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A meta-analytical study about the relation of blood plasma addition in diets for piglets in the post-weaning and productive performance variables

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ABSTRACT

The meta-analysis was used to evaluate the performance of piglets in post-weaning period, without imposition of sanitary challenge and fed diets containing blood plasma, obtained by spray-dried process (SDBP). Piglets are faced with normal challenges in post-weaning period such as environmental stress and the substitution of the liquid diet to a solid one. References regarding sanitary challenges were disregarded in this study. Only data regarding normal and expected challenges were considered. Data were obtained from indexed journals with information extracted from the material, methods and results sections of pre-selected scientific articles. First, the database was analyzed graphically to observe the distribution of data and presence of outliers. Afterwards correlation analysis and variance–covariance analyses were carried out. The database contained a total of 23 articles. The average initial weight of the piglets was 8.02 kg (4.00–9.28 kg) and the average initial age was 27 days (14–32 days). The average duration of feeding diets containing spray-dried blood plasma (SDBP) was 9 days (6–28 days). SDBP increased the feed conversion by 20.2% ($P<0.05$) during the initial period. Feed conversion during the total period was 10.2% higher ($P<0.05$) for animals fed with SDBP. Average daily weight gain and daily feed intake were not affected ($P>0.05$) during the entire period, but average daily gain was higher ($P<0.05$) for animals fed with SDBP during the initial period. The initial age of supplementation influenced the average daily weight gain and average daily feed intake of animals fed with SDBP. Better results were obtained than those obtained for animals up to 35 days of age fed diets without added SDBP supplementation. In early post-weaning period for piglets weaned up to 35 days of age, the SDBP supplementation positively influenced the average daily weight gain and feed conversion.

1. Introduction

The intensification of swine production has generated strong pressure regarding the age of weaning piglets. However, the digestive system of early weaned piglets presented low enzymatic activity for digestion of nutrients such as carbohydrates, since it had been accustomed to digesting protein (i.e. milk) (Lindemann et al., 1986). In addition, the piglet's immune system is not fully mature, until after 35 days of age (Mavromichalis, 2006). Weaning is usually performed before this period; thus, the piglet is predisposed to a higher incidence of diarrhea and infections caused by pathogens present in the nursery environment. Exposure to new housing and the feed pathogens may trigger an immune

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response that negatively affects the metabolic processes of piglets. In response, piglets reduce the intake of feed and water for long periods, which directly affects daily weight gain and subsequent development of these animals (Lallès et al., 2004). Restrictions on consumption, digestion and absorption of feed caused by stress after weaning justify the provision of high quality protein feed for animals in this category (Bikker et al., 2004).

The blood plasma obtained by the spray-dried process (SDBP) is presented as a good alternative to the problems that occur in post-weaning period, primarily by reducing inflammation, scaling and consequently decreasing the intestinal secretion of IgA (Bosi et al., 2004). Spray-dried blood plasma has no anti-nutritional factors that affect its utilization by piglets (Gattás et al., 2008). Among the various products of animal origin, the use of blood plasma has become an alternative due to its biological properties (Bracho et al., 2001). The plasma is considered a high quality supplement and palatable, being touted as an alternative to stimulate the increase in consumption and nutrients absorption in young animals (Bikker et al., 2004).

Despite blood plasma's excellent characteristics, the results observed for the performance of piglets fed diets containing this ingredient are contradictory (Gattás et al., 2008; Assis Júnior et al., 2009). Part of the variability observed in previously published studies can be related to the experimental range of potentially influential factors on the response to supplementation with animal plasma. For this purpose, the use of meta-analysis becomes a viable alternative to generate new results adjusted to the experimental diversity. Due to its analytical properties, the meta-analysis increases the number of observations detecting differences that would not be noticeable in smaller populations. Therefore, the aim of this study was to evaluate, by meta-analysis, the performance of piglets in post-weaning fed diets containing blood plasma obtained by the spray-dried process.

