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Performance response of broiler chickens fed diets containing dehydrated microalgae meal as partial replacement for soybean until 22 days of age

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1	Performance response of broiler chickens fed diets containing dehydrated
2	microalgae meal as partial replacement for soybean until 22 days of age
3	Marco Zampiga ^a , Giorgio Brugaletta ^a , Filiberto Ceccaroni ^b , Alessio Bonaldo ^c ,
4	Stefano Pignata ^a , Federico Sirri ^a
5	
6	^a Department of Agricultural and Food Sciences, Alma Mater Studiorum - University of
7	Bologna, Via del Florio 2, 40064, Ozzano dell'Emilia, Bologna, Italy
8	^b Gesco S.C.A., Via del Rio 400, 47522, San Vittore di Cesena, Forlì-Cesena, Italy
9	^c Department of Veterinary Medical Sciences, Alma Mater Studiorum - University of
10	Bologna, Via Tolara di Sopra 50, 40064, Ozzano Emilia, Bologna, Italy
11	
12	Corresponding author: Federico Sirri. Email: federico.sirri@unibo.it
13	Address: Department of Agricultural and Food Sciences, Alma Mater Studiorum -
14	University of Bologna, Via del Florio 2, 40064, Ozzano dell'Emilia, Bologna, Italy
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17 Abstract

18 Microalgae meal (MM) could represent a sustainable alternative to soybean meal as 19 protein ingredient for broiler diets. The aim of this study was to investigate the effects 20 of the dietary substitution of soybean with MM (Arthrospira spp.) during the first stages 21 of the rearing cycle on the growth performance of broiler chickens. A total of 1 000 one-22 day-old Ross 308 male chicks were divided into 4 experimental groups (10 replicate 23 pens/group with 25 birds each) receiving, during the starter (0-12 days) and grower 24 (13-22 days) phases, either a conventional soybean-based diet (CON group) or the 25 same diet including MM at low (LM group: 50 g/kg in both phases), intermediate (IM 26 group: 100 and 90 g/kg, respectively), or high dosages (HM group: 150 and 140 g/kg, 27 respectively). From 23 d onwards, all groups received the same conventional soybean-28 based diet up to slaughter age (47 days). All diets were formulated to be iso-energetic 29 and with a similar amino acid profile. Productive parameters were recorded on a pen 30 basis at housing (0 day), at 22 days, and at slaughter. At 22 days, body weight was 31 linearly reduced and feed conversion ratio significantly worsened as the dietary 32 inclusion of MM increased (931 vs. 850 vs. 709 vs. 462 g, and 1.539 vs. 1.656 vs. 33 1.783 vs. 2.312 for CON, LM, IM and HM groups, respectively; P<0.001). CON and 34 LM groups presented similar feed intake from 0 to 22 days, which was significantly 35 higher if compared to IM and HM (1.367 vs. 1.333 vs. 1.184 vs. 0.964 kg/bird, 36 respectively; P<0.001). At 47 days, CON and LM groups exhibited comparable body 37 weight, while IM and HM showed lower values (3,455 vs. 3,446 vs. 3,221 vs. 2,802 g, 38 respectively; P<0.001). No significant difference in FCR was observed in the overall period of trial (0-47 days). Similarly, liveability was not substantially affected by the 39 40 treatments. Overall, these results indicate that the dietary administration of MM during 41 the first 22 days of life significantly impaired broiler growth performance regardless of

the dosage. However, by re-feeding a conventional soybean-based diet up to slaughter
(47 days), broilers receiving 50 g/kg of MM up to 22 days achieved similar growth
performance and productive efficiency to those fed a conventional soybean-based diet
in all feeding phases.

Keywords: broiler chicken, nutrition, microalgae, alternative protein source, soybean,
productive performance

Abbreviations: SBM, soybean meal; MM, microalgae meal; CON, control; LM, 50 g/kg of microalgae meal during starter and grower phases; IM, 100 and 90 g/kg of microalgae meal during starter and grower phases; HM, 150 and 140 g/kg of microalgae meal during starter and grower phases; BW, body weight; DWG, daily weight gain; DFI, daily feed intake, FCR, feed conversion ratio; EPEF, European Production Efficiency Factor; EBI, European Broiler Index.

