]	+21†	-0.02	12	+24[ab, *]	+20†	-0.00
Wheat gluten	2	+55[ab, *]	+34	-0.77	15	+22[b, *]	+25*	-0.03
Blood protein	3	+42[ab, *]	+48*	+0.02	7	+16[b]	+27†	+0.01
Potato protein	10	+34[ab, *]	+27*	-0.03	10	+7[b]	+15	+0.01
Pooled STD		33.5	32.7	0.689		38.5	39.7	0.429

[a, b] Values in same column with different letters are significantly different as analysed by Tukey's (HSD) test ($p<0.05$). n: Number of trials.

* $p<0.05$; † $p<0.1$. Statistical significance of improvement over controls without plasma.

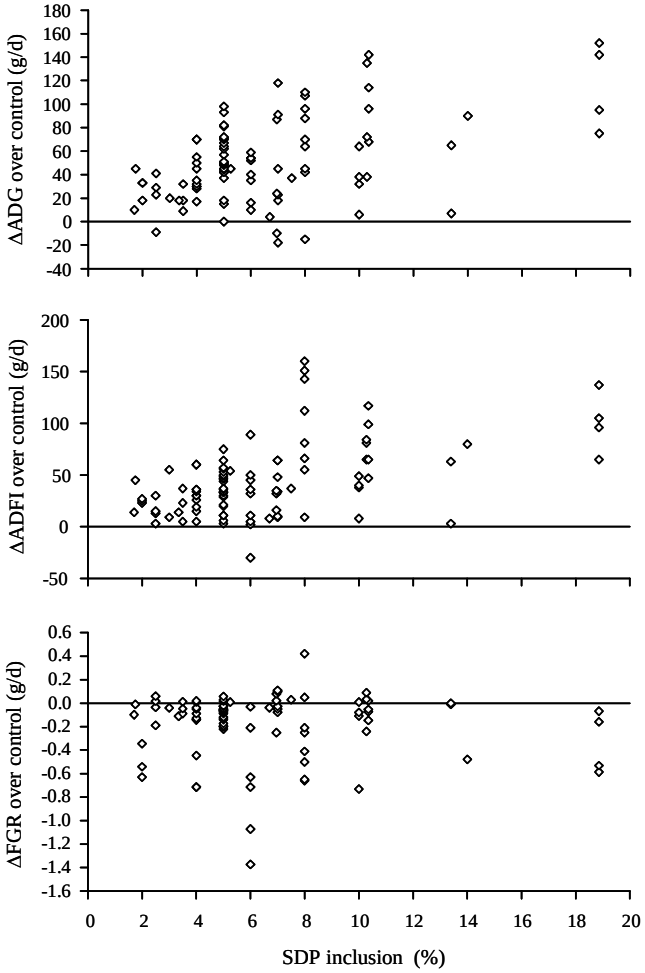

Figure 2. Effect of feeding different doses of spray dried plasma to piglets on the improvement in average daily weight gain, average daily feed intake and feed to gain ratio over the control in the first week after weaning. Number of trials (n) = 95 for ADG, n = 96 for ADFI and n = 92 for FGR.

