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ANIMAL PRODUCTION

Effects of encapsulated sodium butyrate and phytogenic on growth performance, carcass traits and health of growing-finishing pigs

Caio Abércio da Silva[1*] Ana Maria Bridi[1] Cleandro Pazinato Dias[2] Marco Aurélio Callegari[2] Ernani Caixeta Nunes[3] Carlos Rodolfo Pierozan[1] Luciana Foppa[1] David Vanni Jacob[4] Alessandra Luckmann Voorsluys[4] Alexandre José Ulbrich[4] Tim Goossens[4]

[1]Centro de Ciências Agrárias, Universidade Estadual de Londrina (UEL), 86.057-970, Londrina, PR, Brasil. E-mail: casilva@uel.br. [*]Corresponding author.
[2]Akei Animal Research, Fartura, SP, Brasil.
[3]Fazenda Lageado, Fartura, SP, Brasil.
[4]Adisseo Brasil Nutrição Animal Ltda., São Paulo, SP, Brasil.

ABSTRACT: *The aim of this study was to evaluate two feed additives, one based on encapsulated sodium butyrate (Adimix® Precision) (AD) and the other, a phytogenic (Apex® 5) (AX), associated or not with an antimicrobial growth promoter (tylosin) during the growth and finishing phases on performance, carcass characteristics and health conditions. A total of 300 barrows and females were distributed in six treatments in a randomized block design with ten replicates. The treatments consisted of a negative control (NC), positive control (PC) (tylosin), AD (encapsulated sodium butyrate), AX (phytogenic), PC+AD (tylosin+encapsulated sodium butyrate), and PC+AX (tylosin+phytogenic). The performance (live weight, daily feed intake, average daily gain and feed conversion) and carcass data (carcass weight, backfat thickness, loin depth, lean meat on the carcass) were submitted to ANOVA plus Tukey's test, and the health conditions (occurrence of diseases, culling, and spontaneous deaths) were analyzed by χ2. Animals of the AD group had the highest average daily gain (ADG) over the evaluation period and the highest live weight at 120, 140, and 164 days of age, in addition to the highest carcass weight compared to NC and PC groups. The AX treatment increased the ADG in growth phase II and the live weight at 120 and 140 days of age in relation to the NC. The PC+AX group had a higher final live weight compared to the NC and PC groups and higher carcass weight in relation to the NC group. There was no difference among treatments for backfat thickness, percentage of lean meat in the carcass, or occurrence of diseases and deaths. The inclusion of encapsulated sodium butyrate (AD treatment) was effective in increasing ADG, final live weight, and carcass weight compared to supplementation with tylosin (PC treatment), as was the inclusion of a phytogenic (AX treatment) on FC compared to the PC.*
Key words: *acidifiers, botanical product, essential oil, feed additive, plant extract.*

Efeitos do butirato de sódio encapsulado e fitogênico sobre o desempenho, características da carcaça e saúde de suínos em fase de crescimento e terminação

RESUMO: *O objetivo deste estudo foi avaliar dois aditivos alimentares, um a base de butirato de sódio encapsulado (Adimix® Precision) (AD) e outro a base de um fitogênico (Apex® 5) (AX), associados ou não a um antibiótico promotor de crescimento (tilosina), durante as fases de crescimento e terminação, sobre o desempenho, características da carcaça e status de saúde. Foram utilizados 300 suínos machos castrados e fêmeas distribuídos em seis tratamentos em um delineamento em blocos casualizados com dez repetições. Os tratamentos consistiram em um controle negativo (CN), controle positivo (CP) (tilosina), AD (butirato de sódio encapsulado), AX (fitogênico), CP+AD (tilosina+butirato de sódio encapsulado) e CP+AX (tilosina+fitogênico). Os dados de desempenho (peso vivo, consumo diário de ração, ganho de peso médio diário e conversão alimentar) e de carcaça (peso de carcaça, espessura de toucinho, profundidade do lombo e carne magra na carcaça) foram submetidos à ANOVA seguido por teste de Tukey, e os dados de condição de saúde (ocorrência de doenças, animais eutanasiados e mortos espontaneamente) foram analisados pelo teste de χ2. Os animais do grupo AD apresentaram maior ganho de peso diário (GPD) durante o período de avaliação e maior peso vivo aos 120, 140 e 164 dias de idade, além de maior peso de carcaça em comparação aos grupos CN e CP. O tratamento AX aumentou o GPD na fase crescimento II e o peso vivo aos 120 e 140 dias de idade em relação ao CN. O grupo CP+AX apresentou maior peso final em relação aos grupos CN e CP e maior peso de carcaça em relação ao CN. Não houve diferença entre os tratamentos para espessura de toucinho, porcentagem de carne magra na carcaça e ocorrência de doenças e óbitos. A inclusão de butirato de sódio encapsulado (tratamento AD) foi efetiva no aumento de GPD, peso final e peso de carcaça em comparação à suplementação com tilosina (tratamento CP), assim como a inclusão fitogênico (tratamento AX) melhorou a conversão alimentar em comparação ao grupo CP.*
Palavras-chave: *acidificantes, aditivo alimentar, extrato vegetal, óleo essencial, produto botânico.*

