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Herbal choline as an alternative to choline chloride in the diet of nursery piglets

Abstract – The objective of this work was to evaluate the replacement of choline chloride supplementation by herbal choline in the diet of nursery piglets. The experimental design was randomized complete blocks (initial weight and sex) with 80 piglets, in five treatments, with eight replicates. The treatments consisted of: negative control, basal diet supplemented with 300 mg kg^{-1} choline via choline chloride, basal diet supplemented with 600 mg kg^{-1} choline via choline chloride, basal diet supplemented with 100 mg kg^{-1} herbal choline, and basal diet supplemented with 200 mg kg^{-1} herbal choline. Zootechnical performance data, blood parameters, and economic viability were analyzed. Herbal choline supplementation increases the body weight and daily feed intake of nursery piglets. The supplementation with 100 mg kg^{-1} herbal choline presents the highest return on investment. Herbal choline can be used as a source of choline supplementation in the diet of nursery piglets to replace choline chloride.

Index terms: nutritional additive, phosphatidylcholine, swine production, vitamin.

Colina herbal como alternativa ao cloreto de colina em dieta de leitões na creche

Resumo – O objetivo deste trabalho foi avaliar a substituição da suplementação de cloreto de colina por colina herbal na dieta de leitões na creche. O delineamento experimental foi em blocos ao acaso (peso inicial e sexo) com 80 leitões, em cinco tratamentos, com oito repetições. Os tratamentos consistiram em: controle negativo, dieta basal com suplementação de 300 mg kg^{-1} de colina via cloreto de colina, dieta basal com suplementação de 600 mg kg^{-1} de colina via cloreto de colina, dieta basal com suplementação de 100 mg kg^{-1} de colina herbal e dieta basal com suplementação de 200 mg kg^{-1} de colina herbal. Dados de desempenho zootécnico, parâmetros sanguíneos e viabilidade econômica foram analisados. A suplementação de colina herbal aumenta o peso corporal e o consumo diário de ração em leitões na creche. A suplementação com 100 mg kg^{-1} de colina herbal apresenta o maior retorno sobre o investimento. A colina herbal pode ser utilizada como fonte de suplementação de colina na dieta de leitões na creche, para substituir o cloreto de colina.

Termos para indexação: aditivo nutricional, fosfatidilcolina, suinocultura, vitamina.

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Introduction

Choline, an essential nutrient for pigs, is a quaternary ammonium salt whose molecule has three methyl groups, making it a readily active source for methylation reactions (Del Vesco, et al., 2013). It is considered a B-complex vitamin there, although are divergences regarding the classification of this essential amine, whose functions and nutritional concentrations differ from those characteristics of the vitamin group (Bertechini, 2021).

The choline molecule, together with acetic acid, acts in the synthesis of acetylcholine (Farina et al., 2017). In addition, it constitutes about 35% of the phospholipids present in the plasma membrane, acting in cell maintenance and construction (Boesze-Battaglia & Schimmel, 1997). The molecule also participates indirectly in the lipidic metabolism by synthesizing very-low-density lipoproteins and supplying phosphatidylcholine (Nascimento, 2022), even acts as a donor of methyl groups involved in methionine synthesis and, indirectly, in protein synthesis (Del Vesco et al., 2013).

The dietary supplementation with choline, usually as choline chloride (Petrolli at al., 2021), is important because of its positive effect on animal performance and on the reduction of nutritional deficiency symptoms in animals, as observed in studies in which the nutrient was offered to nursery piglets (Ribeiro et al., 2016; Qiu et al., 2020). The concentration of 262.5 mg kg^{-1} choline, higher than that of other B-complex vitamins, is recommended to supplement the diet of nursery pigs in the initial phase, considering their nutritional requirements and feed composition (Rostagno, 2017). However, choline has a high hygroscopicity, which promotes the absorption of free water from the diet and air humidity (Farina et al., 2017). This characteristic may lead to losses of the water-soluble vitamins present in the diet, possible errors in the supplied dosage, and agglutination of the feed (Lisboa et al., 2014; Silveira, 2021). This high hygroscopicity also influences the storage and handling of the choline, requiring specific equipment and well-controlled handling in feed mills (Dias, 2021).