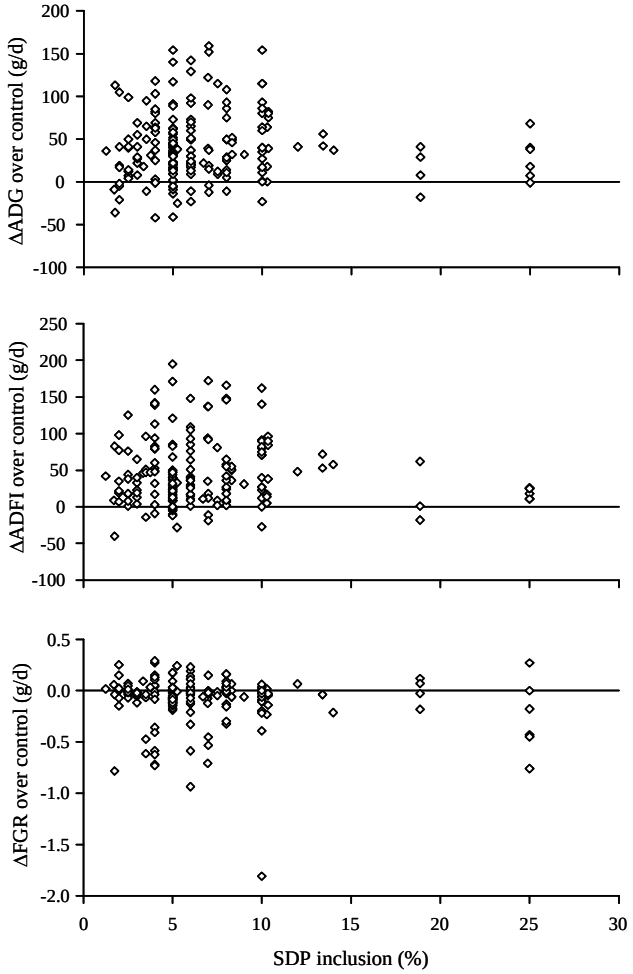

Figure 3. Effect of feeding different doses of spray dried plasma to piglets on the improvement in average daily weight gain, average daily feed intake and feed to gain ratio over the control in the post-weaning phase (0-14 d). Number of trials (n) = 192 for ADG, n = 185 for ADFI and n = 189 for FGR.

(with or without standardised IgG content), a better efficacy for the SDAP standardised in IgG content over the other sources was observed, indicating the relevance of the IgG content of the different sources of plasma (Bosi et al., 2001). The advantadge of a standardised IgG content of SDAP has also been suggested by other authors (Campbell et al., 1998; Conde, 2005). This is supported by studies in which the comparison of SDAP with its albumin, immunoglobulin and low molecular weight fractions show that the beneficial effects are associated with the immunoglobulin fraction (Gatnau et al., 1995; Owen et al., 1995; Weaver et al., 1995; Pierce et al., 2005). Autoclaving SDPP decreases efficacy and this has been explained by an inactivation of its specific antibodies (Owusu-Asiedu et al., 2002), although other bioactive components may have also been destroyed. Two SDPP sources, obtained from pigs exposed to either high or low antigenic exposure were compared, in an attempt to check if the high antigenic exposure resulted in more efficient plasma, but no advantage was obtained (Stahly et al., 1995). Similarly, spray dried immune porcine plasma (SDIPP) obtained from pigs vaccinated against specific pathogens resulted in little productive advantages to piglets experimentally challenged with the same pathogen. This is probably due to an already existing "natural" antigenic load in the conventional non-vaccinated SDPP (Conde, 2005; Niewold et al., 2007).

SPRAY DRIED ANIMAL PLASMA AT DIFFERENT DOSES AND AGE OF THE PIGLETS AT WEANING

The response of piglets according to the inclusion doses of plasma in the feed is presented in Figure 2 and 3. It appears that during the first week post weaning (Figure 2) weight gain and feed intake responses to plasma increase with its level of inclusion in the feed. Over the two-week

Table 5. Effect of weaning age on the performance improvement over the control diet of piglets fed spray dried plasma for one or two weeks after weaning

Weaning age	One week post-weaning				Two weeks post-weaning			
	n	ΔADG (g/d)	ΔADFI (g/d)	ΔFGR (g/g)	n	ΔADG (g/d)	ΔADFI (g/d)	ΔFGR (g/g)
10-17 days	30	+43*	+30[ab, *]	-0.07	38	+25*	+27*	-0.01
18-24 days	47	+60*	+57[a, *]	-0.28*	92	+43*	+46*	-0.13*
25-32 days	6	+32*	+17[b]	-0.11	13	+38*	+42*	-0.05
Pooled STD		36.9	34.4	0.722		40.2	43.2	0.447

[a, b] Values in same column with different letters are significantly different as analysed by Tukey's (HSD) test ($p<0.05$). n: Number of trials.
* $p<0.05$. Statistical significance of improvement over controls without plasma.