54 Introduction

55 The growth of world population and the concomitant increase in animal products 56 demand are leading to a remarkable increment in annual world feed supply (Kim et al., 57 2019). The poultry sector accounts for approximately 600 million tons of dry matter 58 feed per year with relatively high concentrations of feed protein raw materials (Mottet 59 and Tempio, 2017), which are considered as one of the most expensive and limiting 60 ingredients (Beski et al., 2015). Soybean meal (SBM) is the most important and widely 61 used protein source in commercial poultry feeding, primarily because of its wellbalanced amino acid profile (Beski et al., 2015). The forecasted increase in feed 62 63 production is exacerbating the environmental, economic and social issues related to 64 the production, processing and transportation of soybean (Kim et al., 2019; Zalles et

al., 2019; Song et al., 2021). These sustainability concerns are giving momentum to
the identification of alternative protein sources that might replace SBM in poultry diets
without compromising animal growth performance and health status.

68 Microalgae are a heterogeneous group of photosynthetic aquatic plants that utilize 69 atmospheric CO₂ and light energy for their metabolic activities, producing a variety of 70 essential nutrients and bioactive compounds such as proteins, amino acids, long-chain 71 polyunsaturated fatty acids, vitamins and carotenoids (Świątkiewicz, 2015; Saadaoui 72 et al., 2021). Microalgae could be safely included in poultry diets (Świątkiewicz, 2015), 73 with inclusion levels of around 20 g/kg that have been identified by Coudert et al. (2020) 74 as suitable to provide benefits on growth performance, health status and product 75 guality of broilers. However, the same authors also highlighted that most of the studies 76 conducted so far have considered microalgae meal (MM) mainly as feed supplement, 77 which could be included in standard formulations at low dosages to enhance animal 78 health and product quality traits, rather than a major source of macronutrients such as 79 protein and amino acids. Indeed, some microalgae strains such as the widely known 80 Arthrospira spp. (Spirulina) are characterized by relevant amounts of crude protein (up 81 to 700 g/kg) with a balanced essential amino acid profile (Saadaoui et al., 2021). 82 Nevertheless, the large-scale use of MM as protein source is still limited, mostly 83 because of its high cost and the scarce knowledge regarding digestibility and optimal 84 dietary inclusion rates (Saadaoui et al., 2021). A potential strategy to promote an 85 economically sustainable use of MM in broiler nutrition might be administering it during 86 the first phases of the rearing cycle, when diets with high crude protein concentration 87 should be provided to meet the elevated protein and amino acid requirements of 88 animals with still limited feed ingestion capacity. However, the information regarding 89 the animal growth response to this nutritional approach is scant and inconsistent,

especially to as concern the potential implications in the entire rearing cycle. Therefore,
the aim of the present study was to evaluate the growth performance of broiler chickens
fed diets with increasing dosages of MM (*Arthrospira spp.*) up to 22 days of age and
then a conventional soybean-based diet until slaughtering.

94 Material and methods

95 *Ethic statement*

96 Birds were raised, handled and processed according to the Directive 2007/43/EC for 97 the protection of chickens kept for meat production, the Regulation 1099/2009/EC for 98 the protection of animals at the time of killing, and the Directive 2010/63/EU for the 99 protection of animals used for scientific purposes. The Ethical Committee of the 100 University of Bologna approved the experimental protocol (ID: 1145/2020).