Another disadvantage is that about two thirds of the free choline present in choline chloride are susceptible to the action of intestinal microorganisms, which transform it into trimethylamine, the molecule responsible for the typical fish odor in meat and eggs (de la Huerga & Popper, 1952). Trimethylamine can be deposited in the muscle of animals or excreted through urine (Farina et al., 2017), which means that choline supplemented via choline chloride is not completely absorbed and neither potentially metabolized by the body.

In this context, alternative sources have been researched, including herbal choline, is a natural product composed of bioactive sources rich in choline, as phosphatidylcholine, whose bioavailability is of 60 to 90%, resulting in a lower dietary amount when compared with choline chloride (Dias, 2021; Petrolli et al., 2021). This allows the addition of other additives and nutritional components to the diet, optimizing storage space in feed mills.

Herbal choline also does not have a high hygroscopicity, which is an advantage over choline chloride because it does not impair the vitamin concentration of the diet and does not affect feed management (Dias, 2021). Moreover, the intestinal degradation of phosphatidylcholine in vegetable sources is less expressive and, therefore, the absorption and metabolization of choline by the body are more effective (McDowell, 2008).

The main commercialized species used as vegetable sources for choline are: *Silybum marianum* (L.) Gaertn., *Citrullus colocynthis* (L.) Schrad., *Andrographis paniculate* (Burm.f.) Wall. Ex Nees, *Ocimum sanctum* L., and *Azadirachta indica* A.Juss. Since their manufacture does not involve chemical processes, as choline chloride does, the plant compost is allowed in organic production systems (Nascimento, 2022).

Therefore, herbal choline is a potential substitute for choline chloride because it can supply the nutritional requirements of animals without causing nutritional deficiencies. However, although it does not have negative effects on the metabolism and performance of piglets, there are few works on the use of choline as a feed additive for pigs and the results found for piglets receiving supplemented diets in the nursery phase are limited and inconsistent.

The objective of this work was to evaluate the replacement of choline chloride supplementation by herbal choline in the diet of nursery piglets.

Materials and Methods

The study was conducted at the experimental farm of the Swine Research Laboratory of the Department of Animal Feed and Production of Universidade de São Paulo (USP), located in the municipality of Pirassununga, in the state of São Paulo, Brazil, (21°56'56.9"S, 47°27'16.1"W) from July 11 to August 9, 2021, totaling 29 days. The experiment was approved by the ethics committee on animal use of USP under protocol number 3796090821.

The experimental design was randomized complete blocks (initial weight and sex), with five treatments and eight replicates. The treatments were composed of 16 animals, and the experimental unit, of the pen average (two animals).

The following treatments were evaluated: negative control (NC) without choline supplementation, basal diet supplemented with 300 mg kg^{-1} choline via choline chloride (C300), basal diet supplemented with 600 mg kg^{-1} choline via choline chloride (C600), basal diet supplemented with 100 mg kg^{-1} herbal choline (CH100), and basal diet supplemented with 200 mg kg^{-1} herbal choline (CH200).

Lower rates of herbal choline were used in the diet due to its high amounts of bioavailable phosphatidylcholine, phosphatidylinositol, and phosphatidylethanolamine (Calderano et al., 2015; Farina et al., 2017), which have a high gut-receptor affinity, allowing a greater bioavailability than choline chloride. The added rates were suggested by the manufacturer of the used herbal choline, Cholmax Powder (Alpha Facts, Herentals, Belgium), based on data from Farina et al. (2017).

Eighty piglets from the x genetic line (Choice, Bruz, France) were used for the study. All of them were in the initial phase of nursery, at 44 days of age and had a mean weight of 14.11±1.70 kg. The piglets were housed in pairs in pens, with a capacity for four animals, with semi-automatic feeders, nipple drinkers, and a 50% slatted floor. The animals were subjected to an adaptation period during the first five days of the trial, in which they were fed a basal diet (Table 1), containing reduced levels of choline (632.04 mg kg^{-1}) and digestible methionine (0.26%) to reduce their choline body reserves. After the adaptation period, herbal choline or choline chloride was included to the basal diet to replace the inert material (kaolin) in the feed. Feed and water consumption were ad libitum.

Table 1. Basal diet composition and nutritional values.