2. Material and methods

The publications were extracted from indexed journals, the search was carried out using the keywords "spray-dried blood plasma levels, nursery pigs, piglets" and 413 results came up on the search. The articles were selected using the following criteria: (a) addition of different levels of blood plasma obtained by the spray-dried process (SDBP) compared with a control diet without added SDBP, (b) pertinent information regarding the nutritional composition of diets, (c) results regarding average daily weight gain (ADG), average daily feed intake (ADFI) and feed conversion ratio (FCR), (d) no treatments with imposition of health challenges by pathogens. In the absence of any of these criteria the article was deleted from the database. Data were obtained from the material and methods and results sections of selected articles and the reported results were tabulated in a spreadsheet.

The database used for the meta-analysis consisted of 23 articles (Table 1) published in journals on a timeline of 17 years (1993–2010). The studies which were considered had been carried out in different countries: United States (14 papers), Brazil (3), Spain (2), Netherlands (2), Italy (1), and Colombia (1). In the database animals without the experimental imposition of sanitary challenge were preconized, considering only animals that were characterized as "normal challenge"(normal stress during post-weaning period, such as environmental stress and the substitution of the liquid diet to a solid one). The average addition of SDBP was 3.5% (min. 2.5% to max. 18.8%). The average initial weight of piglets was 8.00 kg (4.00–9.28 kg), and the average initial age of the animals was 21 days (14–32 days). The average room temperature registered in the experiments was 28.3 °C (min. 26.8 to max. 30.7 °C). The average duration of feeding diets containing SDBP was 9 days (6–28 days). The amino acids and energy values of diets are presented in Table 2.

Table 1
Article used in database.

Author	Number animals	Age at weaning (days)	Sex	Level of SDBP	Country
Angulo & Cubiló, 1998.	180	22	Male × Female	0%, 3%, 6%	Spain
Assis Júnior et al., 2009.	128	28	Male × Female	0%, 2.8%, 4.2%, 5.6%	Brazil
Barbosa et al., 2007.	112	21	Male × Female	0%, 2%, 2.8%, 3%, 4%,4.2%, 5.6%, 6%, 8%	Brazil
Bergstrom et al., 1997.	300	19	–	0%, 2.5%, 5%	USA
Bikker et al., 2004.	400	26	Male × Female	0%, 4%	Netherlands
Bosi et al., 2004.	48	21	Male × Female	0%, 6%	Italy
Chae et al., 1999.	150	22	Male × Female	0%, 18.86%	USA
Coffey & Cromwel, 1995.	80	28	Male × Female	0%,3%,6%,9%,12%	USA
DeRouchey et al., 2002, 2004.	180	24	Male × Female	0%, 5%	USA
Frank et al., 2003.	40	17	Male	0%, 7%	Colombia
Gattás et al., 2008.	128	14	Male × Female	0%, 2%, 2.8%, 3%, 4%, 5.6%, 6%, 8%	Brazil
Grinstead et al., 2000.	180	19	Male × Female	0%, 2.5%, 5%	USA
Hansen et al., 1993.	236	24	Male × Female	0%, 10%	USA
Hartke et al., 2003.	276	15	Male × Female	0%, 7.5%	USA
Hernández et al., 2010.	96	21	Male	0%, 2.5%, 5%	USA
Jiang et al., 2000.	96	15	Male × Female	0%, 10%	USA
Kats et al., 1994.	534	21	–	0%, 2%, 4%, 6%, 8%, 10%	USA
Nessmith et al., 1997.	360	19	Male	0, 0.75%	USA
Pierce et al., 2005.	80	21	–	0%, 8%	USA
Rodas et al., 1995.	144	19	–	0%, 14%	USA
Torrallardona et al., 2002, 2003.	48	24	Male × Female	0%, 7%	Spain
Van Dijk et al., 2001, 2002.	160	26	Male × Female	0%, 3%	Netherlands
Zhao et al., 2007.	192	22	Male	0%, 6%	USA

Table 2
Average diet composition on as-fed basis per average weight.