101 Animals and housing

102 One thousand day-old male Ross 308 chicks were obtained from the same breeder 103 flock and hatching session. The chicks were vaccinated at the hatchery and then 104 transported to an environmentally-controlled poultry facility, where they were randomly 105 distributed in 40 concrete floor pens arranged in randomized blocks to minimize any 106 environmental effect. Each pen was equipped with one circular pan feeder and 5 107 nipple-type waterers. Wood shaving was utilized as bedding material (3-4 kg/m²). The 108 stocking density did not exceed 33 kg/m² and the photoperiod was 23 h light - 1 h dark 109 during 0-7 and 45-47 days, and 18 h light – 6 h dark from 8-44 days. The environmental 110 temperature within the barn was defined according to the age of the birds in line with 111 the current recommendations.

112 Experimental diets

113 The analysed chemical composition and amino acid profile of the MM (Arthrospira spp.; 114 VAXA Impact Nutrition, Reykjavík, Iceland) is reported in Table 1. The most relevant 115 fatty acids in the MM were palmitic acid (C16:0), palmitoleic acid (C16:1), linoleic acid 116 (C18:2, n-6) and y-linolenic acid (C18:3, n-6) (419.4, 102.4, 186.5 and 271.8 g/kg of 117 total fat, respectively). A 3-phase feeding program was adopted: starter (0–12 days), 118 grower (13-22 days) and finisher (23-47 days). The ingredients as well as the 119 chemical composition of the diets (either analysed or calculated values) in the different 120 feeding phases are shown in Table 2. Briefly, the control diet (CON) was a conventional 121 corn-wheat-soybean basal diet formulated to meet the nutritional requirements of Ross 122 308 (Aviagen, 2019). The experimental diets containing MM were obtained using the 123 same ingredients of the CON diet with the inclusion, during the starter and grower 124 phases, of MM at either low (LM: 50 g/kg in both phases), intermediate (IM: 100 and 125 90 g/kg, respectively), or high dosages (HM: 150 and 140 g/kg, respectively). Each 126 experimental group was constituted by 10 replicate pens of 25 birds each. The 127 inclusion of MM was performed by reducing the dietary concentration of both soybean 128 meal and full-fat soybean in respect to CON diet. All diets were isoenergetic and with 129 a similar amino acid profile, which was optimized maintaining the same ratio of total 130 essential amino acids to total lysine (Table 2). From 23 days to slaughter (47 days), all 131 groups received the CON diet formulated according to the nutritional specifications for 132 the finisher phase (Table 2). All diets were administered in mash form and feed and 133 water provided *ad-libitum*.

134 Productive performance

135 Birds were weighed on a pen basis at housing (0 day), at 22 days and at slaughter (47 136 days). Similarly, feed consumption was determined at 22 and 47 days. Mortality was 137 monitored daily. Dead birds were recorded and weighed to calculate the liveability rate 138 and to adjust the productive performance data. Body weight (**BW**), daily weight gain 139 (DWG), daily feed intake (DFI) and feed conversion ratio (FCR) were obtained 140 accordingly. The results were reported for the following periods: 0-22 days, 23-47 days 141 and 0-47 days. For the overall period of trial (0-47 days), production efficiency 142 indicators such as the European Production Efficiency Factor (EPEF = [liveability (%) 143 × BW (kg) / age (days) × FCR (kg feed/kg gain)] × 100) and the European Broiler Index 144 (EBI = [liveability (%) × DWG (g/bird/day) / FCR (kg feed/kg gain) × 10] were calculated 145 on a pen basis. At 47 d, all birds were processed in a commercial slaughterhouse.

146 Statistical analysis

Data were analysed by means of one-way ANOVA and Tukey post-hoc test considering the diet as experimental factor and the pen as experimental unit. Polynomial contrasts were used to assess linear and quadratic responses to increasing dietary dosages of MM. Prior to analysis, liveability data were submitted to arcsine transformation. Differences were considered as statistically significant when P<0.05.

