Results of hatching and rearing broiler chickens in different incubation systems

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ABSTRACT Hatchery efficiency is based on hatchability and the number of salable chicks. The hatchery sector has been seeking new alternatives to optimize production rates, including the use of different systems (multistage [**MS**] or single-stage [**SS**] machines) to improve incubation conditions. The present study aimed to compare results for hatchability, chick quality, and broiler performance of chicks from 2 incubator systems—MS and SS. The experimental design for hatchability, hatch window, egg weight loss, and chick performance variables was completely randomized with 2 treatments (MS and SS). Performance variables were analyzed as a 2 x 2 factorial arrangement (incubator type x chick sex). Egg weight loss between incubation and transfer was higher for eggs incubated in MS ($P < 0.05$). Hatchability was higher for eggs incubated in SS ($P < 0.05$), and chicks in SS had a longer hatch window ($P < 0.05$). Embryo diagnosis revealed higher final mortality for embryos incubated in MS ($P < 0.05$), as well as higher percentages of alive and dead pipped and cracked eggs ($P < 0.05$). Physical quality was better for chicks from SS ($P < 0.05$). There was no interaction between the studied factors for performance results ($P > 0.05$). Incubator type did not affect broiler performance for any of the studied ages ($P > 0.05$), whereas male broilers had better performance than females ($P < 0.05$). The SS incubation system proved better than the MS system at meeting embryo requirements during embryo development, with better hatching rates and chick quality, although performance variables were not influenced by incubation type.

Key words: hatchability, multistage, newborn chick quality, setters, single-stage

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INTRODUCTION

Artificial incubation is a production process that begins with the entry of fertile eggs and proceeds with the subsequent biological transformation into day-old chicks. Egg incubation is the first step in the broiler production chain, so full control throughout this industrial process is crucial for achieving satisfactory embryo development. Thus, studying and improving the entire process is essential for greater rentability in poultry production. According to Araújo et al. (2016), incubation yield is particularly affected by egg fertility, setters, and hatchery management.

Improvements in the genetic potential of broilers have reduced the average time needed to complete each production cycle by more than 50.0%. Over the last few decades, the broiler production cycle took approximately 84 d to be completed. Slaughter age currently averages 35 d, with the incubation period corresponding to about 30.0% of the entire production cycle (Araújo et al., 2019, 2020).

Owing to the great relevance of the hatching process, commercial hatcheries are constantly seeking ways to increase their production by raising hatchability and improving quality and uniformity of day-old chicks. A possible way to improve these results is to change from a multistage incubation system (**MS**) to single-stage incubation system (**SS**) (Villanueva et al., 2016).

Multi-stage incubators set 3 or 4 loads of eggs per week such that lots of eggs from different broiler breeder farms are incubated in a single machine with embryos being at different stages of development (Baracho et al., 2010).

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According to Araújo et al. (2016), older embryos transfer heat to younger embryos during incubation in an MS, which establishes a thermal balance within the setter; however, this may also increase the temperature inside the setter excessively, triggering embryo mortality. In this way, the production of heat that is used by embryos can reduce energy costs for the incubation of newly hatched eggs, making MS less costly.

On the other hand, SS incubators are fully loaded with a single egg lot such that all embryos are at the same developmental stage, which allows temperature, humidity, and ventilation to be set in accordance with the needs of the embryos (Molenaar et al., 2010). Such systems are recommended for incubating eggs of modern high-yield broiler strains whose embryos generate more heat than slow-growing strains (Boerjan, 2004). In addition, an SS provides better sanitary conditions because the machine becomes completely empty at some point, thus facilitating thorough washing and disinfection.

The use of SS may improve hatchability rates and the physical quality of day-old chicks over that of MS (Araújo et al., 2016). The better incubation performance of SS is due to the use of a high-quality technological automation system. Knowing how to manage these incubators and their productive potential is important for exploring the technical quality of SS. The present study aimed to compare SS and MS by analyzing hatching parameters and hatchling physical quality and performance.

