Effects of feeding-phase duration and anticoccidial inclusion on growth and carcass traits of broilers

Efectos de la duración de la fase de alimentación y la inclusión de un anticoccidial sobre el crecimiento y características de la canal del pollo de engorde

Efeitos da duração da fase de alimentação e inclusão de anticoccidianos no crescimento e características de carcaça de frangos de corte

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To cite this article:
Restrepo-Rojas O, Múnera-Bedoya OD, Giraldo-Mejía AM, Quiñones-Segura L. Effects of feeding-phase duration and anticoccidial inclusion on growth and carcass traits of broilers. Rev Colomb Cienc Pecu 2024; 37(4):195–207. https://doi.org/10.17533/udea.rccp.v37n4a3

Abstract

Background: A typical broiler production program includes three feeding phases: Pre-starter (from day 1 to 10), Starter (11-21 days), and Grower (from day 22 to slaughter). The program should allow the bird to express its genetic potential and respond to the nutritional challenges. **Objective:** To determine the effect of duration of the starter and grower phases on growth performance parameters (feed intake and feed conversion), mortality, skin pigmentation, and carcass yield in broiler chickens. **Methods:** A total of 1,500 Ross 308 AP male broilers were randomly assigned to five feeding programs with different duration, feed presentation (pellet vs. crumble), and anticoccidial (narasin + nicarbazin vs. salynomicin). The variables evaluated were growth performance (body weight, feed intake, and feed conversion), carcass (weight and yield), breast weight and yield, and skin pigmentation. Statistical evaluations were conducted on d 28 and 40 of age. **Results:** On d 28 of age, differences ($p<0.05$) were observed for body weight and feed conversion, but not for feed intake. T4 and T5 resulted in the best weight and feed conversion. Differences ($p<0.05$) were recorded on d 40 for body weight, with higher values in T4 and T5 compared to T1. Carcass weight differed between T1 and T4 ($p<0.05$), without difference for carcass or breast performance. The statistical analyses of carcass pigmentation showed an effect on redness ("a") and yellowness ("b") at d 28. **Conclusions:** Body weight and feed conversion of broilers from d 22 to 28 improve by extending the starter phase one week, using pelleted feed added with an ionophore anticoccidial. Skin pigmentation of broilers at slaughter is not affected by restricting pigment intake for one week.

Keywords: *anticoccidial; broilers; carcass yield; carcass traits; feeding phases; feed restriction; growth performance; ionophores; skin color; skin pigmentation.*

Received: July 5, 2023. Accepted: February 15, 2024

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Resumen

Antecedentes: El programa típico de alimentación de pollos de engorde consta de tres etapas: pre-inicio (entre el día 1 y 10 de edad), inicio (día 11 al 21) y engorde (día 22 al sacrificio). El programa debe garantizar la máxima expresión del potencial genético del animal y responder a sus retos nutricionales. **Objetivo:** Determinar el efecto de cambiar la duración del inicio y engorde sobre los parámetros zootécnicos (consumo de alimento y conversión alimenticia) y mortalidad, pigmentación de piel y rendimiento de la canal en pollos de engorde de línea Ross 308 AP. **Métodos:** Se asignaron al azar cinco planes de alimentación a 1.500 pollos machos de la línea Ross 308 AP con variación en la duración de la etapa de alimentación, forma de presentación del alimento (peletizado vs. crombelizado) y programa anticoccidial (narasina + nicarbazina vs. salynomicina). Se aplicaron evaluaciones estadísticas para los días 28 y 40 de edad. **Resultados:** Se observaron diferencias estadísticas ($p<0.05$) para peso y conversión el día 28 de edad, pero no para el consumo de alimento. Los mejores pesos y conversiones se obtuvieron con los tratamientos 4 y 5. En el corte realizado el día 40 de edad solo se presentaron diferencias estadísticas ($p<0.05$) para peso corporal, siendo los tratamientos 4 y 5 superiores al tratamiento 1. En la evaluación de la canal solo hubo diferencia ($p<0.05$) para peso de la canal entre los tratamientos T1 y T4, sin diferencias en el rendimiento de la canal y de la pechuga. La pigmentación de la canal a los 28 y 40 días de edad mostró efecto sobre la variable “a” (rojo) y “b” (amarillo) al día 28. **Conclusiones:** El peso corporal y la conversión alimenticia del pollo de engorde mejora entre los días 22 al 28 al prolongar la fase inicial de alimentación durante una semana suministrando alimento peletizado con un ionóforo anticoccidial. La pigmentación de la piel del pollo al sacrificio no se ve afectada al restringir durante una semana el consumo de pigmento.

Palabras clave: *anticoccidial; características de la canal; color de la piel; desempeño zootécnico; fases de alimentación; ionóforos; pigmentación de la piel; pollos de engorde; rendimiento en canal; restricción alimenticia.*