Ingredient	Basal diet
Corn 7.8 CP (%)	23.10
Soybean meal 46.5 CP (%)	13.00
White rice (%)	40.00
Soybean oil (%)	3.70
Premix[(1)]	20.00
Inert (%)	0.20
Total	100.00
Nutritional levels	
Crude protein (%)	17.86
Crude fat (%)	5.51
Crude fiber (%)	2.19
Metabolizable energy (kcal kg^{-1})	3,418.02
Total calcium (%)	0.80
Total phosphorus (%)	0.56
Available phosphorus (%)	0.44
Ileal digestible lysine (%)	1.27
Ileal digestible methionine (%)	0.26
Ileal digestible AAS (%)	0.51
Ileal digestible threonine (%)	0.84
Ileal digestible tryptophan (%)	0.24
Ileal digestible valine (%)	0.84
Ileal digestible arginine (%)	1.07
Ileal digestible isoleucine (%)	0.62
Ileal digestible leucine (%)	1.28
Phytase (U kg^{-1})	500.00
Synthetic vitamin A (KUI kg^{-1})	9.00
Synthetic vitamin D3 (KUI kg^{-1})	2.00
Synthetic vitamin E (UI kg^{-1})	54.01
Synthetic vitamin K3 (mg kg^{-1})	4.00
Synthetic thiamine (mg kg^{-1})	1.80
Synthetic riboflavin (mg kg^{-1})	5.00
Synthetic pyridoxidine (mg kg^{-1})	2.90
Synthetic cyanocobalamin (mcg kg^{-1})	30.00
Synthetic pantothenic acid (mcg kg^{-1})	21.00
Synthetic niacin (mg kg^{-1})	40.00
Synthetic folic acid (mg kg^{-1})	0.45
Synthetic biotin (mcg kg^{-1})	160.02
Total choline (mg kg^{-1})	632.04
Total sodium (mg kg^{-1})	0.25
Inorganic manganese (mg kg^{-1})	50.01
Inorganic zinc (mg kg^{-1})	97.01
Inorganic iron (mg kg^{-1})	100.01
Inorganic copper (mg kg^{-1})	150.00
Total iodine (mg kg^{-1})	1.00
Inorganic selenium (mg kg^{-1})	0.40
Enramycin (mg kg^{-1})	10.00

Composition: X-Soy 200 soybean protein concentrate 60% (Selecta, Goiânia, GO, Brazil) at 5.764%; Refinazil corn gluten meal 21% (Products Brasil LTDA, Mogi-Guaçu, SP, Brazil) at 10%; L-lysine powder HCl 99 to 0.7%; L-threonine 98.5% at 0.3%; L-tryptophan 98% at 0.062%; L-valine 98% at 0.111%; dicalcium phosphate 18.5% at 1.304%; calcitic limestone at 0.897%; white salt at 0.6%; Smizyme 5000PT phytase 0,12Pd(Beijing Smile Feed Sci. & Tech. Co., Ltd., Beijing, China) at 0.01%; copper sulfate 35% at 0.039%; Enramax enramycin 8% (Farmabase Saúde Animal, Jaguariúna, SP, Brasil) at 0.013%; 1.0 kg Mg^{-1} Px – Suíno initial vitamins for swine (Treomix: Nutrição Animal, Ariquemes, RO, Brazil) at 0.1%; and 1.0 kg Mg^{-1} Px – Suíno microminerals for swine (Treomix: Nutrição Animal, Ariquemes, RO, Brazil) at 0.1%.

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Animals and feed leftovers in the feeders were weighed at 0, 5, 12, 19, and 26 days of the trial on an anthropometric digital scale (Welmy, Santa Bárbara d'Oeste, SP, Brazil). In addition, the amount of feed supplied and feed waste were measured daily on a regular electronic scale. From these data, the following variables were calculated: average daily weight gain (ADG), considering the difference in piglet weight twice during the evaluated period; average daily feed intake (ADFI), through the difference between the supplied diet and leftovers in each experimental unit during the study period; and feed conversion rate (FCR) by the relation between the amount of feed provided and the weight gain during the evaluation period.

At the end of the trial, after a 12-hour fastening period, blood samples from one animal per experimental unit were collected using collection tubes with EDTA anticoagulant. The complete hemogram test was analyzed by the method of electrical impedance and colorimetry, performed automatedly by the BC-2800 Vet hematology analyzer (Mindray: Animal Care, Shenzhen, China). The percentage of hematocrit, hemoglobin rate in g dL^{-1}, absolute hematimetric indexes (mean corpuscular volume, hemoglobin, and hemoglobin concentration) were obtained. Global counts per uLs were carried out for erythrocytes, total leucocytes, and platelets, as well as counts for alkaline phosphatase, triglycerides, and red cell distribution width (RDW).