pre-starter period (Figure 3), however, an optimal inclusion level of 4-8% is suggested. It is well known that during the first week post weaning piglet's feed intake is very low (Pluske et al., 1997), and therefore, the higher inclusion levels of SDAP may facilitate an adequate intake of IgG. Over the two week period, however, feed intake is normalised and the higher SDAP doses may result in nutrient imbalances (i.e. methionine, isoleucine or salt) that reduce the productive responses. Most dose-response studies have shown an optimum inclusion level for the first two weeks post-weaning, that falls within this range of 4-8%. Thus, an optimum inclusion of 6% was observed compared to inclusion levels of 2 and 4% (Rantanen et al., 1994) or to inclusion levels of 2, 4 and 8% (Gatnau et al., 1991; Burnham et al., 1995). Gatnau and Zimmerman (1992) concluded that performance was maximised at 6-8% of inclusion after testing doses of 2, 4, 6, 8 and 10%. Similarly, higher performances have been observed for 6% over 3% SDPP (Angulo and Cubiló, 1998; Lawrence et al., 2004), for 5% over 2.5% SDAP (Grinstead et al., 2000) and for 7% over 3.5% SDAP (Kerr et al., 1998). Other dose response studies, however, have shown that performance was optimised at levels of inclusion around 3% (Coffey and Cromwell, 1995; Grinstead et al., 2000). Studies with optimised responses at higher inclusion levels have also been reported. Kats et al. (1994) demonstrated that weight gain and feed intake (but not feed efficiency) increased linearly up to inclusion levels of 10% if diets were supplemented with methionine. They concluded that supplemental methionine is required to maximise piglet performance with SDAP diets. It is likely that the maximum SDAP inclusion level will depend on the isoleucine content of the diet as this will become the most limiting amino acid after methionine supplementation (Figure 1). The salt content in some SDAP sources can also be relatively high and could be a limiting factor for the use of high levels of inclusion. Salt concentration can vary depending on the concentration procedure used before drying and on the anticoagulant used. Thus SDAP sources concentrated by reverse osmosis or vacuum drying may have a higher salt content than SDAP concentrated by ultra filtration (10.9 vs. 4.1%). Similarly, the use of tri-sodium citrate as anticoagulant also results in a higher salt content than the use of tri-sodium phosphate. It can be concluded that spray dried plasma can be used in piglet diets up to 10% of inclusion, as long as a correct nutrient balance is maintained.

The response to plasma according to the age of the piglets at weaning was also studied (Table 5). Three age groups were considered 10-17, 18-24 and 25-32 days. Rooke et al. (2003) have shown that the concentrations in blood of specific colostral antibodies transferred from the sow to the piglets decline quadratically during the first weeks of life. They observed a rapid reduction in their concentration between 2 and 14 days of age, and a much slower decline thereafter until day 34. These authors also described that the total IgG concentration did not change between days 7 and 28 of age, but increased between days 28 and 35 suggesting an activation of the pig's own immune system at around four weeks of age. Therefore for the three age groups considered it could be assumed that: i) piglets of 10 to 17 days of age still have some degree of protection from the colostral antibodies, but their own immune system is immature; ii) that piglets of 18 to 24 days of age have a substantially reduced protection from colostral antibodies and an immature immune system; and iii) that the piglets of 25 to 32 days of age also have a reduced protection from colostral antibodies, but their own immune system is at the initial stages of development. No statistically significant differences between weaning age groups on the effect of SDAP on weight gain or feed efficiency were observed. However, a significantly higher feed intake for the 18-24d age group was observed during the first week post-weaning, and numerically, the response in weight gain and feed efficiency for this age group was also higher. The higher response to SDAP for this age group, coincides with their supposed poorest immune protection, and agrees with a possible support of SDAP to the immune system of the piglets via its IgG content or other mechanisms. In a trial by Torrallardona et al. (2002) although no interaction between weaning age and SDAP could be observed in piglets weaned at 22 or 32 days, a higher response for the younger animals is suggested, which supports the above observations. The importance of SDAP in the very young piglet is also supported by the observation that the inclusion of SDPP in creep feed improves the subsequent post-weaning performance (Van Dijk et al., 2001b).

Table 6. Effect of an experimental health-challenge to piglets on their performance response to spray dried plasma in the first one or two weeks after weaning

Challenged	One week post-weaning				Two weeks post-weaning			
	n	ΔADG (g/d)	ΔADFI (g/d)	ΔFGR (g/g)	n	ΔADG (g/d)	ΔADFI (g/d)	ΔFGR (g/g)
YES	10	+38*	+21[b, †]	-0.95[a, *]	23	+46*	+37*	-0.39[a, *]
NO	74	+54*	+47[a, *]	-0.11[b]	120	+36*	+41*	-0.04[b]
Pooled STD		37.7	36.5	0.68		40.7	43.8	0.43

[a, b] Values in same column with different letters are significantly different as analysed by Tukey's (HSD) test ($p<0.05$). n: Number of trials

* $p<0.05$; † $p<0.1$. Statistical significance of improvement over controls without plasma.