	3–5 kg	RSD[a]	5–10 kg	RSD[a]	10–20 kg	RSD[a]
Crude protein, g/kg	223.48	8.52	211.18	7.59	196.40	4.00
Lysine, g/kg	15.75	2.46	14.31	3.47	12.75	2.92
Methionine, g/kg	4.80	0.23	4.62	0.84	4.46	0.00
Threonine, g/kg	9.19	1.29	9.08	2.14	7.91	0.01
Tryptophan, g/kg	2.63	0.07	2.51	0.03	2.25	0.01
Methionine+Cystine, g/kg	8.35	1.81	8.03	1.85	7.40	0.00
Calcium, %	0.93	0.00	0.89	0.00	0.88	0.00
Total phosphorus, %	0.77	0.01	0.73	0.79	0.86	0.00
Digestible energy Kcal/kg	3,520	7.28	3445	16.62	3148	0.40

[a] Residual standard deviation.

The database consisted of 4.148 animals categorized by the criteria “SDBP diets” or “SDBP-free diet”. In addition to this coding category, three other moderating encodings were used: (a) general codification (study effect), where each paper was given a sequence number, (b) inter-study codification, where each treatment was given a number composed by general codification plus another sequential number (article 1, treatment 1=01+01=101), and (c) intra-study codification, a code similar to the inter-codification used when there were repeated measures (over time or doses). Criteria described in the literature were used for the definition of dependent and independent variables (Lovatto et al., 2007; Sauvant et al., 2008).

The analysis of the database was composed of three sequential analysis. A graphical analysis was used to observe the distribution of data to form an overview of the consistency and heterogeneity of data. Through this analysis, correlation assumptions could be formed to define the statistical model (Lovatto et al., 2007). The outliers were not removed from the analysis (Sauvant et al., 2008). Then correlation analysis was performed, which allowed us to observe the interaction of some variables on the results. Finally, the analysis of variance–covariance was performed, from which prediction equations were generated. The statistical model used for covariate adjustment, and the responses were adjusted for average weight in the period. Based on correlation analysis, it was possible to identify the variables that had an effect on the observed results, and adjustments were made possible by variance–covariance analysis. Analyses were performed based on the total period of experimentation where the average age at the end of supplementation was 38 days (ranging between 28 and 59 days) or initial period (which included the first phase of trials, from 7 to 14 days and ages 14–49 days). The codification (categories or moderating) and the variables with the highest correlation coefficients were used in variance–covariance analysis using the General Linear Model procedure of the statistical program Minitab 16 (Minitab Inc., State College, USA).

3. Results

During the first week post-weaning, the ADG and FCR differed ($P<0.05$) between treatments, being better for animals fed diets supplemented with SDBP (Table 2). Each gram of SDBP consumed by the piglets represented a linear increase of 1.55 g in ADG ($ADG=188\times X+1.55$, $R^2=0.82$, where X=grams per day of ingested SDBP). The quadratic effect of consumption of plasma over weight gain was tested in the equations, but there was no significant relationship for this variable ($P>0.05$).

The earlier the piglets were weaned, the better were the results for ADG (Fig. 1) observed for animals supplemented with SDBP ($ADG=-314.59+24.38\times X-0.236\times X^2$ where X=initial age in days). Piglets supplemented with SDBP weaned at 14 days showed ADG 123% higher ($P<0.05$) than the animals that received no supplementation. Piglets supplemented with SDBP weaned at 21 days had ADG 52% higher ($P<0.05$) than the animals without supplementation. In addition, ADG of piglets supplemented with SDBP weaned at 28 days was 12% higher ($P<0.05$) than the non-supplemented ones. At 35 days of age, ADG for both treatments was equivalent in 383 g.

In the initial period of supplementation, SDBP presented an improvement in FCR of 22.2% when compared to control treatments (Table 3). ADFI did not differ between treatments either in the initial period (Table 3) or in the total period (Table 4). During the entire period of the trial, ADG and ADFI were similar ($P>0.05$) in pigs fed with or without SDBP supplementation (Table 4). However a difference was observed in FCR during this period ($P<0.05$), where the animals that fed with SDBP presented better results when compared to those fed without supplementation of SDBP (Table 4). The FCR over the total period of the experiment was 10.2% higher ($P<0.05$) for animals supplemented with SDBP when compared with non-supplemented animals. The consumption of sulphureted amino acids (grams per day) interfered in the ADG of piglets ($ADG=137.07+10.71\times X$ where X=methionine+cystine) Table 5.