INTRODUCTION

For decades, the inclusion of sub-therapeutic doses of antibiotics in livestock farming has been used as an effective resource in improving the health, animal performance, and quality of products for human consumption (HASHEMI & DAVOODI, 2011). However, the detection of antibiotic

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residues in animal products and in the environment (RONQUILLO & HERNANDEZ, 2017), microbial antibiotic resistance (HUYGHEBAERT et al., 2011), and the possibility of transmission of this resistance to humans through the food chain (ZENG et al., 2015) have led to the banning of these antibiotics in several countries (KIM et al., 2016). Therefore, some additives, such as organic acids and phytogenics, which are alternatives to antimicrobial growth promoters (AGPs) (FRANZ et al., 2010; HASHEMI & DAVOODI, 2011; ZENG et al., 2015), have the same purposes, besides modulating the intestinal microbiota and improving health and animal performance (HUYGHEBAERT et al., 2011).

Butyrate is a salt of an acid (butyric acid), but the active ingredient itself is not an acid or acidifier (e.g., lowering the pH and direct antibacterial effects). Butyrate favors gene expression, cell differentiation, immune modulation, oxidative stress reduction, and diarrhea control (BEDFORD & GONG, 2018), supporting energy for the cells of the colon mucosa (LE GALL et al., 2009) and consequently promoting the development of the gastrointestinal mucosa (HUYGHEBAERT et al., 2011). In its free form as butyric acid, butyrate absorption occurs mostly in the upper portion of the gastrointestinal tract, limiting its actions in the large intestine (PITUCH et al., 2013). Nonetheless, butyrate is easily digested in the stomach and therefore it needs protection to reach the large intestine. Protecting sodium butyrate with a triglyceride matrix results in slower release of the principle in the lower gastrointestinal tract, favoring its action (BEDFORD & GONG, 2018).

In turn, phytogenics include products based on different active plant components, including cinnamaldehyde, eugenol, thymol, and carvacrol, which are digestive stimulants (FRANKIČ et al., 2009) and mainly modulate the intestinal microbiota (HASHEMI & DAVOODI, 2011). Some phytogenics may also improve food palatability, increasing feed intake and weight gain (ZENG et al., 2015) as well as stimulating endogenous secretion and acting as anthelmintics and coccidiostats (TAJODINI et al., 2015). Nevertheless, the improvement in nutrient digestibility also manifests as an indirect effect of eubiosis improvement on the diversity and population of the microbiota in the intestinal tract (HASHEMI & DAVOODI, 2011).

Most studies involving organic acids are about propionic, lactic, citric, and butyric acids and their corresponding salts (CHIOFALO et al., 2014), although the main challenge of these evaluations is the lack of consistency of positive results on animal performance (LE GALL et al., 2009; LIU et al., 2018). As for phytogenics, studies evaluating different levels and principles in the diets of growing and finishing pigs have shown benefits over performance, despite the difficulty of comparing their efficiency due to the wide variation of compositions employed (LIU et al., 2018).

In face of the demand for alternative products to AGPs and considering the need for more evaluations of the benefits of these additives, the aim of this study was to evaluate the inclusion of encapsulated sodium butyrate (Adimix® Precision) and a phytogenic (Apex® 5), associated or not with tylosin, on the performance, carcass characteristics, and health conditions of pigs in the growing and finishing phases.