Resumo

Antecedentes: O programa típico de alimentação de frangos de corte consiste em três etapas: pré-início (entre o dia 1 e 10 de idade), início (dia 11 ao 21) e engorda (dia 22 ao abate). É necessário garantir que os programas de alimentação permitam a expressão do potencial genético e respondam aos desafios nutricionais dos animais. **Objetivo:** Determinar o efeito das variações na duração das fases de iniciação e crescimento nos parâmetros de desempenho de consumo de ração, conversão alimentar e mortalidade, pigmentação da pele e rendimento de carcaça em frangos de corte da linha genética Ross 308 AP. **Métodos:** Cinco planos de alimentação foram aleatoriamente atribuídos a 1.500 frangos machos da linha Ross 308 AP, nos quais foram introduzidas variações na duração da fase de alimentação, apresentação do alimento (pellet vs. triturado) e mudança do programa anticoccidial (narasina + nicarbazina vs. salynomicina). As variáveis zootécnicas avaliadas foram (peso corporal, consumo da dieta e conversão alimentar), carcaça (peso e rendimento), peso e rendimento do peito e pigmentação da pele. As avaliações estatísticas foram aplicadas para os dias 28 e 40 de idade. **Resultados:** No dia 28 de idade, foram observadas diferenças estatísticas ($p<0.05$) para peso e conversão, mas não para consumo da dieta. Os melhores pesos e conversões foram obtidos com os tratamentos 4 e 5. No corte realizado no dia 40 de idade, apenas houve diferenças estatísticas; ($p<0.05$) para o peso corporal, sendo os tratamentos 4 e 5 superiores aos do tratamento 1. Na avaliação da carcaça, houve apenas diferença ($p<0.05$) para o peso da carcaça entre os tratamentos T1 e T4, sem diferenças no rendimento da carcaça e do peito. As análises estatísticas da pigmentação da carcaça dos frangos aos 28 e 40 dias de idade mostraram que houve apenas efeito sobre a variável “a” (vermelho) e “b” (amarelo) no corte dos 28 dias. **Conclusões:** O peso corporal e a conversão alimentar dos frangos de corte melhoraram entre os dias 22 e 28 (prolongando a fase inicial de alimentação em uma semana, como ocorreu neste estudo) ao fornecer ração peletizada com ionóforo. A pigmentação no abate da pele dos frangos não foi afetada pela restrição do consumo de pigmentos por uma semana.

Palavras-chave: *anticoccidiano; características da carcaça; cor da pele; desempenho de crescimento; fases de alimentação; frangos de corte; ionóforos; pigmentação da pele; rendimento da carcaça; restrição alimentar.*

Introduction

Feed represents about 70% of the total production costs of broiler chickens (Gómez, 2020; Alhotan, 2021). Phase-feeding programs are based on bird age to assign the nutrients required by broilers (Taheri *et al.*, 2020) and generate growth performance improvements such as weight gain and feed conversion ratio (Karan *et al.*, 2021). This allows to adjust the physical form of the feed and modify coccidia control programs as chickens grow.

Current poultry production systems use three or four feeding stages (Buteri *et al.,* 2009). According to Jaramillo (2020), three stages are commonly used in Colombia: pre-starter (from hatching to day 14), starter (up to day 22 of age), and grower (from day 23 to slaughter). At the commercial level, the most common feeding program includes three phases, with feed change on days 11 and 22 of age, respectively. The digestive tract of broiler chicks differs between one and two weeks of age (Khadour *et al.*, 2002). Thus, the first-phase diet should facilitate the enlargement of the gastrointestinal tract (including crop, esophagus, proventriculus, pancreas, gizzard, liver, and small intestine), which significantly develops during the first week after hatching (Mateos *et al.*, 2007). Coccidia control usually takes place between days 22 and 28 using feed additives such as chemical products and ionophores (Sumano and Gutierrez, 2010; De Gussem, 2007).

Several parameters allow monitoring the efficiency of chicken management and nutrition programs. Chicken mortality allows to evaluate the efficiency of feeding programs, including feed restriction in terms of metabolic problems, ascites, and sudden death syndrome (Quintana-Ospina *et al.*, 2023), especially at high-altitudes.

Acceptability of chicken meat is influenced by skin color in some Latin American countries (Mendoza *et al.*, 2020). Synthetic carotenoids are usually added in the finishing diets of intensive production systems to meet market demands (Meza *et al.*, 2018). These additives increase the final cost of the diet. Additionally, the effects of the pigment vary depending on the period of supplementation, impacting meat acceptance and its final price. The amount of pigment inclusion varies depending on the country, region, and company (Mendoza *et al.*, 2020).

Therefore, this study aimed to determine the effect of length of the starter and grower phases on feed intake, feed conversion, mortality, skin pigmentation, and carcass yield of Ross 308 AP broiler chickens.

Materials and Methods

Ethical considerations

The study received ethical approval from the Animal Care and Use Committee of Universidad Nacional de Colombia, Medellín Campus, by Statute 06-23 of January 26, 2023.

Location

The study was conducted at Avilandia Experimental Farm, located in Rionegro municipality (Antioquia province, Colombia), at 2,150 m.a.s.l and 17 °C average temperature.

Experimental design

A total of 1,500 one-day-old Ross 308 AP male chickens housed in floor pens were used. Five treatments were evaluated, with six random repetitions each, and 50 chickens per pen. A three-feeding phase regime was used (pre-starter, starter, and grower).

In the pre-starter phase (1-10 days), crumble feed with anticoccidial "c" was offered to all treatments. The starter phase (from days 11 to 28) was extended one week for treatments 2, 3, 4 and 5, and the same type of feed (Crumble) and anticoccidial "c" was provided until day 21. From days 22 to 28 a variation was introduced in terms of feed presentation (Crumble vs. 3 mm Pellet) and anticoccidial ("c" vs. "d"). Lastly, during the grower phase (from days 29 to 40) the same type of food (Pellet, 3 mm) was provided with anticoccidial "d". Table 1 shows the evaluated treatments.

https://doi.org/10.17533/udea.rccp.v37n4a3

Table 1. Treatment groups evaluated between days 22 to 28 of age.