4. Discussion

Several studies regarding normal health challenge situations have demonstrated the relationship between the addition of SDBP in the diet of weaning piglets and higher weight gain (Bikker et al., 2004; Bosi et al., 2004; Chae et al., 1999). On the other hand through this study it was observed that this higher weight gain for animals supplemented with SDBP may vary with factors such as the age of weaning. For piglets with 35 days old at weaning, supplementation with SDBP does not seem to

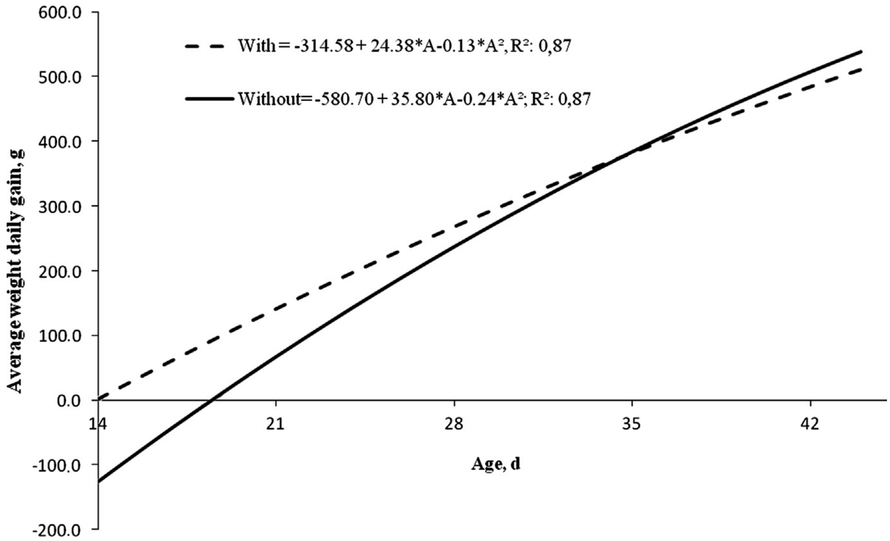

Fig. 1. Average daily gain of piglets supplemented or not supplemented with SDBP as a function of initial age.

Table 3
Performance obtained by meta-analysis, in the initial period (7–14 days post-weaning) supplementation adjusted by covariate for weight.

Variables	Supplementation			
	With	Without	RSD[a]	P^b
Daily feed intake, g/day	262.9	255.6	41.62	0.54
Daily weight gain, g/day	200.4	170.7	39.09	0.01
Feed Conversion ratio, kg/kg	1.4	1.8	0.20	0.04

[a] Residual standard deviation.
[b] Significant at 5% probability (Tukey test).

Table 4
Performance obtained by meta-analysis, in pigs supplemented or not supplemented SDBP for a total period of supplementation (38 days post-weaning).

Variables	Supplementation			
	With	Without	RSD[a]	P[b]
Daily feed intake, g/day	353	340	80.7	0.65
Daily weight gain, g/day	281	266	64.2	0.20
Feed Conversion ratio, kg/kg	1.32	1.47	0.14	0.04

[a] Residual standard deviation.
[b] Significant at 5% probability (Tukey test).

promote better results than no supplementation, due to the fact that the observed ADG was the same. This occurs because the piglet's digestive tract completes development at approximately five weeks of age (Mavromichalis, 2006). With a completely developed digestive tract more gastro-intestinal secretion occurs, which decreases the incidence of pathogens since many of these are destroyed by the acidity of gastric fluid (Lallès et al., 2007). In contrast, when the digestive tract is immature there is lower secretion of potentially bactericidal substances, so supplementation with SDBP had better results (Gattás et al., 2008) probably by increasing active immunity due to the presence of immunoglobulins in SDBP. In cases of great health challenges, blood plasma is often recommended, especially in the presence of *Escherichia coli* by inhibiting the adhesion of bacteria to the digestive tract (Lallès et al., 2004).