SPRAY DRIED ANIMAL PLASMA UNDER INFECTIOUS CHALLENGE AND COMBINATION WITH MEDICATED FEED

Table 6 shows the effect of spray dried plasma according to whether the piglets had been subjected to an experimental health challenge or not. It appears that plasma improves feed to gain ratio more markedly when the piglets are exposed to an experimental challenge. This could be indicative of a lower expenditure of energy and nutrients to build an immune response against the challenge. Studies in which SDPP has been tested under different health environments conclude that the benefits from plasma are significantly higher under lower health conditions, which supports this view. Coffey and Cromwell (1995) observed that weight gain and feed intake were clearly enhanced by SDPP under a conventional environment, but that the response to SDPP was much smaller when pigs were kept in a very clean environment, which resulted in a significant SDPP by environment interaction. Stahly et al. (1995) also tested the effect of adding 6% of SDAP in the diet with piglets that had been either reared under a conventional environment (high antigen exposure) or via a medicated early weaning scheme (low antigen exposure). They also observed a significant interaction between SDAP and environment so that SDAP improved weigh gain, feed intake and feed efficiency in high antigen exposed pigs but not in low antigen exposed pigs. Similarly, Bergstrom et al. (1997) also concluded that high health segregated early weaning pigs responded less to SDAP than pigs with a lower health status conventionally reared in an on-site nursery. Bregendahl et al. (1998) also observed that the addition of 5% SDAP in pre-starter feeds improved weight gain by 34% under a dirty environment, but only by 10% under a clean environment. For antibiotics, it has also been observed that they have little or no effect on growth when the animals are kept under clean conditions (Roura et al., 1992), which supports the hypothesis that the modes of action of antibiotics and SDAP may share similar mechanisms.

A more marked improvement in FGR in response to SDAP is also observed if feed does not contain medication (Table 7). It has to be noted, however, that in many of the trials considered in this review, animals submitted to an experimental challenge were also offered feed that was not medicated, and therefore both factors may be confused to some degree. Trials evaluating plasma and presence or absence of medication together have shown no interaction between the two factors, so that both effects are additive (Rojas et al., 1994; Coffey and Cromwell, 1995; Torrallardona et al., 2002; Bosi et al., 2004). Cain and Zimmerman (1997) observed that plasma was effective against rotavirus but not against *E. coli*, which could explain the additivity of plasma and antimicrobials. Other studies however, have shown tendencies or significant interactions between SDAP and antimicrobials (Torrallardona et al., 2003; Bikker et al., 2004). In most studies in which SDAP has been compared directly against antibiotics (Rojas et al., 1994; Coffey and Cromwell, 1995; Torrallardona et al., 2002, 2003, 2007; Bikker et al., 2004; Bosi et al., 2004; Conde, 2005), organic acids (Owusu-Asiedu et al., 2003b; Torrallardona et al., 2007), other sources of immunoglobulins (Owusu-Asiedu et al., 2002, 2003a,b), plant extracts (Nofrarias et al., 2006), zinc oxide (Owusu-Asiedu et al., 2003b) or carbadox (Owusu-Asiedu et al., 2003b) SDAP results in superior or equivalent results. Srichana et al. (2004) observed that whereas the effect of SDAP occurs mainly in the first week post-weaning that of antibiotics persists for many weeks. The reduction of SDAP

Table 7. Effect of feed medication on the performance response of piglets to spray dried plasma in the first one or two weeks after weaning

Medication	One week post-weaning				Two weeks post-weaning			
	n	ΔADG (g/d)	ΔADFI (g/d)	ΔFGR (g/g)	n	ΔADG (g/d)	ΔADFI (g/d)	ΔFGR (g/g)
YES	69	+55*	+50[a, *]	-0.09[b]	110	+36*	+43*	-0.02[b]
NO	15	+37*	+17[b, †]	-0.72[a, *]	33	+41*	+32*	-0.34[a, *]
Pooled STD		37.4	35.3	0.689		40.8	43.5	0.428

[a, b] Values in same column with different letters are significantly different as analysed by Tukey's (HSD) test ($p<0.05$). n: Number of trials

* $p<0.05$; † $p<0.1$. Statistical significance of improvement over controls without plasma.