Treatment	Feeding phase	Feed presentation	Anticoccidial
T1	Grower	Pellet*	d
T2	Starter	Crumble	c
T3	Starter	Pellet*	c
T4	Starter	Crumble	d
T5	Starter	Pellet*	d

*3-mm pellets. T1: grower feed between days 22 and 28 of age provided in pellet with an ionophore anticoccidial; T2: starter feed between days 22 and 28 of age provided in crumble with a chemical anticoccidial + ionophore; T3: starter feed between days 22 and 28 of age provided in pellet with a chemical anticoccidial + ionophore; T4: starter feed between days 22 and 28 of age provided in crumble with an ionophore anticoccidial; T5: starter feed between days 22 and 28 of age provided in pellet with an ionophore anticoccidial.
Crumble: feed made by crushing 3-mm pellets.
c: a combination of 40 ppm of an ionophore antibiotic (narasin) and 40 ppm of nicarbazin (complex of 4.4 dinitrocarbanilida and 2hidroxi 4.6 dimetilpirimidina); d: salynomicin (60ppm) ionophore compound.

Diets for each phase and treatment were calculated following the nutritional requirements for the Ross 308 line, according to Aviagen (2019) genetic guide. The A-Systems' feed formulation software Allix[3] ©2021 was used (Alix, 2021). For the evaluation of skin pigmentation, a commercial pigment based on natural products was formulated for the grower phase (0.2% inclusion of xanthophyll at 93%). The diets are presented in Table 2.

Growth performance parameters

On the day of chick placement, birds were randomly distributed into 30 pens. Birds were daily fed according to the feeding chart (offer) of the farm (Table 3) and depending on the number of chicks in each pen.

All birds in each pen were weighed, and weight gain, feed conversion ratio, and mortality were calculated on days 10, 21, 28, and 40. The following expressions were used to calculate performance parameters:

$$weight\ gain = final\ weight - initial\ weight$$

Feed conversion ratio:

$$Conversion = \frac{feed\ offered(g) - feed\ rejected}{weight\ gain(g)}$$

Mortality:

$$Mortality(\%) = \frac{final\ broilers}{initial\ broilers} * 100$$

Carcass evaluation was performed with samples taken on d 40 by randomly selecting three broilers per replicate for a total of 18 chickens per treatment. Before slaughter, chickens had an eight-hour fasting period. Birds were slaughtered by cervical dislocation (Espinoza, 2017). Information related to live weight, carcass and breast weights were recorded, then used to calculate carcass yield and percentage of breast against live weight and carcass weight, using the following expressions:

$$Carcass\ yield: \frac{carcass\ weight}{live\ weight}$$

$$Breastyield: \frac{breast\ weight}{carcass\ weight}$$

Breast skin pigmentation was evaluated on 18 chickens per treatment on days 28 and 40, and determined by reflectance colorimetry (Minolta, 1991) using a Minolta CR-300 Chromameter (Minolta Camera Co., Ltd., Osaka, Japan), which uses the CIEL, a, b color system, corresponding to the measurements of luminosity “L”, redness “a” and yellowness “b”.

Statistical analysis

The statistical package R v. 4.1.3 was used (R Core Team, 2022), with the following libraries: Tidyverse (Wickham *et al.*, 2019), Lme4 (Bates *et al.*, 2015), FactoMineR (Husson *et al.*, 2010) and Car (Fox & Weisberg, 2018).

Analysis of variance (ANOVA) was carried out, with means compared by Tukey’s test with significance level at $p<0.05$ to evaluate growth performance variables (weight, feed intake, and feed conversion ratio), carcass weight and yield, breast weight and yield, and skin pigmentation,

The evaluation models for the analyzed variables are presented below.

For growth performance variables, a mixed linear model for measures repeated in time was used. The model was:

$$y\_ijk=\beta\_i+\omega\_j+(\beta\omega)\_ij+b\_k+\epsilon\_ijk$$

Where:

y_ijk: Dependent variable (weight, gain, conversion).

β_i: Effect of the *i-nth* treatment, with $i=1,2,3,4,5$.

ω_j: Effect of the j-nth phase, with $j=1,2,3,4,5$.

$(\beta\omega)\_ij$: Interaction effect between the *i-nth* treatment and the *j-nth* phase.

b_k: Random effect.

ϵ_ijk: Random error, with $\epsilon\_ijk\sim N(\mu=0.\sigma^2=1)$.

Model for carcass weight and breast yield:

$$y\_ij=\beta\_i+b\_j+\epsilon\_ij$$

Where:

y_ij: Dependent variable (carcass weight or breast yield).

β_i: Effect of the i-nth treatment, with $i=1,2,3,4,5$.

b_j: Random effect.

ϵ_ij: Random error, with $\epsilon\_ij\sim N(\mu=0.\sigma^2=1)$.

For carcass yield:

$$y\_ij=\beta\_i+b\_j+\epsilon\_ij$$

Where:

y_ij: Dependent variable (carcass yield).

β_i: Effect of the i-nth treatment, with $i=1,2,3,4,5$.

b_j: Random effect.

ϵ_ij: Random error, with $\epsilon\_ij\sim N(\mu=0.\sigma^2=1)$.

For breast weight:

$$y\_ijk=\beta\_i+b\_j+c\_k+\epsilon\_ijk$$

Where:

y_ijk: Dependent variable (breast weight).

β_i: Effect of the i-nth treatment, with $i=1,2,3,4,5$.

b_j: Random effect individual live weight.

c_k: Random effect individual carcass weight.