At the end of the experimental period, economic feasibility was analyzed considering the different sources and rates of choline, using the method of Alves et al. (2022) to calculate swine production costs. The cost variables analyzed were: feed, animal acquisition, other production costs, total cost, and cost per kilogram of piglets produced. The other production costs included: health and reproductive management costs; consumer goods used in production; labor; maintenance and depreciation; transportation and insurance; telephone and internet; energy and fuel; taxes, fees and remuneration on land use; capital; breeding; and animals in stock. The profitability variables analyzed were: total revenue, gross margin, economic profit, cost-benefit ratio, and return on investment.

Return on investment was also calculated for the use of each choline source and rate. All indicators were estimated according to data from a swine production cost index developed for June 2021 in São Paulo state, Brazil (Alves et al., 2021). The total production costs consisted of 52.8% animal acquisition, 36.3% feed, and 10.9% other production costs. To calculate the activity revenue, the average sale value of the animal was considered, as stipulated in the swine stock market of Associação Paulista dos Criadores de Suínos for June 2021 (Alves et al., 2021).

The data were analyzed for normality using the Shapiro-Wilk's test, and, when they did not present normal distribution, they were transformed using PROC RANK of the SAS software (SAS Institute Inc., Cary, NC, USA). All variables were subjected to the analysis of variance. When there was a statistical difference using the F-test at 5% probability, means were compared by Tukey's test, at a 95% confidence level. The data were analyzed using the statistical package of the SAS software (SAS Institute Inc., Cary, NC, USA).

Results and Discussion

The use of choline chloride and herbal choline resulted in positive effects for the variables body weight and ADFI under the C600 and CH300 treatments (Table 2). For ADG, the best result was observed with CH100. However, FCR was not affected by choline supplementation.

Although the amount of herbal choline added to the diet of the piglets was lower than that of choline chloride, the positive effects on animal performance were statistically equal for both forms, since the phosphatidylcholine in the herbal choline is more available for absorption, use, and metabolization in the piglet's organism (Farina et al., 2017). Therefore, herbal choline may be a potential substitute for choline chloride due to its optimal concentrations of phosphatidylcholine, which allows of using a smaller quantity of the product (Petrolli et al., 2021), leaving more free space for the addition of other nutrients and feed to the diet. Contrastingly, Farina et al. (2017) found that only about 25.4% of the choline chloride consists of chlorine molecules, which increases the demand for the synthetic source. At the end of the trial, the group of supplemented piglets had a higher ADG than those of the control (Table 2). For the C300 and C600 treatments, the daily increase in ADG was 83 and 105 g, respectively, whereas, for CH100 and CH200, it was 85 and 102 g compared with the control. Furthermore, in the supplemented groups, the high ADG stimulated a greater ADFI.

Regarding ADFI at the end of the trial, the piglets treated with C600 and CH200 showed an increase of 162 and 155 g, respectively, when compared with those of the control (Table 2). Animals with the highest possible ADFI are desirable due to the stressor factors during the nursery phase and the physiological effects of feed intake on the piglet health and intestinal maturity (Upadhaya & Kim, 2021).

A higher ADG, followed by a higher ADFI, evidences the effectiveness of choline its metabolized from methionine in improving animal performance leading to a better protein synthesis and body development, which results in heavier animals, as observed during the second trial period.

Table 2. Performance of nursery piglets according to diets with different sources and concentrations of choline(1).