Higher weight gain scores for animals supplemented with SDBP may be linked to the health status of the piglet. There are two types of acquired immunity: humeral and cellular. During the first 24 h of life, the animal receives immunoglobulin, that is provided by colostrum, IgG being present in greater quantities and it is absorbed intact in the intestine. However, after this short period of time, the intestine starts its activity preventing the absorption of intact IgG (Mavromichalis, 2006). The plasma is rich in immunoglobulins especially IgG that acts forming a kind of physiological barrier that protects the epithelium (Lallès, 2008). For this plasma action, there occurs a reduction of epithelial desquamation that is induced by diarrhea after weaning (Bikker et al., 2004). This influences directly on the ADG and FCR. Plasma presents immunological properties similar to breast milk which may be one of the reasons for the improved performance of early-weaned piglets (Mavromichalis, 2006).

Despite the low health challenge of studies inserted in the database, the weaning period generates distress due to changes in environment, feed and presence of piglets from other litters causing a possible decrease in immunity (Barbosa et al., 2007). The physiological immaturity combined with post-weaning distress induces morphological alterations, reduced enzyme activity, and decreased intestinal absorption (Lallès et al., 2004). Distress rises corticotrophin levels which in turn activate the receptors in the intestinal cells, triggering a gut barrier dysfunction (Moeser et al., 2007). The SDBP acts by modulating epithelial barriers preventing intestinal disorders (Pérez-Bosque et al., 2006). The SDBP prevents the infiltration of pathogens by associating the intestine to the lymphoid tissue based on the action of macrophages and lymphocytes (Nofrarías, 2007; Gallois and Oswald, 2008). It is due to the presence of IgG in SDBP

Table 5
Equations for performance variables of animals supplemented with SDBP obtained by analysis of variance–covariance.

Responses	Covariates	Equations	R^2
Daily feed intake, g/d	Aw	86.13+39.45 × Aw	0.82
	Lys	50.95+17.29 × Lys	0.70
	M+C	137.07+10.71 × MC	0.94
Average daily gain, g/d	IA	105.34+0.237 × IA	0.92
	IA	−314.58+24.38IA × −0.12765 × IA^2	0.88
	Aa	52.72+0.6407 × Aa+0.9932 × Aa^2	0.99
	g/PI	188 +1.55 × g/PI	0.82
Feed Conversion ratio, kg/kg	Aw	2.21−0.09 × Aw	0.63
	MC	2.11−0.121 × MC	0.80
	IA	1.804+0.02 × IA	0.91
	$Aw^{0.6}$; Le	2.18−0.25 × $Aw^{0.6}$−0.006 × Le+0.0002 × Le^2	0.97

Aw (average weight), Aw (average weight), Lys (Lysine), M+C (Methinine plus cysteine), IA (Initial Age), IA (Initial Age), Aa (Average Age), g/PI (grams of SDBP intake), Aw (average weight), MC (Methionine+Cystine), IA (Initial Age), Aw0,6 (metabolic average weight), Le (Level of SDBP addition).

components that contribute to immune effects (Moretó and Pérez-Bosque, 2009).

FCR was better ($P < 0.05$) for piglets supplemented with SDBP both in the initial period (22.2%) and the total period (10.2%). Similar results are described in the literature (Angulo & Cubiló, 1998; Van Dijk et al., 2001). These results may be related to the high biological protein value in the SDBP which causes an increase in protein absorption (Gallois & Oswald, 2008; Gattás et al., 2008). In experiments with mice sanitarily challenged the capacity of the galactose and glucose transporter complex increased (Moretó and Pérez-Bosque, 2009). Furthermore, the SDBP is free of antinutritional factors that irritate the intestinal mucosa and cause an increase in the epithelial cell renewal (Lallès, 2008). It is possible that the combination of these factors improve the utilization of ingested nutrients directly impacting on feed conversion.