ϵ_ijk: Random error, with $\epsilon\_ijk\sim N(\mu=0.\sigma^2=1)$.

An analysis of variance (ANOVA) was carried out for skin pigmentation, with means compared with a significance level of $p< 0.05$).

Results

Growth performance

No differences were observed ($p>0.05$) for body weight, feed intake, and feed conversion until day 21. The average bird weight at placement was 41.27 g. By the end of the pre-starter phase (d 10), the average weight was 225.8 g, feed intake was 203.84 g/bird, and feed conversion was1.11. On d 21, body weight, feed intake and conversion were 826.84, 757.88, and 1.26 g, respectively.

On day 28, differences ($p<0.05$) were observed between treatments for body weight and conversion, but not for diet intake. Treatment 1 resulted in the lowest performance for weight gain and feed conversion, presenting differences ($p<0.05$) with respect to T2, T4 and T5.

The best weight gain was obtained with T5 (1,496.57 g), being different ($p<0.05$) from treatments 1, 2 and 3. The best feed conversion was obtained with treatment T5 (1.34), being different ($p<0.05$) from treatments 1, 2, 3 and 4. Changes in phase duration with the same feed presentation and the same anticoccidial showed differences ($p<0.05$) for weight gain and feed conversion in favor of T5 when compared to T1.

Table 2. Centesimal and nutritional composition of the experimental diets.

Ingredient	Pre-starter phase	Starter phase	Grower phase
	Centesimal composition		
Yellow corn	53.75	57.26	64.17
Soybean meal	28.00	19.80	16.00
Soybean	7.80	12.00	7.20
Corn gluten	3.60	4.00	5.00
Tallow	-	-	2.50
Meat and bone meal (45% crude protein)	1.70	2.30	2.60
Available phosphorus	1.61	1.18	
Palm oil	1.50	1.50	
Vitamin-mineral premix*	0.45	0.45	0.45
Calcium carbonate	0.40	0.38	0.67
Lysine, 98.5%	0.32	0.30	0.34
Methionine, solid 99%	0.32	0.27	0.24
Sodium chloride	0.17	0.17	0.14
Threonine, 98%	0.14	0.10	0.09
Anti-fungal	0.10	0.10	0.10
Choline chloride, liquid 75%	0.08	0.08	0.09
Sodium sesquicarbonate	0.05	0.11	0.25
Valine, 99%	0.02		
Xanthophyll, 93%			0.20
L-arginine, 98.5%			0.03
Propionic acid			0.03
Fractions	**Nutritional composition** (values expressed in the diet)		
Crude protein	23.00	21.50	19.10
Gross fat	5.90	6.90	6.80
Ash	5.90	5.40	4.40
Crude fiber	2.20	2.30	2.20
ME (kcal/kg feed)	3,000	3,100	3,200

*Vitamin and mineral premix: Vitamin A and/or AD, D and/or AD, E, K, B1, B2, B6, B12, biotin, folic acid, niacin and/or niacinamide, calcium pantothenate, iron and copper sulfates, zinc sulfate and/or zinc oxide, manganese sulfate and/or manganese oxide, potassium iodide and/or EDDI and/or potassium iodate, sodium selenite, choline chloride and/or biocholine, nicarbazin and/or narasin and/or salinomycin sodium and/or monensin sodium and/or lasalocid sodium and/or maduramicin and/or semduramicin and/or clopidol, virginiamycin and/or flavofosfolipol and/or halquinol and/or zinc bacitracin and/or avilamycin and/or enramycin, antioxidant BHT; excipients: calcium carbonate and/or rice husk and/or mineral oil. ME: Metabolizable energy. Except for ME, chemical fractions are expressed in g/100 g of feed.

When evaluating the anticoccidial effect (T3 with a chemical anticoccidial + ionophore vs T5 with ionophore anticoccidial) in diets with the same composition (Starter) and Pellet presentation (3 mm) differences ($p<0.05$) were found in favor of the ionophore anticoccidial (T5) for weight gain and feed conversion. Statistical differences between anticoccidials within the starter phase with crumble feed (T2 vs T4) were not observed (Table 4). Treatment 1 showed the lowest performance in weight gain and feed conversion, presenting differences ($p<0.05$) with T2, T4 and T5.

Regarding body weight on d 40 of age, differences ($p<0.05$) were observed between treatment 1 and

https://doi.org/10.17533/udea.rccp.v37n4a3

treatments 4 and 5, and between treatments 2 and 5. In relation to feed intake and conversion, no differences were observed (p>0.05; Table 5).

Mortality at the end of the experiment was 3.06%, with no difference (p<0.05) between treatments.

Values observed for carcass and breast weight, and carcass and breast yield are reported in Table 6.

For carcass weight, differences (p<0.05) were only observed between T1 and T4, favoring the latter.

Results for carcass and breast yield showed no effect of the feeding programs (Table 7).

Table 8 summarizes the results of carcass pigmentation of broilers on d 28 and 40. On d 28 of age, variables "a" (red) and "b" (yellow) were affected by treatments.

Table 3. Feeding chart (feed offer) used in the experimental farm (g/day).

Week	Day							Total (g/week)
	1	2	3	4	5	6	7	
1	8	10	12	16	16	20	23	105
2	27	33	36	40	45	52	57	290
3	62	66	72	84	89	95	95	563
4	104	110	118	125	133	140	145	875
5	151	157	162	168	168	173	180	1,159
6	185	190	195	200	205			975
Total								**3,967**

Table 4. Growth performance of broilers on d 28 of age under different feeding programs.