Variable(3)	Treatment(2)				
	NC	C300	C600	CH100	CH200
Initial body weight (kg)	14.15	14.12	14.10	14.10	14.11
Body weight at 5 days (kg)	16.92	17.08	17.55	17.43	17.51
ADG at 0–5 days	0.556	0.593	0.693	0.668	0.681
ADFI at 0–5 days (kg)	0.894	0.895	0.983	0.940	0.995
FCR at 0–5 days	1.864	1.535	1.428	1.431	1.464
Body weight at 12 days (kg)	21.27b	22.24ab	22.57a	22.17ab	22.50a
ADG at 6–12 days (kg)	0.622	0.738	0.717	0.678	0.713
ADFI at 6–12 days (kg)	1.014b	1.127ab	1.156a	1.083ab	1.142a
FCR at 6–12 days	1.666	1.534	1.615	1.609	1.605
Body weight at 19 days (kg)	27.42b	28.66ab	29.05a	28.37ab	29.05a
ADG at 13–19 days (kg)	0.878	0.917	0.926	0.886	0.935
ADFI at 13–19 days (kg)	1.464	1.547	1.553	1.474	1.557
FCR at 13–19 days	1.701	1.705	1.691	1.672	1.665
Body weight at 26 days (kg)	34.20b	36.33a	36.88a	36.36a	36.80a
ADG at 20–26 days (kg)	0.970b	1.095ab	1.119ab	1.141a	1.108ab
ADFI at 20–26 days (kg)	1.573b	1.796ab	1.881a	1.870a	1.859a
FCR at 20–26 days	1.630	1.724	1.676	1.636	1.677
ADG at 0–26 days (kg)	0.771b	0.854a	0.876a	0.856a	0.873a
ADFI at 0–26 days (kg)	1.263b	1.376ab	1.425a	1.373ab	1.418a
FCR at 0–26 days	1.639	1.616	1.622	1.599	1.623

(1)Means followed by equal letters, in the rows, do not differ from each other by Tukey's test, at 5% probability. (2)NC, negative control, basal diet without choline supplementation; C300, basal diet with supplementation of 300 mg kg^{-1} choline via choline chloride; C600, basal diet with supplementation of 600 mg kg^{-1} choline via choline chloride; CH100, basal diet with supplementation of 100 mg kg^{-1} herbal choline; CH200, basal diet with supplementation of 200 mg kg^{-1} herbal choline. (3)ADG, average daily gain; ADFI, average daily feed intake; and FCR, feed conversion rate.

In the trial period from 6 to 19 days, the groups supplemented with C600 and CH200 showed a greater body weight than those of the control (Table 2). At 19 days, the difference in weight was 1.63 kg when compared to the animals in the NC group. Furthermore, at the end of the trial, all supplemented groups had greater body weight than the ones in the NC group, which were: 2.13 kg in the C300, 2.68 kg in the C600, 2.16 kg in the CH100, and 2.60 kg in the CH200.

FCR, as expected, was not affected by the different supplementation concentrations, since it represents the relationship between ADG and ADFI, which, throughout the study, showed a similar behavior (Table 2). For this same variable, Ribeiro et al. (2016) did not observe any effect of both forms of supplementation as they increased linearly the weight gain of the evaluated animals. However, unlike in the present study, these authors concluded that herbal choline had a greater positive effect on the daily weight gain of piglets.

Regarding choline supplementation, Qiu et al. (2021) reported positive effects on daily weight gain and body weight, suggesting a greater efficiency of the lipid metabolism in the supplemented groups. However, Ribeiro et al. (2016) and Qiu et al. (2021) did not observe any effects of choline supplementation on daily feed intake. In this line, Russett et al. (1979) found that choline supplementation had no significant effect on the ADG and FCR of pigs, contrasting with the results obtained here. Although, according to these authors, supplementation concentrations for piglets should not exceed 520 mg kg^{-1} choline, in the present study, 600 mg kg^{-1} choline via choline chloride had positive effects on animal body weight and daily weight gain (Table 2).

Blood analysis showed that the only variable significantly affected by the level and form of choline supplementation was RDW parameter (Table 3), which informs the heterogeneity of red blood cell size distribution from the degree of anisocytosis in the blood sample (Failace & Fernandes, 2015). Based on this result, RDW can be used to determine if an animal presents anemia, which is confirmed when values above the reference for RDW, from 16.4 to 32.2%, are obtained (Cooper et al., 2014).

McDowell (2008) found that choline nutritional deficiency can cause anemia in animals. However, in the present study, it is possible to conclude that the piglets did not present anemia since the value obtained for the group treated with C600 was 16.28% for RDW, slightly below the reference, the C600 group had the lowest means for RDW among the evaluated treatments.

As to costs with feed, the highest values obtained for groups CH200 and C600, whose piglets had the highest ADFI, about 13% higher than those of the control, due to the larger quantities of additives included, directly influencing feed cost (Table 4). Consequently, those groups presented the highest total cost averages, which increased in 4.30 and 4.16%, respectively, for the C600 and CH200 groups, when compared with the control.

The cost per kilogram of piglets produced was lower in all supplemented groups in relation to the control (Table 4), influencing directly animal body weight and ADG. Total revenue followed the same behavior of cost per kilogram of piglets produced, because it is directly related to animal body weight and the return on the sale of each kilogram produced.