MATERIAL AND METHODS

Experiments were conducted at a hatchery in the city of Goiânia, GO, Brazil (−16.67926° N, −49.25629° W). All experimental procedures were evaluated and approved by the local Ethics Committee for the Use of Animals (Protocol no. 031/2012).

Incubators

Five incubation trials were conducted to evaluate the effects of incubator type on hatching parameters, hatch window, residual analysis, and hatchling physical quality. A performance experiment was conducted at the end of the last incubation trial to evaluate broiler performance. Experiments were conducted at a University in Goiânia, Goiás, Brazil, and at Itaberaí, a commercial hatchery company also in the state of Goiás (16°01′13″ S, 49°48′37″ W).

Two artificial egg incubation systems (MS and SS) were compared for all the studied variables: CASP CMg 125 HT, an MS incubation system with a capacity of 124,416 eggs with 96 per tray and 36 trolleys; and CASP Ug 62 HT, an SS incubation system with a capacity of 61,920 eggs with 86 per tray and 12 trolleys.

The SS was equipped with infrared sensors, which constantly monitored eggshell temperature, coupled with setter control to provide the ideal temperature for each embryo development stage. The SS also possessed an egg-weighing system, a dehumidification system, and CO_2 level control.

Profile incubation was used in SS, which was programmed to control temperature, humidity, air renewal, and O_2 levels during the entire incubation process in accordance with embryo development (Table 1). For MS, the thermostat was set to keep the dry bulb temperature constant at 99.3°F and relative humidity (**RH**) at 58.00%. Egg turning was performed once every hour in both SS and MS.

The five incubation trials included eggs from Cobb 500 breeders of the following ages: first incubation (46-wk-old); second incubation (33-wk-old); third incubation (37-wk-old); fourth incubation (46-wk-old); and fifth incubation (41-wk-old).

All eggs were candled and viable embryos were vaccinated against Marek's disease in ovo at 18 d of embryo development (**DE18**) and then transferred to hatcheries (CASP 108 HR) regulated to maintain a temperature of 97.7°F and an RH of 65.00%. Nonviable eggs are breakout analysis to determine the infertiles and early deaths.

Hatchability, Hatch Window, and Residual Analysis

A total of 126,800 eggs were used to assess hatchability, hatch window, and residual analysis, with 25,360 eggs for each incubation. The eggs were distributed in a randomized block design with the 2 incubation systems (MS and SS). The blocks were each incubation trial (5 experimental trials) ($P > 0.05$). As previously described, the flock ages of the 5 incubation trials were 46, 33, 37, 46, and 41 wk, respectively. This effect was considered to be random in the statistical model.

After selection, eggs were distributed in trays and placed in the incubator trolleys then stored for 4 d at 17°C and 75% RH. The eggs were sent to a preheating room for 6 h until reaching 77.0 to 80.6°F. For each incubation, the eggs were allocated among 285 trays, with 85 trays being incubated in MS and 200 in SS. The trays were identified and equally distributed at 3 different positions inside the incubators (upper, middle, and lower positions). The other spaces of incubation trolleys were occupied with other trays containing eggs from the same broiler breeder batches to maintain the environmental conditions of the incubator within required technical standards.

The percentage hatch in relation to the total number of eggs set (total percentage hatch) and percentage hatch in relation to fertile eggs were evaluated for each tray. The number of fertile eggs was calculated from the residual analysis (96.57% (MS) and 96.68% (SS)).

Hatch window was monitored from 470 h until hatch. To determine percentage hatch, the hatcheries were opened at regular intervals of 6 h until all the trays were removed (504 h) and the number of hatched birds counted. The mean hatch window consisted of the time in hours between the first and the last chick hatched in each hatch tray.

All unhatched eggs remaining after 504 h of incubation were removed from the experimental trays and classified according to Araújo et al. (2016). All unhatched

Table 1. Parameters of dry bulb temperature, wet bulb temperature, ventilation (valve position), eggshell temperature, and O_2 levels in single-stage incubator.