Treatment	Body weight (g)		Feed intake (g)	Feed conversion	
	Mean	SEM	Mean	Mean	SEM
T1	1,441[a]		876	1.47[d]	
T2	1,464[bc]		876	1.41[bc]	
T3	1,458[ab]	4.95	877	1.43[cd]	0.01
T4	1,481[cd]		878	1.39[b]	
T5	1,496[d]		876	1.34[a]	
p-value	1.19-e[05]			1.52-e[06]	

Means with different superscript letters (a, b, c, d) within columns indicate statistical differences (p<0.05). SEM: Standard error of the mean.

Table 5. Growth performance of broilers on d 40 of age under different feeding plans.

Treatment	Body weight (g)		Feed intake (g)	Feed conversion	
	Mean	SEM	Mean	Mean	SEM
T1	2,765[a]		2,180	1.75	
T2	2,776[ab]		2,153	1.72	
T3	2,780[abc]	6.89	2,169	1.74	0.01
T4	2,804[bc]		2,148	1.69	
T5	2,805[c]		2,184	1.78	
p-value	1.19-e[05]			1.52-e[06]	

Means with different superscript letters (a, b, c) within columns indicate statistical differences (p<0.05). SEM: Standard error of the mean.

Table 6. Carcass and breast weight of broiler chickens under different feeding programs.

Treatment	Carcass weight (g)		Breast weight (g)	
	Mean	SEM	Mean	SEM
T1	1,917[a]	10.3	673	6.82
T2	1,918[ab]	11.4	679	6.87
T3	1,934[ab]	10.0	686	6.87
T4	1,957[b]	11.1	699	6.99
T5	1,946[ab]	10.0	698	6.72
p-value	0.02		2.68-e^{02}	

Means with different superscript letters ([a, b]) within columns indicate statistical difference (p<0.05). SEM: Standard error of the mean.

Table 7. Carcass and breast yield of broiler chickens under different feeding programs.

Treatment	Carcass yield (%)		Breast yield (%)	Feed conversion	
	Mean	SEM	Mean	SEM	SEM
T1	69		35	1.75	
T2	69		0.00362	35	
T3	69	0.00359	0.00357	35	0.00347
T4	68		0.00364	36	
T5	69		0.00357	36	
p-value	0.99			0.69	

SEM: Standard error of the mean.

Table 8. Breast skin pigmentation of broiler chickens under different feeding programs on d 28 and 40 of age.

Treatment	Age	*a*		*b*		*L*	
		Mean	SEM	Mean	SEM	Mean	SEM
T1		1.32[a]		12.54[c]		63.67	
T2		2.35[b]		7.31[b]		64.56	
T3	28	2.25[b]	0.21	5.80[ab]	0.54	64.17	0.47
T4		2.51[b]		4.41[a]		63.78	
T5		2.36[b]		6.04ab		64.50	
p-value		0.00094		1.02-e^{16}		0.57	
T1		-2.19	0.38	26.22	0.12	64.74	0.87
T2		-1.91	0.39	25.85	0.16	65.15	0.89
T3	40	-1.70	0.38	24.40	0.12	63.65	0.87
T4		-1.32	0.39	25.51	0.16	64.15	0.89
T5		-1.62	0.39	23.84	0.16	64.02	0.89
p-value		0.57		0.54		0.76	

Means with different superscript letters ([a, b, c]) within columns indicate statistical difference (p<0.05). SEM: Standard error of the mean. a: redness; b: yellowness; L: luminosity.

Discussion

Growth performance parameters from days 1 to21

Values for weight and feed intake during the pre-starter phase were lower than those suggested by the feeding guide of Ross 308 AP genetic line (Aviagen, 2019), with differences of 28 and 30%, respectively. However, body weights on d 10 were higher than those reported by Akinsola *et al.* (2021), who found similar weights to ours in Arbor Acre broilers subjected to feed restriction programs at four days later (on day 14). At the end of the starter phase, on d 21, the difference in feed intake and body weight was 14 and 16% lower compared to the guide. For body weight, the values were higher than those reported by Somaia (2019) who found 650 g for broilers without restriction, and 530 and 431g for 90 and 70% restrictions, respectively.

Dereser (2015) reported that bird weight can be low compared with the standards established in the genetic line guides during the first weeks of life; however, when feed is provided in pelleted form, these values can increase between weeks five and six (Rodriguez, 2022). In the present study, the values obtained for body weight and feed intake during the first three weeks of life are the result of the feed restriction program proposed by the farm, which aims to reduce the ascites syndrome as suggested by López (2012).

Growth performance parameters from days 22 to 28

Compared to the feeding guide of the AP genetic line (Aviagen, 2019), the values in the present study expected at d 28 were lower; for instance, there was a difference of 76 g for feed intake (average of treatments) and of 168 and 223 g in body weight for treatments T5 and T1, respectively.

For body weight and feed conversion, there were differences ($p<0.05$) between T1 and T5, favoring the latter. The feed conversion expected according to the guide is 1.29, while the values obtained in this study ranged from 1.34 (T5) to 1.47 (T1). Villar (2019) reported values ranging from 1.40 to 1.48 for feed conversion of Ross 308 AP broilers working with different feeding tables.