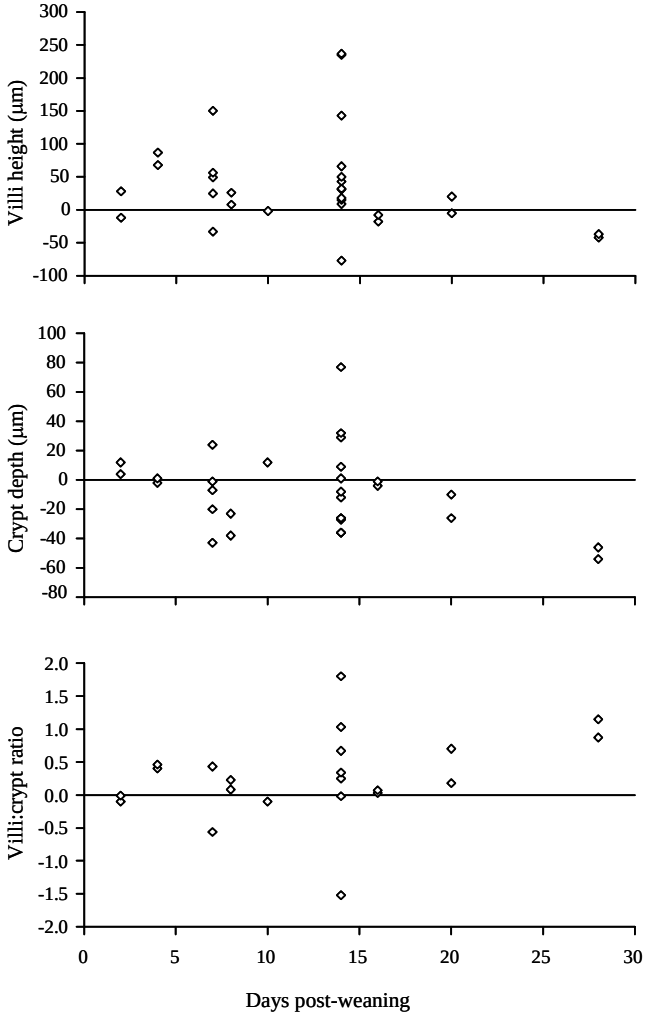

Figure 4. Effect of feeding spray dried plasma to piglets on the change in villus height, crypt depth and villus:crypt ratio relative to the control at different days post-weaning. Number of trials (n) = 30 for villi height, n = 30 for crypt depth and n = 22 for V:C ratio.

efficacy beyond the third week post-weaning may be explained in part by the reduction in its level of inclusion.

MODE OF ACTION OF SPRAY DRIED ANIMAL PLASMA

Plasma is a protein source of high interest for pre-starter piglet diets. Most studies evaluating SDAP have shown to improve growth, feed intake and in some cases feed conversion (Table 2). Some authors claim that the beneficial effect of plasma results from the associated increase in feed intake, whereas others maintain that they are the result of the action of its specific bioactive components. Those supporting that the effect is mediated by an increase in the palatability of the diet and the corresponding increase in feed intake base their hypothesis on the observations of Ermer et al. (1994) for a higher preference for SDAP over dry skim milk feeds. However, Torrallardona and Solà-Oriol (2009) in a series of double free-choice tests, observed that SDPP preference was intermediate among fourteen common protein sources tested and in some cases SDPP's preference was much lower than that of protein sources (e.g. fishmeal) shown to result in worse productive results. This suggests that the increased feed intake observed for the SDAP containing diets is not a palatability mediated effect. It is possible that the higher feed intake is a consequence of the effect of these diets on the health of the piglets (Torrallardona et al., 2003). It is well known that macrophages secrete cytokines in response to antigenic stimuli, and that cytokines act in the brain to reduce feed intake (Johnson, 1997). Therefore the increased feed intake observed for the SDAP containing diets could be due to a reduction in the pro-inflammatory cytokines produced as a consequence of a lower antigenic load with SDAP containing diets. In pair feeding trials, piglets offered the same amount of feed with or without plasma have shown that the effects of plasma are independent of intake, which suggests a specific biological effect (Jiang et al., 2000b). In weaning pigs, feed intake has been shown to be closely correlated with the integrity of the gut mucosa (Pluske et al., 1997). Figure 4 shows the changes in villi and crypt morphology due to SDAP measured at different days post-weaning obtained form different studies (Jiang et al., 2000b; Owusu-Asiedu et al., 2002, 2003a,b; Torrallardona et al., 2003, 2007; Conde, 2005; Nofrarias et al., 2006). SDAP clearly increases villus height (particularly in the first two weeks post-weaning), but its effect on crypt depth is not as clear.