MATERIALS AND METHODS

A total of 300 PIC (Camborough x Ag 337) pigs, being 150 barrows and 150 females, with an initial weight of 21.78 ± 2.45 kg and mean age of 63 days, were used. The animals were housed in a barn with 60 pens of 5.0 m² each equipped with a Dutch model feeder, nipple drinking through, and partially slatted floor. The temperature in the barn was regulated by curtain control. The experimental period comprised the growth and finishing phases (63 to 164 days of age). Animals were distributed into five blocks by initial body weight and by sex, with six treatments involving the use of additives, with ten replicates, being the pen the experimental unit.

The treatments, doses, and the period of use (Table 1) were defined by the use, combined or not, of three performance-enhancing additives, i.e. 30% encapsulated sodium butyrate (Adimix® Precision), a phytogenic composed of a blend of components from essential oils, mixed with dry herbs (Apex® 5)—a mixture of garlic oil (41%) and an essential oil component core (6%), with cinnamic aldehyde, thymol, carvacrol and eugenol—and a antimicrobial growth promoter (tylosin). The nutritional program had four phases: growth I (63–100 days of age), growth II (100–120 of age), finishing I (120–140 of age), and finishing II (140–164 of age) (Table 2). All diets were based on ground corn and soybean meal and were provided ad libitum throughout the experimental period.

Pen feed intake and live weight (LW) were recorded at the end of each production phase (at 100, 120, 140, and 164 days of average age). These values were used in the calculation of daily feed intake (DFI), average daily gain (ADG), and feed conversion (FC).

Table 1 – 16 Description of treatments, doses, and supplementation periods.

Treatment	---------------------------Inclusion of additive in the basal diet---------------------------	
	Growth I and II (63 to 120 days)	Finishing I and II (120 to 164 days)
NC	No inclusion	No inclusion
PC	22 ppm of tylosin	11 ppm of tylosin
AD	500 ppm of Adimix® Precision	250 ppm of Adimix® Precision
AX	150 ppm of Apex® 5	150 ppm of Apex® 5
PC+AD	22 ppm of tylosin + 500 ppm of Adimix® Precision	11 ppm of tylosin + 250 ppm of Adimix® Precision
PC+AX	22 ppm of tylosin + 150 ppm of Apex® 5	11 ppm of tylosin + 150 ppm of Apex® 5

NC = negative control; PC = positive control (tylosin; T-Grow®); AD = encapsulated sodium butyrate (Adimix® Precision); AX = phytogenic (Apex® 5).

The animals were slaughtered at an average age of 164 days and after being stunned by the three-point electron-accumulation method. The carcasses were submitted to electronic grading (Hennessy Grade Probe, Hennessy Grading Systems, Auckland, NZ) by measuring backfat thickness (BT) and Longissimus thoracis et lumborum depth (LD) at point P2 (59 mm lateral to the carcass dorsal line, immediately caudal to the last rib, left half carcass), according NPPC (1991). The carcasses were weighed (CW), and the values of percentage and content of lean meat in the carcass (LM) were obtained. The percentage of LM was calculated based on the equation proposed by the Hennessy Grading Systems (% LM = 61.33 - [0.76 x BT] + [0.1 x LD]), and the content of LM was calculated by multiplying the carcass weight by LM percentage.

The occurrence of diseases requiring therapeutic treatment, as well as the number of outliers that died spontaneously, were recorded daily throughout the experimental period. In the first two weeks of the study (63 to 77 days of age), fecal consistency was assessed individually, and feces were classified as normal, pasty, doughy fluid, and diarrhea (LIU et al., 2010). The score was calculated by dividing the number of days the animals had diarrhea by the total number of days evaluated.

Each pen with five animals of the same sex was an experimental unit for the growth performance parameters (LW, DFI, ADG, FC), whereas each individual animal was the experimental unit for carcass traits (CW, BT, LD, LM) and health. The growth performance and carcass data were submitted to ANOVA, and the means were compared by the Tukey's test using the statistical program R version 3.5.0. The occurrences of diarrhea and other conditions, as well as of dead and culled animals, were analyzed by $\chi 2$. For both tests, a P value of 0.05 was used as the significance threshold.