The treatment pairs comparisons (T2 vs T3) and (T4 vs T5) did not show differences ($p<0.05$), indicating that feed presentation (crumble vs. pellet) did not influence performance parameters. This result differs from the findings of Valencia *et al.* (2011), who argued that crumble feed improves broiler productivity considerably after d 21; they found statistical differences between pelleted and crumbled feed for body weight and feed conversion, among other variables, although no differences were found on d 41 for those variables. Other researchers, such as Massuquetto *et al.* (2020) and Lv *et al.* (2015), suggested that pelleted diets promote better broiler performance because of increased feed intake, which is associated with shorter consumption time, reduced feed waste, and lower energy expenditure when compared to a mash or crumble diet.

The ionophore anticoccidial in the 3 mm pellet diet (T5) showed better performance in terms of weight and feed conversion when compared to the combination of a chemical product plus an ionophore (T3). This result contrasts when performing the same comparison in crumble diets (T2 vs T4), since there was no difference ($p<0.05$) between anticoccidials. The differences observed in favor of the ionophore anticoccidial (T3 vs T5) contrast with the findings reported by Moyano (2012), who did not observe any differences when comparing diets with four different chemical and ionophore anticoccidial drugs in broilers that reached an average weight of 1,100 g at d 28 of age. Ionophore anticoccidials, such as salinomycin have been widely studied. They control avian coccidiosis and improve weight gain and feed conversion (Conway *et al.*, 1993). For treatments using ionophore from d 22 to 28 (T1, T4, T5), the lowest weight was 1,441 g, corresponding to T1. This weight is similar to that reported by Oñate *et al.* (2018) who found 1,443 and 1,413 g for chickens supplemented with salinomycin versus a natural anticoccidial based on hot pepper (*Capsicum minimum*), respectively. Zavala (2017) reported weights of 1,408 g and 2,650 g on d 28 and 42, respectively, when evaluating performance of Cobb 500 broilers using a combination of a chemical anticoccidial with an ionophore (nicarbazin and salinomycin) during the whole production cycle; it is worth noting that those values were lower than the ones found in the present study with similar feed intakes.

Growth performance parameters from days 29 to 40

The high weights observed in treatments T4 and T5 vs T1 (ionophore anticoccidial) were due to the prolongation of the starter phase for one more week, until day 28 (T4 and T5), which suggests the convenience of using the ionophore anticoccidial from day 22 until the grower phase. Implementing this adjustment in the nutritional program would imply a starter feed with the grower anticoccidial ionophore to be supplied from day 22, which could be interpreted as a new feeding phase, increasing the number of feed references. Buteri *et al.* (2009) recommended the inclusion of a fourth feeding phase, deviating from the three-phase program currently used in Colombia. This additional phase may be used to adjust the nutritional and anticoccidial programs to respond to broiler requirements for this period. Multiphase feeding programs are known to provide adequate nutrients according to the physiological needs of birds as they grow (Tikate *et al.*, 2021); however, its implementation generates difficulties in managing feed inventory and references for the industry and farmers.

In this study, the average carcass weight recorded on d 40 of age was 1,938 g, which is higher than that observed by Haščík *et al.* (2021) and Moses *et al.* (2022), who reported 1,588 g for broilers of the same sex, age and genetic line.

Carcass performance

According to recommendations for the Ross 308 AP line, males with final weights from 2,600 to 2,800 g should have breast weights ranging from 658 g to 720 g (Aviagen, 2019). The values obtained in the present study fall within that range and that of Moses *et al.* (2022), with breast weights from 614.9 to 741.15 g, but are higher than those found by Haščík *et al.* (2021), who reported values ranging from 471.31 to 557.63 g in 40-days-old broilers of the same sex and genetic line.

The modifications proposed in the present study did not affect either breast weight or carcass yield; furthermore, the results showed lower values than those recommended by the Ross 308 AP guide, which establishes yields ranging from 73.96 to 74.36%. Moses *et al.* (2022) reported similar values, with yields ranging from 73.3 to 76.2% for 40-days-old males. The value obtained in this study was approximately 68.9%, which is similar to that reported by Martínez & Valdivié (2021) for 35-days-old Ross 308 broilers.

Skin pigmentation

A pigmentation difference was observed on d 28 of age ($p<0.05$), with values for T1 lower for redness and higher for yellowness. This was possibly a result of diet T1 including pigment from d 22 of age, while the other treatments remained with the starter feed without the additive. Changes in redness decreased between 22 and 40 d of age, with values from 2.16 to -1.75, while yellowness increased from 7.22 to 25.16. Pérez *et al.* (2021) obtained similar yellowness values (between 9.31 and 25.64) in broilers supplemented with xanthophylls on d 42, while redness ranged from 0.66 to 1.88, which are higher than the values obtained in the present study. Regarding luminosity on d 28 and 40 of age, our results are similar to those of Pérez *et al.* (2001), who reported values ranging from 66.95 to 69.06.

The evaluation of pigmentation on d 40 showed no differences for the studied variables. This suggests that including the pigment from d 28 offers similar results to those observed in broilers that received it from d 22, which can impact formulation costs. These results agree with the values reported by Pérez *et al.* (2001) in broilers supplemented with pigments from d 22, which showed similar yellowness and luminosity values; consequently, better consumer acceptance of the final product is expected, which translates into better income for the producer or fewer penalties for low pigmentation. Regarding mortality, it is a normal percentage for the farm conditions (3.06%) which historically ranges between 3 and 4.5%.

In conclusion, body weight and feed conversion of Ross 308 AP broiler chickens improves from d 22 to 28 when extending the feeding starter phase for one week and feed is provided in pellet with an ionophore anticoccidial. Skin pigmentation is not affected by restricting pigment intake for one week.

Declarations

Funding

The work was fully funded by the SOLLA S.A. feed company.