As all supplemented groups presented a greater body weight and ADG at the end of the experiment in relation to the control, total revenue also showed higher values under choline supplementation, even though the total cost was higher in these treatments. Compared with the control, total revenue was 3.97, 5.00, 4.04, and 4.86% higher in the C300, C600, CH100, and CH200 groups, respectively.

The return on investment with choline supplementation presented the highest average for the CH100 group (Table 4), which may be related to the greater weight gain observed during the last experimental period that comprised the time interval with the highest ADG.

The obtained results are an indicative that the use of herbal choline as an alternative to choline chloride is an economically viable option, since there were no economic losses among the supplemented groups, nor damage to the return on investment. Despite the higher costs of supplemented groups, total income was higher than that of the control, showing choline supplementation had a positive economic result.

Table 3. Blood parameters of nursery piglets according to diets with different sources and concentrations of choline(1).

Variable(3)	Treatment(2)				
	NC	C300	C600	CH100	CH200
Alkaline phosphatase (U L^{-1})	301.88	291.63	265.00	281.75	254.25
Triglycerides (mg dL^{-1})	37.01	36.55	35.39	36.30	35.16
RBC (x10^6 μL^{-1})	6.55	6.60	6.31	6.61	6.68
Hemoglobin (g dL^{-1})	12.38	12.26	12.03	12.20	12.55
Hematocrit (%)	38.39	38.41	37.54	38.49	39.55
Mean corpuscular volume (fL)	58.61	58.24	59.53	58.35	59.25
MCH (pg)	18.91	18.59	19.07	18.50	18.81
MCH concentration (%)	32.26	31.93	32.05	31.70	31.74
Red cell distribution width (%)	16.93ab	17.05ab	16.28b	17.46a	17.11ab
Leucocytes (number per μL)	12550	13163	12650	12863	14450
Platelets (x10^3 μL^{-1})	376.12	479.13	425	443	477.75

(1)Means followed by equal letters, in the rows, do not differ from each other by Tukey's test, at 5% probability. (2)NC, negative control, basal diet without choline supplementation; C300, basal diet with supplementation of 300 mg kg^{-1} choline via choline chloride; C600, basal diet with supplementation of 600 mg kg^{-1} choline via choline chloride; CH100, basal diet with supplementation of 100 mg kg^{-1} herbal choline; CH200, basal diet with supplementation of 200 mg kg^{-1} herbal choline. (3)RBC, red blood cells, and MCH, mean corpuscular hemoglobin.

Table 4. Economic feasibility of the use of different sources and concentrations of choline in the diet of nursery piglets(1).

Variable(3)	Treatment(2)				
	NC	C300	C600	CH100	CH200
Feed cost (R$)	115.22b	125.66ab	130.32a	125.34ab	129.61a
Total cost (R$)	334.95b	345.07ab	349.36a	344.39ab	348.9a
Cost per kg (R$)	16.79a	15.58b	15.32b	15.4818b	15.36b
Total revenue (R$)	367.17b	381.77a	385.55a	382.03a	385.04a
Gross margin (R$)	69.75	74.22	73.71	75.16	73.65
Economic profit (R$)	32.23	36.70	36.19	37.65	36.14
Cost-benefit ratio	1.10	1.11	1.11	1.11	1.11
ROI (%)	9.99	10.93	10.81	11.37	10.89
ROI supplementation (%)	0.000c	9943.46ab	6122ab	16177a	9819.32ab

(1)Means followed by equal letters, in the rows, do not differ from each other by Tukey's test, at 5% probability. (2)NC, negative control, basal diet without choline supplementation; C300, basal diet with supplementation of 300 mg kg^{-1} choline via choline chloride; C600, basal diet with supplementation of 600 mg kg^{-1} choline via choline chloride; CH100, basal diet with supplementation of 100 mg kg^{-1} herbal choline; CH200, basal diet with supplementation of 200 mg kg^{-1} herbal choline. (3)Cost per kg, cost per kilogram of piglets produced; ROI, return on investment; and ROI supplementation, return on investment in relation to the supplementation.

Conclusions

1. Herbal choline supplementation increases the body weight and daily feed intake of nursery piglets.

2. Choline supplementation with 100 mg kg^{-1} herbal choline presents the greatest return on investment.

3. Herbal choline can be used as a source of choline supplementation in the diet of nursery piglets to replace choline chloride.

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