The most widely accepted hypothesis for the mode of action for plasma is probably that its immunoglobulin content is biologically active against pathogens and enterotoxins. This was initially supported by studies in which plasma was proven to reduce the incidence in post-weaning diarrhoea (Gatnau and Zimmerman, 1991; Peet Schwering et al., 1995; Cain and Zimmerman, 1997). Furthermore, studies testing SDPP under environments of different health status have shown that the benefits of plasma are significantly higher under poor sanitary conditions (Coffey and Cromwell, 1995; Stahly et al., 1995; Bergstrom et al., 1997; Bregendahl et al., 1998). Gatnau et al. (1995), Owen et al. (1995), Weaver et al. (1995) and Pierce et al. (2005) have separated plasma into high, medium and low molecular weight fractions, representing globulins, albumin and fibrin, respectively and compared their efficacy with that of SDAP. Their results show that the high molecular weight (immunoglobulin) fraction is the responsible for the beneficial effects of plasma. Godfredson-Kisic et al. (1999) showed that a diet with 2% porcine globulin concentrate, is as effective in maintaining

growth and intake of recently weaned piglets as a diet with 8% plasma. Immunoglobulins keep their biological activity after processing the plasma (Gatnau et al., 1989). They can reach the proximal intestine of recently weaned piglets without being digested, most likely preserving their ability to bind to bacteria and virus (Morel, 1995). The destruction of SDAP antibodies by autoclaving has been shown to reduce its efficacy (Owusu-Asiedu et al., 2002), although it cannot be ruled out that other bioactive components in plasma could also be damaged with this procedure.

Plasma contains antibodies against pathogenic bacteria such as enterotoxic *E. coli* (Owusu-Asiedu et al., 2002). Therefore, plasma immunoglobulins may provide antimicrobial protection, reduce the intestinal immune system activation and prevent mucosal damage by pathogenic bacteria in particularly susceptible animals such as the newly-weaned pig. It has been shown that plasma with guaranteed high levels of immunoglobulins is superior to conventional plasma (Bosi et al., 2001; Conde, 2005). In Bosi et al. (2001)'s study, piglets challenged with *E. coli* K88 and fed plasma with high IgG levels had a lower concentration of specific IgA against K88 in plasma and saliva. This suggests a protective effect against the adhesion *E. coli* K88, since IgA production against a specific bacteria, requires adhesion of this bacteria (using its fimbriae) to the enterocytes in the mucosal villi. Since IgG cannot be absorbed through the intestinal wall in 3-4 week old piglets, they have to act in the intestinal lumen. IgG bind to the virus or bacteria, avoid their union to the enterocytes and prevent the colonisation and damage of the intestinal wall. This is supported by the observations of Perez-Bosque et al. (2004) in challenged rats, who observed a lower activation of the intestinal immune system with the use of SDAP. It has also been hypothesised that the IgG against soyabean proteins present in SDAP, could help weaning piglets to adapt better to the weaning diet rich in highly antigenic soybean proteins. However this could not be demonstrated in a trial designed for this purpose (Hartke et al., 2003).