Hours	Dry bulb (°F)	Wet bulb (°F)	Ventilation (m/s)	Eggshell (°F)	O_2 (%)
00–24	100.2	90.00	0	99.80	0.30
25–48	100.2	89.00	0	99.80	0.30
49–72	99.80	89.00	0	99.70	0.30
73–96	99.80	87.00	5–10	99.70	0.30
97–120	99.80	87.00	10–20	99.70	0.30
121–144	99.70	86.00	10–20	99.70	0.30
145–168	99.60	86.00	15–25	99.70	0.30
169–192	99.50	85.00	15–25	99.70	0.30
193–216	99.40	85.00	15–25	99.70	0.30
217–240	99.20	84.00	15–35	99.70	0.30
241–264	99.00	84.00	15–35	99.70	0.30
265–288	98.80	84.00	15–35	99.70	0.30
289–312	98.60	82.00	15–35	99.70	0.30
313–336	98.40	80.00	15–70	99.70	0.30
337–360	98.20	80.00	15–70	99.70	0.30
361–384	98.00	80.00	15–70	99.70	0.30
385–408	97.80	78.00	15–70	99.70	0.30
409–432	97.60	78.00	15–70	99.70	0.30
433–456	97.40	78.00	15–70	99.70	0.30

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eggs from the 285 trays were evaluated for residual analysis. Data were analyzed by frequency dispersion with Fisher's exact test. The results of total percentage hatch, percentage hatch of fertile eggs, and hatch window were analyzed by ANOVA. Statistical analyses were performed with R software (R Development Core Team, 2010), with 5% significance.

Egg Weight Loss and Chick Quality

In each incubation, a total of 1,400 eggs were distributed in a randomized block design with 2 treatments (MS and SS). The blocks were each incubation experimental trial (5 experimental repetitions). A total of 1,400 eggs from each incubation system were sampled in each experiment trial (700 MS and 700 SS).

Eggs were individually weighed and identified. To individualize each egg, at the moment of transfer (18 d), eggs were individually placed in trays adapted with air-permeable metallic divisions such that hatching chicks could be associated with their respective egg.

Egg weight loss during incubation, chick body weight at hatching, chick body weight at pulling, chick weight loss between hatching and pulling, residual yolk weight, yolk-free body weight, and chick length and physical quality score were all evaluated. The relative percentage of chick weight at hatching and at pulling and yolk-free body weight in relation to set egg weight were also calculated.

Table 2. Effect of incubator type (multistage and single-stage) on egg weight loss between incubation and transfer.

	Incubator type		
Items	Multistage	Single-stage	
Egg weight (g)	64.30 ± 0.11	63.98 ± 0.12	0.064
Egg weight at DE18 (g)	56.54 ± 0.11	56.44 ± 0.12	0.537
Egg weight loss (%)	12.06[a] ± 0.09	11.76[b] ± 0.09	0.021

[a-b]Means within the same line with different letters are different by F test of the analysis of variance ($P < 0.05$).

Egg weight loss was calculated as the difference between egg weight at the beginning of incubation and egg weight at transfer. To determine chick body weight at hatching, chicks that had emerged from eggs were removed from the hatchery at approximately 6 h intervals and individually weighed. At 504 h of incubation, experimental trays were removed from hatcheries and newborn chicks were weighed (chick body weight at pulling), measured for length (Wolanski et al., 2007), and macroscopically examined to determine physical quality (Tona et al., 2003). After measurement, chicks were euthanized by cervical dislocation and the residual yolk sac was removed and weighed.

Data were analyzed by ANOVA and chick quality score was analyzed by the Friedman test, both using R (R Development Core Team, 2016) software, with 5% significance.

Broiler Chicken Performance

Performance was evaluated in the experimental broiler house at a University in Goiânia, Goiás (16° 35′ 33″ S, 49° 16′ 51″ W; 710 m). A total of 600 broiler chicks (300 males and 300 females) from the fifth incubation (41-wk-old breeders) were selected and distributed in a completely randomized experimental design in a 2 x 2 factorial arrangement with 2 incubation systems (SS and MS) and 2 sexes (male and females), for a total of 4 treatments with 6 replicates and 25 birds per replicate.