152 Results and Discussion

At placement, chick BW was similar among experimental groups with group values ranging from 42.2 to 42.6 g (Table 4). After 22 days, the dietary inclusion of MM determined a significant reduction in BW and DWG compared to CON (931 vs. 850 vs. 709 vs. 462 g, and 40.3 vs. 36.6 vs 30.1 vs. 18.9 g/bird/day, respectively for CON, LM, IM and HM; both linear and quadratic, P<0.001). However, CON and LM groups

158 presented comparable DFI and FI, which were significantly higher than those of IM and 159 HM (62.0 vs. 60.5 vs. 53.7 vs. 43.7 g/bird/day, and 1.364 vs. 1.330 vs. 1.181 vs. 0.961 160 kg/bird, respectively for CON, LM, IM and HM; both linear and quadratic, P<0.001). 161 FCR from 0 to 22 days was significantly affected by MM administration, with the lowest 162 value observed in CON and the highest one in HM (1.539 vs. 1.656 vs. 1.783 vs. 2.312, 163 respectively for CON, LM, IM and HM; both linear and guadratic, P<0.001). The dietary 164 treatments did not significantly influence liveability rate. Overall, the dietary inclusion 165 of MM up to 22 days of age dramatically impaired the growth performance of broiler 166 chickens. Early studies on this topic reported a significant reduction of weight gain in 167 Single Comb White Leghorn chickens fed diets containing 100 or 200 g/kg of 168 dehydrated Spirulina as a substitute for SBM during the first three weeks of life (Ross 169 and Dominy, 1990). However, the same authors reported that FCR was not 170 significantly affected by the dietary treatment. Similarly, the dietary provision of 75 g/kg 171 of defatted diatom Staurosira sp. biomass as a replacement for SBM during the first 3 172 weeks negatively affected body weight gain and tended to reduce FI and gain:feed 173 ratio (Austic et al., 2013). Our results do not support those reported by Evans et al. 174 (2015), who stated that up to 160 g of dehydrated full-fat Spirulina meal per kg feed 175 can be included into starter diets without negative consequences on growth 176 performance or amino acid digestibility of Hubbard x Cobb 500 broilers. However, 177 higher dosages (i.e., 210 g/kg) were associated with a significant reduction in BW, FI 178 and amino acid digestibility. Furthermore, the authors reported that neither FCR nor 179 mortality were substantially influenced by the dietary dosage of Spirulina. In the 180 present study, even the lowest dosage (50 g/kg) significantly worsened DWG and 181 FCR, although the birds belonging to LM group consumed a comparable amount of 182 feed compared to CON. These outcomes could suggest that the negative effects on

183 growth performance exerted by MM inclusion are not exclusively a direct consequence 184 of FI reduction, but also other factors such as poor digestibility rate and unbalanced 185 composition could have played a role. This hypothesis finds confirmation in the work 186 of Coudert et al. (2020). In particular, digestibility could be affected by the high fiber 187 and polysaccharides content of algae as well as by the presence of phenolic 188 compounds that can react with amino acids forming insoluble complexes (Saadaoui et 189 al. 2021). Further studies are warranted to evaluate the digestibility rate of the MM 190 used in the present study.

191 At slaughtering (47 days; Table 4), CON and LM achieved similar BW, whereas IM and 192 HM birds were significantly lighter (3,455 vs. 3,446 vs. 3,221 vs. 2,802 g, respectively 193 for CON, LM, IM and HM; both linear and quadratic, P<0.001). HM group presented 194 lower DWG than the other groups from 23 to 47 days (101.0 vs. 104.0 vs. 100.3 vs. 195 93.6 g/bird/day, respectively for CON, LM, IM and HM; both linear and quadratic, 196 P<0.001). DFI was similar between CON and LM, which consumed more feed than IM 197 and HM (193.7 vs. 189.3 vs. 176.2 vs. 159.5 g/bird/day, and 4.843 vs. 4.733 vs. 4.406 198 vs. 3.988 kg/bird, respectively for CON, LM, IM and HM; linear, P<0.001; guadratic: 199 P<0.01). FCR was linearly affected by the dietary treatments with the highest value 200 observed for CON group, followed by LM, IM and HM (1.921 vs. 1.822 vs. 1.757 vs. 201 1.704 g feed/g bird, respectively; P<0.001). Once again, liveability showed comparable 202 values among groups. In this feeding phase, the growth performance of LM birds was 203 comparable to that of CON ones, coupled also with a better FCR. This allowed to cover 204 the BW gap between CON and LM accumulated during the first 22 days of trial, 205 resulting in similar BW at slaughter. On the other hand, final BW and DFI of IM and HM 206 broilers were still significantly lower than those of CON and LM. It should be considered 207 that MM administration during the first 22 days generated large differences in BW