RESULTS

In growth phase I (63 to 100 days of age), no differences (P>0.05) were found among treatments for the parameters evaluated (Table 3). In growth phase II (100 to 120 days of age), no differences (P>0.05) were found among treatments for DFI. The animals of the negative control (NC) treatment had worse ADG (P<0.05) in relation to treatments of encapsulated sodium butyrate—Adimix® Precision (AD) and a positive control—tylosin plus phytogenic—Apex® 5 (PC+AX), but no differences (P>0.05) were seen between this treatment and PC, AX, or PC+AD. The LW at the end of the period (LW120) was higher (P<0.01) for pigs in groups AD, AX, and PC+AX compared to the NC treatment.

In finishing phase I (120 to 140 days of age), no difference (P>0.05) was found among the treatments for the parameters evaluated. In finishing phase II (140 to 164 days of age), the lowest ADG results were seen in treatments PC and NC, being significantly different (P<0.001) in relation to treatment AD. Furthermore, PC+AD and PC+AX treatments had better ADG (P<0.001) than NC treatment. The LW at the end of the period (LW164) was higher (P=0.05) for the pigs of the treatments AD and PC+AX compared to those of the treatments NC and PC. No differences (P>0.05) were seen among the treatments for DFI.

Considering the total period of the study (63 to 164 days of age), differences (P<0.05) were found for ADG among treatments, with the lowest

Table 2 - Ingredientsand calculated composition in the experimental diets.

	------Phases------			
	Growth I (63–100 days)	Growth II (100–120 days)	Finishing I (120–140 days)	Finishing II (140–164 days)
Ingredients (%)				
Corn	68.54	72.46	77.09	81.76
Soybean meal 45%	28.10	24.72	20.39	15.90
Dicalcium phosphate	1.14	0.93	0.86	0.79
Limestone	0.69	0.64	0.60	0.56
Soybean oil	0.58	0.27	0.02	0.00
L-lysine	0.12	0.15	0.20	0.24
DL-methionine	0.03	0.02	0.03	0.02
L-threonine	0.02	0.03	0.03	0.03
L-tryptophan	0.00	0.00	0.00	0.02
Vitamin premix[1]	0.10	0.10	0.10	0.08
Mineral premix[2]	0.10	0.10	0.10	0.10
Sodium chloride	0.38	0.38	0.38	0.38
Calcium aluminosilicate	0.15	0.15	0.15	0.15
Premix with products[3]	0.05	0.05	0.05	0.05
Total	100.00	100.00	100.00	100.00
------Calculated composition (%)------				
Metabolizable energy (MJ/kg)	3,209	3,212	3,215	3,230
Crude protein	18.35	17.16	15.60	14.00
Calcium	0.67	0.58	0.54	0.49
Total phosphorus	0.52	0.48	0.46	0.43
Available phosphorus	0.30	0.26	0.24	0.22
Sodium	0.19	0.19	0.18	0.19
Potassium	0.49	0.47	0.44	0.40
Total lysine	1.04	0.97	0.90	0.82
Digestible lysine	0.94	0.88	0.82	0.82
Total methionine	0.31	0.28	0.28	0.25
Digestible methionine	0.29	0.27	0.26	0.23
Total methionine + cystine	0.62	0.58	0.55	0.49
Digestible methionine + cystine	0.55	0.52	0.49	0.44
Total threonine	0.74	0.70	0.64	0.57
Digestible threonine	0.64	0.61	0.55	0.49
Total tryptophan	0.22	0.20	0.17	0.17
Digestible tryptophan	0.19	0.17	0.15	0.15
Total valine	0.87	0.81	0.74	0.62
Digestible valine	0.77	0.72	0.65	0.58

[1]Vitamin premix provided per kg of diet: 6,000 IU vitamin A; 1,500 IU vitamin D_3; 15 mg vitamin E; 1.5 mg vitamin K_3; 1.35 mg vitamin B_1; 4 mg vitamin B_2; 2 mg vitamin B_6; 20 µg vitamin B_{12}; 20 mg niacin; 9.35 mg pantothenic acid; 600 µg folic acid; 80 µg biotin; 300 µg Se.

[2]Mineral premix provided per kg of diet: 100 mg Fe; 10 mg Cu; 40 mg Mn; 1 mg Co; 100 mg Zn; 1.5 mg I.

[3]Caulim/Adimix® Precision/Apex® 5/tylosin.

Table 3 - Effect of encapsulated sodium butyrate and essential oils, alone or in combination with a growth-promoting antibiotic, on growth performance of growing-finishing pigs (n = 50/treatment).