Chicks were housed in 24 boxes with concrete floors covered with wood-shaving litter, and reared until 28 d of age. During the experimental period, all birds received feed and water *ad libitum*, with diet following the recommendations of Rostagno et al. (2011). Feed intake, average weight, body weight gain, feed conversion ratio, and mortality were evaluated weekly for 28 d.

Data were submitted to ANOVA and means compared by using Tukey test, considering 5% significance.

Table 3. Effect of incubator type (multistage and single-stage) on hatchability and hatch window.

Items	Incubator type		*P*-value
	Multistage	Single-stage	
Hatch (%)	87.15[b] ± 1.19	89.06[a] ± 0.09	0.003
Hatch/fertile (%)	90.25[b] ± 1.11	92.12[a] ± 1.15	0.004
Hatch window (h)[1]	19.28[b] ± 1.00	22.15[a] ± 1.10	<0.001

[a-b]Means within the same line with different letters are different by F test of the analysis of variance ($P < 0.05$).
[1]Mean hatch window: period (h) between the first and the last chick that hatched in the basket.

Statistical analyses were performed using R software (R Development Core Team, 2016).

RESULTS

Egg weight was similar between groups ($P > 0.05$), indicating uniformity in the selected sample. The two groups also did not differ in egg weight at transfer ($P > 0.05$); however, egg weight loss was greater ($P < 0.05$) for eggs incubated in MS (Table 2). Percentage hatch and percentage fertile hatch were higher ($P < 0.05$) in SS (Table 3).

A shorter hatch window was found for chicks from MS ($P < 0.05$). The average hatch window for SS was 22.15 h (Table 3). Figure 1 shows the average hatch window for each incubation trial. The hatching peak for SS (33.43%) was at hour 17 (487 h of incubation), whereas for MS, the peak (34.46%) occurred at hour 21 (491 h of incubation), demonstrating the earlier onset of hatching in SS.

Evaluation of residual analysis revealed a significantly ($P < 0.05$) higher percentage for MS than SS for the following categories: mortality III, mortality IV, dead pipped, live pipped, and cracked eggs (Table 4). The infertility percentage found by residual analysis was 2.63% (MS) and 2.75% (SS). Analysis of the odds ratio results revealed a 1.43 times greater chance of mortality III, a 1.42 times greater chance of mortality IV, a 1.02 times greater chance of dead pipped, a 1.17 greater chance of live pecked, and a 2.35 times greater chance of cracked eggs in MS than in SS.

Incubation system (MS or SS) had no effect on chick body weight at hatch and percentage of chick body

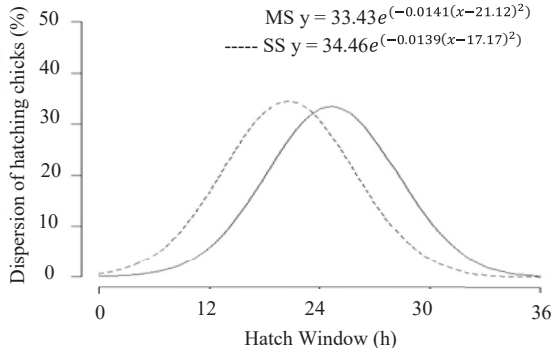

Figure 1. Dispersion of hatching chicks incubated in multistage (MS) and single-stage (SS) machines.

Table 4. Residual analysis results (%) of unhatched eggs from multistage and single-stage incubators.