among the experimental groups, particularly for IM and HM (i.e., approximately -25 and
-50% compared to CON), which could have hindered feed ingestion capacity during
the last part of the rearing cycle although all groups received the same basal diet.

211 Considering the results in the overall period of trial (0-47 days; Table 4), CON and LM 212 showed comparable DWG and DFI, followed by IM and then by HM (71.9 vs. 71.6 vs. 213 66.6 vs. 57.7 g/bird/day, and 130.5 vs. 127.4 vs. 117.3 vs. 103.9 g/bird/day, 214 respectively; both linear and quadratic, P<0.001). FCR as well as liveability exhibited 215 no substantial variations among experimental groups. Furthermore, EPEF and EBI 216 were similar among CON, LM and IM groups, but significantly lower in HM (Table 4). 217 These results indicate that, in the overall period of trial (0-47 days), broiler chickens 218 receiving 50 g/kg MM from 0 to 22 days and then a conventional soybean-based diet 219 performed similarly to those fed the soybean-based diet in all feeding phases. 220 However, the negative impact exerted by higher dietary dosages of MM was not 221 completely reversed by this feeding strategy. Overall, it can be concluded that the 222 dietary administration of MM during the first 22 days of life significantly impaired the 223 growth performance of fast-growing broiler chickens regardless of the inclusion 224 dosage. However, by re-feeding a conventional soybean-based diet up to slaughter 225 (23-47 days), broilers receiving 50 g/kg of MM up to 22 days achieved similar growth 226 performance and productive efficiency to those fed a conventional soybean-based diet 227 in all feeding phases.

228 Author contributions

229 Marco Zampiga: Conceptualization; Data curation; Formal analysis; Investigation,

230 Methodology; Visualization; Writing - original draft; Writing – review & editing.

231 **Giorgio Brugaletta**: Data curation; Investigation; Writing – review & editing.

- 232 Filiberto Ceccaroni: Conceptualization; Methodology.
- Alessio Bonaldo: Conceptualization; Funding acquisition; Project administration;
 Resources.
- 235 **Stefano Pignata:** Data curation; Investigation; Methodology.

Federico Sirri: Conceptualization; Funding acquisition; Methodology; Project
administration; Resources; Supervision; Writing – review & editing.

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- 289

- **Table 1.** Analysed chemical composition and amino acid profile of the microalgae
- 291 meal.

Composition	g/kg				
Dry matter	940.0				
Crude protein	702.4				
Crude fiber	46.8				
Ash	73.3				
Total fat	116.0				
Calcium	3.10				
Phosphorous	11.3				
Sodium	6.30				
Chlorine	1.30				
Lysine	31.7				
Methionine	15.9				
Cysteine	6.30				
Methionine + Cysteine	22.3				
Threonine	32.3				
Arginine	49.9				
Isoleucine	37.3				
Leucine	57.7				
Valine	41.1				
Histidine	10.4				
Serine	31.6				
Glycine	33.3				
Proline	24.1				
Alanine	50.5				
Phenylalanine	31.5				
Glutamic acid	94.4				
Aspartic acid	68.7				
AME (MJ/kg) ¹	12.6				
Abbreviations: AME = Apparent Metabolizable Energy ¹ Estimated value.					

Table 2. Composition of the experimental diets.