Variable	---Treatment---						CV	*P*-value
	NC	PC	AD	AX	PC+AD	PC+AX		
---Growing I (63–100 days of age)---								
LW63 (kg)	21.72	21.63	21.95	21.96	21.70	21.77	7.82	0.720
DFI (kg)	1.61	1.58	1.56	1.59	1.64	1.62	6.67	0.621
ADG (kg)	0.77	0.77	0.80	0.80	0.80	0.80	10.32	0.081
FC (kg/kg)	2.09	2.07	1.97	2.05	2.08	2.02	6.33	0.311
LW100 (kg)	50.12	50.29	51.63	51.61	51.50	51.53	7.16	0.129
---Growing II (100–120 days of age)---								
DFI (kg)	2.18	2.29	2.41	2.27	2.33	2.29	8.15	0.178
ADG (kg)	0.93[b]	0.98[ab]	1.02[a]	1.00[ab]	0.98[ab]	1.03[a]	13.99	0.014
FC (kg/kg)	2.33	2.38	2.36	2.29	2.40	2.28	7.32	0.592
LW120 (kg)	68.79[b]	69.85[ab]	71.96[a]	71.67[a]	71.19[ab]	72.15[a]	7.31	0.009
---Finishing I (120–140 days of age)---								
DFI (kg)	2.68	2.72	2.71	2.72	2.65	2.73	10.28	0.986
ADG (kg)	1.08	1.07	1.08	1.05	1.06	1.05	13.78	0.449
FC (kg/kg)	2.56	2.57	2.50	2.50	2.51	2.50	8.94	0.948
LW140 (kg)	89.77	91.32	92.59	93.72	92.38	93.21	6.68	0.057
---Finishing II (140–164 days of age)---								
DFI (kg)	2.78	2.84	2.96	2.74	2.78	2.83	9.13	0.497
ADG (kg)	0.93[b]	0.90[c]	1.03[a]	0.95[abc]	0.99[ab]	0.99[ab]	13.55	0.000
FC (kg/kg)	3.02	3.26	3.00	2.91	2.98	2.93	10.20	0.165
LW164 (kg)	112.55[b]	112.79[b]	117.45[a]	115.20[ab]	115.55[ab]	116.31[a]	6.68	0.021
---Total period (63–164 days of age)---								
DFI (kg)	2.21	2.24	2.29	2.21	2.25	2.26	6.33	0.848
ADG (kg)	0.90[b]	0.91[b]	0.95[a]	0.92[ab]	0.93[ab]	0.94[a]	7.90	0.013
FC (kg/kg)	2.45[ab]	2.51[b]	2.40[ab]	2.38[a]	2.44[ab]	2.38[a]	4.17	0.047

NC = negative control; PC = positive control (tylosin; T-Grow®); AD = encapsulated sodium butyrate (Adimix® Precision); AX = phytogenic (Apex® 5); LW = live weight (the number on the side corresponds to the average age of the animals; 63, 100, 120, 140, and 164 days of age); DFI = daily feed intake; ADG = average daily gain; FC = feed conversion.

[a,b,c]Means within a row with different superscript letters significantly differ at P<0.05.

results being presented by treatments NC and PC in relation to treatments AD and PC+AX. The animals of treatments AX and PC+AD did not differ from the others (P>0.05). Considering each evaluation period separately, no differences (P>0.05) were found among treatments for FC, yet, over the total period (63 to 164 days of age), worse FC (P<0.05) was observed for the PC treatment in relation to AX and PC+AX. Treatments NC, AD, and PC+AD did not differ from the others (P>0.05).

A difference (P=0.001) was found in CW (Table 4) between the NC and PC treatments and the AD treatment, with advantages for the latter. Furthermore, the PC+AX treatment was better than the NC treatment (P=0.001). Treatments PC, AX, and PC+AD had intermediate results for this parameter, not differing among each other (P>0.05). The AD treatment resulted in an increase in CW by 4.86 kg (+6.01%) and 4.52 kg (+5.57%), respectively, compared to NC and PC. Furthermore, supplementation with PC+AX resulted in an increase by 3.78 kg (+4.68%) in CW compared to NC.

No differences were found among the treatments (P>0.05) for BT and LD. More LM (kg) was obtained (P<0.05) for animals from the AD and PC+AX treatments compared to animals from the

Table 4 - Effect of encapsulated sodium butyrate and essential oils, alone or in combination with a growth-promoting antibiotic, on carcass traits of growing-finishing pigs (n = 50/treatment).