Conflicts of interest

The authors declare they have no conflicts of interest regarding the work presented in this report.

Author contributions

Oliver Restrepo conducted most of the experimental work to obtain his Master´s degree in agricultural sciences. Oscar D Múnera Bedoya advised on the development of the experiment and revised the manuscript. Angel M Giraldo-Mejía, thesis director of Oliver Restrepo, revised the manuscript. Libardo Quiñonez Segura advised on the development of the experiment.

Use of artificial intelligence (AI)

No AI or AI-assisted technologies were used during the preparation of this work.

References

Abdollahi MR, Ravindran V, Svihus B. Influence of grain type and feed form on performance, apparent metabolizable energy and ileal digestibility of nitrogen, starch, fat, calcium, and phosphorus in broiler starters. J Food Sci Technol 2013; 186(3–4):193–203. https://doi.org/10.1016/j.anifeedsci.2013.10.015

Akinsola KL, Olawumi SO, Abiloro OB, Obasi EN, Nathaniel J. Effects of strain and skip a day feed restriction on growth characteristics of broiler chickens. Nig J Anim Prod 2021; 48(3):122–133. https://doi.org/10.51791/njap.v48i3.2953

Alix (2021). SoftwareAllix³ ©2021 A-Systems. URL: https://www.a-systems.com/es/solutions-et-services-2/logiciels/allix/

Alhotan RA. Commercial poultry feed formulation: current status, challenges, and future expectations. World Poultry Sci J 2021; 77(2):279–299. https://doi.org/10.1080/00439339.2021.1891400

Alkhair SM. The effect of physical feed restriction during the starter period on broilers performance. Int J Livest Prod 2019; 10(1):1–8. https://doi.org/10.5897/IJLP2018.0523

Aviagen NL. Ross 308/Ross 308 FF Broiler: Performance Objectives 2014.

Bates D, Maechler M, Bolker B, Walker S. Fitting linear mixed-effects models using lme4. J Stat Softw, 2015, vol. 67, no 1, p. 1–48.

Broiler R. Nutrition Specifications 2019. Aviagen: Huntsville, AL, USA.

Buteri CB, Tavernari FDC, Lelis GR, Rostagno HS, Albino LFT. Effects of different nutritional plans on broiler performance. Braz J Poult Sci 2009; 11:225–234. https://doi.org/10.1590/S1516-635X2009000400003

Conway DP, Johnson JK, Guyonnet V, Long PL, Smothers CD. Efficacy of semduramicin and salinomycin against different stages of *Eimeria* tenella and *E. acervulina* in the chicken. Vet Parasitol 1993; 45(3–4):215–229. https://doi.org/10.1016/0304-4017(93)90077-Z

De Gussem M. Coccidiosis in poultry: review on diagnosis, control, prevention and interaction with overall gut health. In Proceedings of the 16th European Symposium on Poultry Nutrition (pp. 253–261). Proceedings of the 16th European Symposium on Poultry Nutrition 2007. https://www.cabi.org/Uploads/animal-science/worlds-poultry-science-association/WPSA-france-2007/125.pdf

Dereser L, Betancour L. Factores relacionados con la presentación del síndrome ascítico y síndrome de muerte súbita en pollos de engorde. Cienc Anim 2015; (9):11–28. https://ciencia.lasalle.edu.co/zootecnia/218/

Espinoza-Fuenzalida S. Análisis del sacrificio de pollos de carne desde el punto de vista del bienestar animal. 2017. http://repositorio.udla.cl/xmlui/handle/udla/283

Fox J, Weisberg S. An R companion to applied regression. Sage publications. 2018.

Gómez W. Modelo de negocio y evaluación de costos en la producción de pollos broiler para recría 2020. http://hdl.handle.net/20.500.12894/6854

Haščík P, Čech M, Čuboň J, Bobko M, Arpášová H, Pavelková A, Čeryová N. Effect of grape pomace supplementation on meat performance of broiler chicken ross 308. J Microbiol Biotechnol Food Sci 2021; 10(1):140–144. https://doi.org/10.15414/jmbfs.2020.10.1.140-144.

Husson F, Josse J, Pages J. Principal component methods-hierarchical clustering-partitional clustering: why would we need to choose for visualizing data. Applied Mathematics Department 2010, 17.

Jaramillo F. Alimentación del pollo de engorde: fases preiniciación, iniciación y engorde. Itagüí. Solla S.A. 2020. https://www.solla.com/wp-content/uploads/2022/02/25.AlimentacionPolloEngordeFases-1.pdf

Khadour HVN, Parsons BW, Utterback PL, Campbell JM, Parsons CM, Emmert JL. Metabolizable energy and amino acid digestibility in spray-dried animal plasma using broiler chick and precision-fed rooster assays. Poult Sci 2022; 101(5). https://doi.org/10.1016/j.psj.2022.101807

López SD. Síndrome Ascítico en la Crianza de Pollos Broilers; Tesis de Licenciatura. Escuela superior politécnica de Chimborazo 2012. http://dspace.espoch.edu.ec/handle/123456789/2095

Lv M, Yan L, Wang Z, An S, Wu M, Lv Z. Effects of feed form and feed particle size on growth performance, carcass characteristics and digestive tract development of broilers. Anim Nutr 2015;1(3):252–256. https://doi.org/10.1016/j.aninu.2015.06.001

Martínez Y, Valdivié M. Efficiency of Ross 308 broilers under different nutritional requirements. J Appl Poult Res 2021; 30(2):100140. https://doi.org/10.1016/j.japr.2021.100140