It was observed that the ADG behaves quadratically as a function of the initial supplementation age. The same has been described previously in the literature (Van Dijk et al., 2001). The similarity observed for ADG among supplemented with SDBP and non-supplemented animals for the total period of experimentation has also been described in previous studies (Bikker et al., 2004; Gattás et al., 2008; Zhao et al., 2007). In all, the similarity ($P >$ 0.05) between ADG of the two treatments in the total period of the experiment could be explained by compensatory weight gain as described in the literature by some authors (Gattás et al., 2008; Assis Júnior et al., 2009). Soon after weaning, if it does not consume feed, the piglet goes into a state of feed restriction, when it adapts to this new way of feeding a compensatory growth effect can occur due to an increase in muscle protein turnover (Kristensen et al., 2004). However one must consider that in short periods of feed restriction followed by ad libitum feeding the increased energy efficiency may be related to the recovery of digestive tract organs and not to compensatory gain (Lovatto et al., 2006).

The post-weaning change from a liquid diet to a solid diet is identified as a major reason for piglets having low feed intake and not developing their entire genetic potential (Mavromichalis, 2006). The SDBP is cited by some authors as an influential potential for increased ADFI (Zhao et al., 2007, Pierce et al., 2005; Gattás et al., 2008). However, this study showed no difference in ADFI with the addition of SDBP ($P >$ 0.05). Similar results were described by other authors (Van Dijk et al., 2002; Bikker et al., 2004; Barbosa et al., 2007).

In a meta-analytic study conducted previously by Van Dijk et al. (2001), it was observed that ADFI may increase when piglets received diets supplemented with SDBP. However most of the studies that composed this database were performed in the USA. By adding studies conducted in Brazil and in Europe, it was possible to notice some effects of SDBP on ADFI. There is a notable difference between the composition of the basal diets in different countries. In Brazil, for example, diets are primarily composed of corn and soybean meal. While in the USA there is a larger addition of wheat meal. The same author (Van Dijk et al., 2002) did not observe difference in ADFI of piglets supplemented or not with SDBP when conducting two studies using soybean meal basal diet. It is possible that the basal diet interferes in ADFI by its composition. By using the inter-studies codification, the variation between treatments regarding the composition of the diet (type of ingredient, type of SDBP) was removed, showing no difference in ADFI of piglets supplemented or not supplemented with SDBP. It is probable that the change in consumption is dependent on the type and origin of ingredients. In this context, it is possible that the diet composition had influences on consumption due to the transit time of the diet in the intestinal tract (Black et al., 2009).

The consumption of sulphureted amino acids (grams per day) affected the ADG of piglets (ADG = 137.07+10.71 × MC where MC = methionine+cystine). Similar results were found in previous studies (Kats et al., 1994; Chae et al., 1999). This is due to the fact that SDBP are rich in lysine but poor in isoleucine and methionine. Methionine then becomes the limiting amino acid for piglets fed high levels of SDBP (Barbosa et al., 2007). In this case a possible reason for performance similarities between piglets supplemented with SDBP over the total period and non-supplemented ones may be due to the need for dietary adjustments. This would occur by increasing the sulphureted amino acid supplementation, which is required for animals that were fed with high doses of SDBP (NRC, 1998).

Overall, the meta-analysis allowed us to study systematically the effects of adding SDBP. However, there are still doubts as to the optimum levels of SDBP and the relation with sulphureted amino acids adjustment. Due to this, future studies are needed to explore the interactions of the PSSD addition and nutritional composition of diets in post-weaned piglets.

5. Conclusion

In situations of normal challenge, diets supplemented with SDBP should be used for piglets no later than 35 days old, because when used up to 35 days of age SDBP supplementation positively influences average daily weight gain and feed conversion ratio. For the total period in nursery, SDBP supplementation improves piglet feed conversion ratio. However adjustment in levels of sulphureted amino acids may be necessary for animals receiving SDBP supplementation.

Conflict of interest

We wish to confirm that there are no conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In doing so we confirm that we have followed the regulations of our institutions concerning intellectual property.

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