Variable	Treatment						CV	*P*-value
	NC	PC	AD	AX	PC+AD	PC+AX		
CW (kg)	80.82[c]	81.16[bc]	85.68[a]	84.17[abc]	83.79[abc]	84.60[ab]	7.82	<0.001
BT (mm)	13.57	14.12	14.69	14.69	14.60	14.26	17.30	0.205
LD (mm)	66.03	63.28	64.84	64.43	64.43	65.32	9.40	0.375
LM (%)	57.62	56.93	56.65	56.60	56.68	57.03	3.45	0.124
LM (kg)	46.57[ab]	46.15[b]	48.50[a]	47.61[ab]	47.43[ab]	48.19[a]	7.56	0.014

NC = negative control; PC = positive control (tylosin; T-Grow®); AD = encapsulated sodium butyrate (Adimix® Precision); AX = phytogenic (Apex® 5); CW = carcass weight; BT = backfat thickness; LD = loin depth; LM = lean meat on the carcass.
[a,b,c]Means within a row with different superscript letters significantly differ at *P*<0.05.

PC treatment. The other treatments did not differ from each other. No differences were observed among treatments (P>0.05) for the occurrence and intensity of diarrhea, sanitary occurrences, or number of animals that were culled or died spontaneously (Table 5).

DISCUSSION

The absence of statistical differences among the treatments for daily feed intake (DFI) in all experimental phases shows that the additives did not show any benefit or compromised consumption, contradicting, in the case of essential oils, the improvement that such additives cause in DFI, as reported by ZENG et al. (2015).

The supplementation of diets with tylosin (positive control - PC) did not result any significant advantages in growth performance. Although tylosin is an antimicrobial growth promoter (AGP), others studies did not report significantly effective results when using tylosin. For example, the use of this growth promoter in pigs between 24–136 days of age at doses of 44, 22, and 11 mg/kg of feed for 21, 21, and 70 days, respectively (HOLMAN & CHÉNIER, 2013), as well as at doses of 40 mg/kg of feed for pigs aged 100–170 days (KIM et al., 2016), did not lead to improvements compared to the performance of the

Table 5 - Effect of encapsulated sodium butyrate and essential oils, alone or in combination with a growth-promoting antibiotic, on the occurrence of diseases requiring antibiotic therapy, number of animals culled, and spontaneous deaths of growing-finishing pigs (n = 50/treatment).

Occurrence	Treatment					
	NC	PC	AD	AX	PC+AD	PC+AX
Arthritis (n)	00	00	02	00	00	00
Encephalitis (n)	00	00	00	00	01	01
Pneumonia (n)	02	05	07	01	04	03
Diarrhea (n)	01	00	00	00	00	00
Culled (n)	00	01	03	03	02	02
Death (n)	01	01	03	01	01	01

NC = negative control; PC = positive control (tylosin; T-Grow®); AD = encapsulated sodium butyrate (Adimix® Precision); AX = phytogenic (Apex® 5).

control group with antibiotic-free animals. The action of tylosin as a growth promoter is attributed to the modulation of intestinal microbial composition, thus influencing metabolic activity (KIM et al., 2016). Nonetheless, according to HOLMAN & CHÉNIER (2013), when pigs are housed under low densities and under good health conditions, similar to the situation reported in this study, some antimicrobial growth promoters (AGPs), including tylosin, do not result in consistent actions on performance.

Although the benefits of sodium butyrate for performance and carcass characteristics are considered more evident when it is supplemented in the diet of young animals (BEDFORD & GONG, 2018), in this study, the use of encapsulated sodium butyrate (AD treatment) in the diet of growing and finishing pigs improved the animal performance (higher ADG, final live weight, and carcass weight). WALIA et al. (2016) evaluated finishing pigs and found that the use of sodium butyrate at a dose of 3,000 ppm for 24 and 28 days before slaughter resulted in improved ADG (respectively, +2.6 and +7.0%) and feed conversion (FC) (respectively, between -4.3 and -8.5%) compared to animals that did not receive supplementation. The better ADG could be attributed to increased digestibility of dietary nutrients and the bioavailability of amino acids, effects specific of the segment of the gastrointestinal tract in which the molecule acts (MOQUET et al., 2017). In addition, in the protected condition, butyrate release is greater in the lower portion of the gastrointestinal tract (BEDFORD & GONG, 2018), influencing intestinal quality.