Glycoproteins have been proposed for being responsible for SDAP's effects instead of (or in addition to) immunoglobulins, by impeding antigen binding. Thus Sanchez et al. (1993) showed *in vitro* that certain glycoproteins obtained from plasma could act as a binding site for *E. coli* fimbriae, and Mouricout and Julien (1986) observed that bovine plasma glycoproteins inhibited *E. coli* adhesion to enterocytes. Subsequently in a study in calves, Mouricout et al. (1990), saw that glycoproteins obtained from bovine plasma inhibited intestinal adhesion of *E. coli* and protected the calves which had been deprived of colostrum against lethal doses of the bacteria. Nollet et al. (1999), in studies of piglets, used a plasma source without specific immunoglobulins for *E. coli* F18, and showed that it impeded *E. coli* F18 binding to enterocytes by receptor competition, which suggested a non-specific protection mechanism. Challenge studies in which diarrhoea was evaluated have shown that SDAP improves faecal scores (Owusu-Asiedu et al., 2003a,b; Conde, 2005), and body condition (Van Dijk et al., 2002a). Torrallardona et al. (2003) observed increased Lactobacilli counts in ileum and caecum of piglets fed SDAP, suggesting that SDAP promotes a beneficial microbiota. This observation however, could not be confirmed in posterior studies by the same group (Conde, 2005; Torrallardona et al., 2007). In experiments with piglets, Jiang et al. (2000b) saw that plasma increased efficiency in dietary protein utilisation and reduced intestinal mass, cell density between villi in the lamina propia and circulatory urea concentration, which the authors attributed to a minimisation in amino acid catabolism by the microflora and an increase in dietary amino acid availability for growth. According to Jiang et al. (2000a), SDAP consumption reduces dietary amino acid catabolism in the intestine, and increases the efficiency of dietary protein utilisation, enabling greater availability of dietary amino acids for growth of lean tissue.

Touchette et al. (2002) showed a lower basal activation of the immune system in piglets fed SDAP than in piglets without SDAP. The same group of researchers described an increased activation of the hypothalamic-pituitary-adrenal (HPA) axis in SDAP-fed piglets following a challenge with LPS or E. coli (Touchette et al., 1999; Carroll et al., 2002). Carroll et al. (2002) proposed two mechanisms by which plasma prevents HPA axis activation. The first is a direct effect of plasma, preventing growth and colonisation of antigenic bacteria in the small intestine, by immunoglobulins. The second is an indirect effect of plasma on mucosal integrity, promoting intestinal growth, improving villi height and the villus height: crypt depth ratio as shown in previous studies (Spencer et al., 1997; Touchette et al., 1997). This would enable the animals to have a better barrier, which would prevent potential pathogens from crossing the intestinal wall. Both mechanisms would reduce HPA axis activation in piglets, reducing immunological stress, and immune system stimulation. Immune system activation has been shown to be associated with reduced intake and growth (van Heugten et al., 1994), due to the increase in pro-inflammatory cytokines which inhibit growth and intake (Johnson, 1997), and with a change in nutrient distribution, no longer used for skeletal muscle growth but for supporting the energy expenditure necessary for the immune system (Klaising and Johnstone, 1991). Bosi et al. (2004) confirmed a reduction in the production of the pro-inflammatory cytokines (tumour necrosis factor-α, interleukin-8 and interferon-γ) in the jejunum of SDAP-fed piglets challenged with enterotoxigenic *E. coli* (ETEC) K88. Therefore the reduction in immune system activation, which results from

the consumption of diets with SDAP by piglets, would improve their intake and growth (Touchette et al., 2002).

CONCLUDING REMARKS

Plasma is a widely accepted ingredient for pre-starter piglet diets that has been shown to improve growth, feed intake and/or feed conversion. There is evidence suggesting that the improvement in feed intake is due to a reduction in the production of pro-inflammatory cytokines as a consequence of a lower antigenic load when SDAP is provided, rather than to an improvement in feed palatability. The superiority of SDAP over all the other protein sources it has been compared to (even those that have been shown to have equivalent or better nutritional value) is against a nutritionally driven effect. Most of the evidence provided suggests a specific action of the IgG or other bioactive substances in SDAP against porcine pathogens. IgG and other bioactive substances may prevent the binding of pathogens to the gut wall, reduce the activation of the immune system and reduce the incidence of diarrhoea in the post-weaning phase. The specificity of the IgG could explain the better efficacy of plasma from porcine origin over that of plasma from bovine or mixed origin. The suggested higher efficacy of SDAP for piglets weaned at 18-24 days of age (coinciding with a low protection from colostral antibodies and an immature immune system of the piglet), also supports an IgG mediated mode of action. Finally, as for antibiotics, SDAP efficacy is much higher under poor sanitary conditions (i.e. experimental challenge or absence of medication in the feed). In conclusion spray dried plasma appears to prevent the adhesion of pathogenic bacteria to the gut wall, reduces de activation of the immune system and the production of pro-inflammatory cytokines (thus avoiding a reduction in feed intake), and reduces the needs for energy and nutrients to build an immune response against the challenge, which results in better growth. For all this plasma can be postulated as an excellent alternative to in-feed antimicrobials for piglets in the post-weaning phase.

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