	Starter			Grower				Finisher	
Inaredients (a/ka)	CON	LM	Z U) IM	нм	CON	LM	IM	нм	(23-47 U) CON
Microalgae meal	0.00	50.0	100.0	150.0	0.00	50.0	90.0	140.0	0.00
Corn	358.0	392.0	428.0	462.0	389.0	432.0	488.0	531.0	386.0
Wheat	150.0	150.0	150.0	150.0	150.0	150.0	150.0	150.0	200.0
Vegetable oil	24.9	18.4	11.6	5.10	27.6	20.2	12.5	5.1	40.4
Wheat bran	20.0	29.9	40.1	50.0	20.0	23.9	28.0	31.9	20.0
Soybean meal	219.0	159.0	97.5	37.6	173.0	116.0	57.1	0.00	117.0
Full-fat soybean	99.9	73.5	46.4	20.0	150.0	118.0	85.1	53.2	150.0
Sunflower meal	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Corn gluten	30.0	30.0	30.0	30.0	0.00	0.00	0.00	0.00	0.00
Pea	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Calcium carbonate	3.90	4.30	4.70	5.00	5.50	5.80	6.10	6.40	9.60
Dicalcium phosphate	10.9	9.50	8.00	6.60	5.60	4.30	3.00	1.80	1.10
Sodium chloride	3.50	2.80	2.00	1.30	3.00	2.40	1.70	1.00	2.40
Sodium bicarbonate	0.70	0.60	0.60	0.50	0.70	0.60	0.60	0.50	1.70
Choline	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Lysine sulphate	5.60	6.80	8.00	9.20	3.70	5.20	6.70	8.20	3.40
DL-Methionine	2.90	2.70	2.40	2.20	3.00	2.80	2.60	2.40	2.50
L-Threonine	1.20	0.90	0.60	0.30	0.90	0.70	0.50	0.40	0.70
Phytase	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.50
NSP enzyme	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Mix amino acids (Arg+Val)	0.70	0.70	0.60	0.50	0.50	0.50	0.50	0.50	0.50
Mycotoxin binder	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
Vitamin-mineral premix ¹	5.00	5.00	5.00	5.00	4.50	4.50	4.50	4.50	2.50
Composition (g/kg)									
Dry Matter ²	912.0	903.0	905.0	903.0	903.0	905.0	904.0	903.0	904.0
Crude protein ²	229.0	221.0	224.0	226.0	200.0	204.0	208.0	205.0	183.0
Total lipid ²	63.0	56.0	49.0	44.0	73.0	65.0	55.0	47.0	90.0
Crude fibre ²	33.0	28.0	23.0	27.0	32.0	28.0	28.0	28.0	30.0
Ash ²	51.2	45.0	46.7	47.7	50.1	48.6	44.5	42.6	35.8
Calcium (total)	7.30	7.30	7.30	7.30	6.40	6.40	6.40	6.40	6.10
Phosphorous (total)	6.00	6.00	6.00	6.00	4.90	4.90	4.90	4.90	4.00
Lysine (total)	14.0	14.0	14.0	14.0	12.6	12.6	12.6	12.6	11.0
Meth + Cys (total)	10.5	10.5	10.5	10.5	9.70	9.70	9.70	9.70	8.70
Threonine (total)	9.50	9.50	9.50	9.50	8.50	8.50	8.50	8.50	7.50
AME (MJ/kg)	12.6	12.6	12.6	12.6	13.0	13.0	13.0	13.0	13.5

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Abbreviations: AME = Apparent Metabolizable Energy. NSP: Non-starch polysaccharides. ¹ Provided the following per kg of diet: vitamin A (retinyl acetate), 13,000 IU; vitamin D3 (cholecalciferol), 4,000 IU; vitamin E (DL- α _tocopheryl acetate), 80 IU; vitamin K (menadione sodium bisulfite), 3 mg; riboflavin, 6.0 mg; pantothenic acid, 6.0 mg; niacin, 20 mg; pyridoxine, 2 mg; folic acid, 0.5 mg; biotin, 0.10 mg; thiamine, 2.5 mg; vitamin B12 20 µg; Mn, 100 mg; Zn, 85 mg; Fe, 30 mg; Cu, 10 mg; I, 1.5 mg; Se, 0.2 mg; ethoxyquin, 100 mg. ² Analyzed values.