Regarding the phytogenic treatment (AX), no significant improvement in ADG was observed with respect to the NC or PC treatments. Significant increases in ADG have been obtained with the supplementation of pig diets with phytogenic agents during lactation (7–35 days of age) (HANCZAKOWSKA & ŚWIĄTKIEWICZ, 2012), growth (YAN et al., 2011), and finishing phases (CHO et al., 2012). Although, in the finishing phase, the improvement in ADG (on average 5.8% higher) is not always significant (HANCZAKOWSKA et al., 2015). Nonetheless, in this study, live weight (LW) at 120 days of age was significantly higher for AX supplemented animals, besides the final LW being approximately 2.5 kg higher than in the NC and PC treatments. The composition of phytogenic used in our study mainly included garlic oil but also cinnamic aldehyde, thymol, carvacrol, and eugenol. It has been suggested that these components have many beneficial effects, such as antimicrobial activity (medium for carvacrol and thymol and strong for eugenol, cinnamaldehyde, and garlic—allicin) (ADAMS, 1999) and anti-inflammatory action (FRANKIČ et al., 2009). The reasons that different results are obtained between studies include differences in the quality of herbal components, inclusion of particular herbs, and forms of their administration (WINDISCH et al., 2008). The FC of the animals of the AX and PC+AX treatments were significantly better in relation to the PC treatment when considering the total period of the study. Treatments with phytogenic agents compared to NC treatments have generated considerable numerical improvements over the FC (-5.9% on average) (HANCZAKOWSKA et al., 2015) and some statistically significant improvements (HANCZAKOWSKA & ŚWIĄTKIEWICZ, 2012). However, there are studies that demonstrate variation in results of feed efficiency and dry matter, nitrogen, and energy digestibility with the use of this class of phytogenics (YAN et al., 2011; CHO et al., 2012), whose reasons may include variations in the housing conditions of the animals and in the species of plants used to compose the phytogenic agent (HANCZAKOWSKA et al., 2015), as well as differences in composition and nutritional contribution of the basal diets (CHO et al., 2012).

In this study, although not significant, the inclusion of phytogenics in the diets caused a 2.1% increase in the final LW compared to the PC treatment, which can be attributed to the significant improvement in FC in the total test period for the AX compared to the PC treatment. Such an effect may be due to the phytogenic benefits described above, since the product used has many components that are digestive stimulants (e.g. cinnamaldehyde, eugenol, thymol, and carvacrol) (FRANKIČ et al., 2009).

As for the association between AGP and their substitutes, the use of PC+AD in the diets, compared with the AD treatment, did not favor the performance of the animals. The use of PC+AX also provided similar results to those obtained with the exclusive use of AX. For PC+AX treatment, ADG improved during finishing phase II in relation to the PC treatment, and the final LW improved in comparison to the NC and PC treatments, which was not observed for the animals treated exclusively with AX.

The bactericidal, bacteriostatic, and modulatory action in the intestinal microbiota of acids and phytogenics is primary and therefore has positive effects on the animal (PARTANEN & MROZ, 1999; DAVIDSON & TAYLOR, 2007). When these additives were associated with tylosin, as previously noted, results were not potentialized. This condition may have been limited by the impairment of the intestinal microbiota due to the action of tylosin, which, under low doses, has a bacteriostatic action against Gram-positive bacteria (BARCELLOS et al., 2014). In addition, according to GAVIOLI et al. (2013), when tylosin is used in the diet of pigs in the growing and finishing phase, it results in higher shedding of the intestinal epithelium compared with diets containing pre- and probiotics, with worsening of the villous-to-crypt ratio.

According LI et al. (2018), organic acids are more effective than antibiotics as growth promoters on the cecum microbiota modulation, improving the production of short chain fatty acids, which represents an important energy source for enterocyte renewal (WILLIAMS et al., 2001).

It should also be considered that the evaluation was conducted under conditions of few health and environmental challenges, since the main requirements of the animals were preserved for the phases to which they were submitted. Such a situation fits under the considerations of BORATTO et al. (2004), who consider that the beneficial action of the AGPs is inversely related to animal health and environmental conditions of the farm. Under ideal hygienic-sanitary conditions, the effect of antibiotics is minimal.