Variables	Incubator type		*P*-value	Odds ratio	IC[1]	
	MS	SS				
Infertile eggs	2.63	2.75	0.659	1.043	0.878	1.245
M I	3.57	3.63	0.878	1.015	0.874	1.183
M II	0.62	0.64	0.928	1.025	0.723	1.479
M III	1.59[a]	1.11[b]	0.004	1.435	1.121	1.831
M IV	1.82[a]	1.02[b]	<0.001	1.808	1.420	2.296
Dead pipped	0.36[a]	0.20[b]	0.030	1.803	1.027	3.128
Alive pipped	0.67[a]	0.38[b]	0.004	1.768	1.179	2.634
Abnormality	0.07	0.07	1.000	1.080	0.294	3.374
Cracked eggs	0.88[a]	0.38[b]	<0.001	2.350	1.621	3.406
Contamination	0.25	0.16	0.189	1.497	0.765	2.851

Abbreviations: MS, multistage; SS, single-stage; M I, mortality from 0 to 4 d of embryo development; M II, mortality from 5 to 10 d of embryo development; M III, mortality from 11 to 17 d of embryo development; M IV, mortality from 18 to 21 d of embryo development.
*P-value of Fisher's exact test ($P < 0.05$).
[1]IC = confidence interval (0.95).

weight at hatch in relation to egg weight ($P > 0.05$). However, incubation system did have an effect on chick body weight at pulling, percentage of chick body weight at pulling in relation to egg weight, chick weight loss and residual yolk sac weight, with it being higher for chicks incubated in MS than in SS ($P < 0.05$) (Table 5).

Yolk-free chick body weight was found to be higher ($P < 0.05$) for chicks incubated in SS (average 39.93 g) than in MS (average 39.60 g) (Table 5). Percentage of yolk-free body weight in relation to egg weight was also higher ($P < 0.05$) for SS. The difference in yolk-free body weight between treatments was found to be a function of the difference in residual yolk sac weight, which was lower ($P < 0.05$) for chicks from SS incubation. In addition, average chick length was higher for chicks incubated in SS than in MS.

Chicks incubated in SS had an average physical quality score of 94.10 points, which was higher ($P < 0.05$) than that for chicks incubated in the MS system (91.79 point). In addition, the SS system had a higher ($P < 0.05$) percentage of chicks with scores above 96.00 points, whereas the MS system had higher numbers of chicks in lower ranges of quality (76–80 points and 86–90 points) (Table 6).

The interaction between incubation system and broiler sex had no effect ($P > 0.05$) on the performance variables for any of the studied periods. The initial body weight of male chicks (42.52 g) was higher ($P < 0.05$) than that of females (41.71 g) (Table 7). Male chick body weight was higher ($P < 0.05$) in SS (43.09 g) than in MS (41.96 g). Female initial body weight was similar in the 2 incubation systems ($P > 0.05$). Performance results during 1 to 7 d of age are also shown in Table 7, with sex having an effect with male chicks having higher average weight and weight gain ($P < 0.05$) compared with females.

For the periods of 1 to 14 d (Table 7) and 1 to 21 d of age (Table 8), differences between the sexes were observed only for final body weight, weight gain, and feed conversion, with males having greater final body

Table 5. Effect incubator type (multistage and single-stage) on chick quality parameters.

Chick quality parameters	Incubator type		*P*-value
	MS	SS	
Chick body weight at hatching (g)	47.06 ± 0.11	46.79 ± 0.11	0.070
Chick body weight at hatching/egg weight (%)	73.25 ± 0.09	73.20 ± 0.09	0.644
Chick body weight at pulling (g)	46.01[a] ± 0.11	45.69[b] ± 0.11	<0.001
Chick body weight at pulling/egg weight (%)	71.61[a] ± 0.09	71.40[b] ± 0.09	<0.001
Chick weight loss (%)	2.23[b] ± 0.07	2.80[a] ± 0.07	<0.001
Yolk weight (g)	6.41[a] ± 0.06	5.76[b] ± 0.06	<0.001
Yolk weight/chick body weight at pulling (%)	13.88[a] ± 0.12	12.49[b] ± 0.12	<0.001
Yolk-free body weight (g)	39.60[b] ± 0.09	39.93[a] ± 0.09	0.007
Yolk-free body weight/egg weight (%)	61.65[b] ± 0.10	62.41[a] ± 0.10	<0.001
Chick length (cm)	16.89[b] ± 0.02	16.96[a] ± 0.03	0.049

[a-b]Means within the same line with different letters are different by F test of the Analysis of Variance ($P < 0.05$).