Table 4. Growth performance of broiler chickens fed a conventional soybean-based 305 306 diet (CON) or diets with different dosages of microalgae meal (LM, IM and HM) up to 307 308 22 days of age.

Paramotor	Experimental groups					B valuo	Response				
Falanciel	CON	LM	IM	НМ	SLIM	F-value	Linear	Quadratic			
0-22 d											
Chick BW (g)	42.6	42.2	42.4	42.3	0.10	0.61	0.51	0.60			
BW (g)	931 A	850 B	709 C	462 D	29.5	<0.001	<0.001	<0.001			
DWG (g/bird/day)*	40.3 A	36.6 B	30.1 C	18.9 D	1.34	<0.001	<0.001	<0.001			
DFI (g/bird/day)*	62.0 A	60.5 A	53.7 B	43.7 C	1.22	<0.001	<0.001	<0.001			
Fl (kg/bird)*	1.364 A	1.330 A	1.181 B	0.961 C	0.03	<0.001	<0.001	<0.001			
FCR (g feed/g gain)*	1.539 D	1.656 C	1.783 B	2.312 A	0.05	<0.001	<0.001	<0.001			
Livability (%)	99.2	99.6	98.2	98.2	0.02	0.36	0.16	0.75			
23-47 d											
BW (g/bird)	3,455 A	3,446 A	3,221 B	2,802 C	45.6	<0.001	<0.001	<0.001			
DWG (g/bird/day)*	101.0 A	104.0 A	100.3 A	93.6 B	0.77	<0.001	<0.001	<0.001			
DFI (g/bird/day)*	193.7 A	189.3 A	176.2 B	159.5 C	2.38	<0.001	<0.001	<0.01			
Fl (kg/bird)*	4.843 A	4.733 A	4.406 B	3.988 C	0.06	<0.001	<0.001	<0.01			
FCR (g feed/g gain)*	1.921 A	1.822 B	1.757 BC	1.704 C	0.02	<0.001	<0.001	0.31			
Livability (%)	99.6	98.3	99.5	100.0	0.01	0.09	0.27	0.07			
		0-4	17 d								
BW (g/bird)	3,455 A	3,446 A	3,221 B	2,802 C	45.6	<0.001	<0.001	<0.001			
DWG (g/bird/day)*	71.9 A	71.6 A	66.6 B	57.7 C	0.98	<0.001	<0.001	<0.001			
DFI (g/bird/day)*	130.5 A	127.4 A	117.3 B	103.9 C	1.80	<0.001	<0.001	<0.001			
Fl (kg/bird)*	6.209 A	6.066 A	5.591 B	4.951 C	0.08	<0.001	<0.001	<0.001			
FCR (g feed/g gain)*	1.818	1.781	1.762	1.799	0.01	0.27	0.41	0.08			
Livability (%)	98.8	98.0	97.8	98.2	0.02	0.78	0.56	0.41			
EPEF [†]	401 A	404 A	380 A	326 B	6.23	<0.001	<0.001	<0.001			
EBI [#]	392 A	394 A	370 A	316 B	6.23	<0.001	<0.001	<0.001			

309 310 311 312 313 314 Abbreviations: BW = body weight; DWG = daily weight gain; DFI = daily feed intake; FI = feed intake; FCR = feed conversion ratio; EPEF = European Production Efficiency Factor; EBI = European Broiler Index; SEM = standard error of the mean.

*: corrected for mortality.
*: EPEF = [liveability (%) × BW (kg) / age (days) × FCR (kg feed/kg gain)] × 100
#: EBI = [liveability (%) × DWG (g/bird/day) / FCR (kg feed/kg gain) × 10].

A, B: P<0.01