The results of the treatments on hot carcass weight (CW) were similar to the one observed on final LW, with advantages observed for the animals of the AD treatment, which had higher CW in comparison to treatments NC and PC, and of the PC+AX treatment, with higher CW than the pigs in the NC treatment. Although advantages have been found for phytogenic agents over the control and antibiotic groups, ROSSI et al. (2013) observed that the CW of animals fed from weaning to finishing with the inclusion of these products were not different from the NC carcass weights without supplementation. The same was also observed in pigs fed 125 ppm and 500 ppm of a plant extract mixture containing thymol, carvacrol capsaicin, cinnamon aldehyde, eugenol, flavonoids, and essential oils (composition similar to the phytogenic of this study) from 20 to 100 kg LW (KORNIEWICZ et al., 2007).

In the same sense, treatments AD and PC+AX yielded higher amounts of lean meat in the carcass (represented in kg) compared to the carcasses of the NC animals, once again attributed to the higher final LW and CW of animals from both treatments with additives compared to NC. In relation to the percentage of lean meat in the carcass, no significant differences were seen among the treatments. While some studies have observed the absence of differences between treatments with and without phytogenic agents for carcass lean meat (KORNIEWICZ et al., 2007; HANCZAKOWSKA et al., 2015) and percentage of intramuscular fat (KOŁODZIEJ-SKALSKA et al., 2011), others have demonstrated advantages for the *Longissimus dorsi* muscle area (indirect indicator of the proportion of lean meat in the carcass) when pigs are supplemented with phytogenic compounds (KORNIEWICZ et al., 2007; YAN et al., 2010; CHO et al., 2012), a situation mostly attributed to the higher protein retention due to the improved digestibility provided by these additives (YAN et al., 2010).

No differences were observed in backfat thickness (BT) among the treatments, corroborating with HANCZAKOWSKA et al. (2014), who made use of sodium butyrate, and ROSSI et al. (2013) and KORNIEWICZ et al. (2007), who supplemented the diets of pigs with plant extracts. Heavier animals, influenced by the positive effects of treatments with sodium butyrate and a phytogenic, should have higher BT values; however, the large variation of this measure is inherent to this parameter, resulting in high coefficients of variation, which hinders the observation of differences among the treatments.

No differences in the occurrence of diseases and deaths were observed among the treatments. This may indicate that the use of the additives in the diets influenced the results (LIU et al., 2018). From a health point of view, butyrate is an important source of energy for epithelial cells of the large intestine (BEDFORD & GONG, 2018), maintaining high efficiency in epithelial development (GÁLFI & BOKORI, 1990). CHIOFALO et al. (2014) observed that piglets treated with two types of sodium butyrate, one in free form and the other encapsulated, during 45 days after weaning, presented occasional diarrhea and no deaths. In addition, for essential oil treatments, the benefits in intestinal mucosal integrity preservation, immune system stimulation, and antibacterial action (BRENES & ROURA, 2010) may justify the health status observed in this study, which would justify the best performance and carcass indexes obtained for this treatment.

The use of butyrate and phytogenic, without association with tylosin, showed an improvement in performance, carcass weight, and lean meat. According to Huyghebaert et al. (2011), alternative additives to AGPs should at least act in a similar manner to that of the antibiotic in use. Nevertheless, the results may vary in intensity given the dependence of some factors such as diet type and herd status (LIU et al., 2018).

CONCLUSION

The inclusion of encapsulated sodium butyrate (AD treatment) was effective in increasing ADG, final live weight, and carcass weight compared to supplementation with tylosin (PC treatment). The inclusion of phytogenic (AX treatment) improved FC compared to the PC. Supplementation of AD+PC and AX+PC had no positive effect on growth performance and carcass traits compared to inclusion AD or AX only.

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BIOETHICS AND BIOSSECURITY COMMITTEE APPROVAL

All procedures were previously approved by the Akei Animal Research Ethics Committee (protocol no. 04/2016).

DECLARATION OF CONFLICTS OF INTERESTS

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

The authors David Vanni Jacob, Alessandra Luckmann Voorsluys, Alexandre José Ulbrich, and Tim Goossens report their affiliation and involvement in Adisseo, an organization with interest in the subject matter and materials discussed in this manuscript.

AUTHORS' CONTRIBUTIONS

All authors contributed equally to the design and writing of the manuscript. All authors critically reviewed the manuscript and approved the final version.

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