Massuquetto A, Panisson JC, Schramm VG, Surek D, Krabbe EL, Maiorka, A. Effects of feed form and energy levels on growth performance, carcass yield and nutrient digestibility in broilers. Anim 2020; 14(6):1139–1146. https://doi.org/10.1017/S1751731119003331

Mateos G, Jiménez E, González JM, Valencia DG. Estrategias de alimentación en la primera semana de vida del pollito. XXIII curso de especialización FEDNA 2007; 25:65–92. https://www.produccion-animal.com.ar/produccion_aves/produccion_avicola/70-07CAP_IV.pdf

Mendoza Rivadeneira FA, Vargas Zambrano PA, Vivas Arturo WF, Valencia Llanos NF, Verduga López CD, Dueñas Rivadeneira AA. Sustitución parcial de maíz por harina integral de Cucurbita moschata y su efecto sobre las variables productivas de pollos Cobb 500. Cienc Tecnol Agropecuaria 2020; 21(2). https://doi.org/10.21930/rcta.vol21_num2_art:1298

Meza M, Hinojosa F, Lobo R. Uso de pigmentantes naturales para la coloración de la yema de huevo y evaluación de parámetros productivos en aves de postura de la Universidad Francisco de Paula Santander Ocaña. Rev. Med. Vet. Zoot 2018; 4(7): 38–42. http://anzoo.org/publicaciones/index.php/anzoo/article/view/28/19

Moses C, Manyeula F, Radikara MV, Mareko MHD, Madibela OR. Carcass characteristics and meat quality of Ross 308 broiler chickens fed malted red and white Sorghum-based diets. Poult 2022; 1(3):169–179. https://doi.org/10.3390/poultry1030015

Moyano Tapia JC. Efectividad de los anticoccidiales químicos y ionóforos y determinación del score de lesiones en pollos de ceba. Tesis de grado. Escuela Superior Politécnica de Chimborazo 2012.http://dspace.espoch.edu.ec/handle/123456789/1377

Oñate FJ, Fiallos L, Duchi N, Villafuerte A, Peñafiel I, Flores Á, Morales K. Harina de ají de ratón (*Capsicum mínimum*) como anticoccidial natural en pollos de engorde, Manabí-Ecuador. Eur Sci J 2018; 14:12. https://doi.org/10.19044/esj.2018.v14n12p15

Pérez-Vendrell AM, Hernandez JM, Llaurado L, Schierle J, Brufau J. Influence of source and ratio of xanthophyll pigments on broiler chicken pigmentation and performance. Poult Sci 2001; 80(3):320–326. https://doi.org/10.1093/ps/80.3.320

Quintana-Ospina GA, Alfaro-Wisaquillo MC, Oviedo-Rondon EO, Ruiz-Ramirez JR, Bernal-Arango LC, Martinez-Bernal GD. Data analytics of broiler growth dynamics and feed conversion ratio of broilers raised to 35 d under commercial tropical conditions. Anim 2023; 13(15):2447. https://doi.org/10.3390/ani13152447

R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Rodríguez KF. Efecto de la restricción alimentaria sobre los índices productivos e incidencia de ascitis en pollos COBB 500 2022. Tesis de Licenciatura Universidad Técnica de Ambato 2022. https://repositorio.uta.edu.ec/jspui/handle/123456789/35259

Svihus B, Hetland H. Ileal starch digestibility in growing broiler chickens fed on a wheat-based diet is improved by mash feeding, dilution with cellulose or whole wheat inclusion. Br Poult Sci 2001; 42(5):633–637. https://doi.org/10.1080/00071660120088461

Sumano H, Gutierrez L. Antiparasitarios en Farmacología Clínica en Aves. Editorial Interamericana 2010; 3:365–454.

Taheri HR, Mansouri A, Ghaderi O. Comparison of multi-step phase-feeding programs (eight or thirteen steps) with a commercial three-step feeding program for broiler chickens. Poult Sci J 2020; 8(1):9–15. https://doi.org/10.22069/PSJ.2020.16997.1491

Tikate K, Wade M, Ranade AS, Patodkar VR, Dhaygude VS, Bhalerao SM. Influence of dietary multiple phase feeding on growth performance of commercial broiler chicken. Indian J Anim Res 2021; 55(1):66–70. https://doi.org/10.18805/ijar.B-3928

Valencia G, Serrano P, Mateos G. El tamaño de partícula y la presentación del pienso en pollos de engorde. Selecciones avícolas 2011. https://seleccionesavicolas.com/pdf-files/2011/12/6409-el-tamano-de-particula-yla-presentacion-del-pienso-en-pollos-de-engorde. pdf

Villar MO. Evaluación del desempeño zootécnico y rendimiento en canal de pollos ross 308 AP, sometidos a diferentes tablas de consume. Trabajo para potar al título de médico veterinario zootecnista. Bucaramanga-Colombia. Universidad Cooperativa de Colombia 2019. https://repository.ucc.edu.co/server/api/core/bitstreams/17d6788a-3c78-4b87-a600-49b36fa1d443/content

Wickham H, Averick M, Bryan J, Chang W, McGowan LDA, François R, Yutani H. Welcome to the Tidyverse. J Open Source Softw 2019; 4(43):1686. https://doi.org/10.21105/joss.01686

Zavala De La Jara CM. Efectos de la suplementación con salinomicina y nicarbazina sobre los parámetros productivos en pollos de engorde. Lima -Perú 2017. https://hdl.handle.net/20.500.12672/6423