Abbreviations: MS, multistage; SS, single-stage.

weight and weight gain and lower feed conversion ratio than females ($P < 0.05$). For the period of one to 28 d (Table 8), male broilers had greater ($P < 0.05$) average body weight, weight gain and feed intake and lower feed conversion ratio than females.

DISCUSSION

There are no studies in the literature involving as many experimental trials and eggs to evaluate artificial incubation systems. In fact, it is not easy to compare SS and MS systems because not only system but also machine design, capacity, and equipment in the machines are different. Thus, the present study provides information useful in choosing the incubation system that ensures the best productivity in commercial hatcheries. The results presented here demonstrate how improved artificial incubation technologies can increase hatching rates and chick quality.

The egg weight loss was 12.06% for SS and 11.76% for MS, both within the expected normal range of 11.00–13.00% (Boerjan, 2011). According to Araújo et al. (2017), controlling egg weight loss during incubation optimizes incubation results. The rate of evaporative loss of eggs is controlled by the RH inside the machine and is influenced by eggshell quality (Tullett and Burton, 1982).

Table 6. Effect of incubator type (multistage and single-stage) on chick physical quality score.

Score	Incubator type		*P*-value
	MS	SS	
<70	3.64 ± 1.19	2.71 ± 1.15	0.418
71–75	3.15 ± 0.99	2.23 ± 0.99	0.381
76–80	5.96[a] ± 1.04	2.55[b] ± 1.04	0.004
81–85	4.97 ± 0.41	4.46 ± 0.41	0.788
86–90	18.54[a] ± 0.26	13.06[b] ± 0.23	0.012
91–95	26.16 ± 0.98	26.91 ± 0.98	0.796
96–100	37.58[b] ± 0.56	48.09[a] ± 0.56	<0.001
Mean score	91.79[b] ± 0.59	94.10[a] ± 0.59	0.007

[a-b]Means within the same line with different letters are different by Friedman test ($P < 0.05$).

Abbreviations: MS, multistage; SS, single-stage.

In turn, eggshell quality is directly influenced by the age of broiler breeders. Older broiler breeders produce thinner and more porous eggshells, which provides greater conductance, thus increasing gas exchange between eggs and the external environment and, consequently a higher rate of weight loss during incubation (Araújo et al., 2017). Because the ages of broiler breeders of the 2 treatments in each incubation trial were similar, the difference in egg weight loss was due to the better control of RH inside the SS machine, with higher water loss likely being due to increased embryonic metabolism in the MS. The results for chick body weight and chick length confirm that chicks used the nutrition provided by the eggs more efficiently.

Hatch window is an important variable in the evaluation of artificial incubation and should usually be 24 h (Araújo et al., 2016) to avoid any damage to chick hydration. The hatch windows for both of the studied incubation systems were within the recommended range; however, the largest hatch window observed was for SS (22.15 h). Analyzing all the experiments together (Figure 1) revealed that hatching in SS was earlier than in MS. Based on the dispersion curves, at hour 15, which corresponds to 485 h of incubation, 46.62% of hatching had already occurred in SS, whereas only 23.71% had occurred in MS.

The preset study revealed lower residual yolk in the yolk sac and higher yolk-free body weight for chicks of the SS treatment. Thus, it can be concluded that chicks of the SS system consumed nutrients present in the yolk more efficiently and, consequently, exhibited better body development, than chicks in MS. According to Da Silva et al. (2017), immunoglobulins are present in the residual yolk sac, which guarantee immunity to chicks during the first days of life. Despite SS having a better body condition at pulling, incubation type was not found to have an effect on broiler performance during any of the studied periods. Perhaps in a condition of microbiological challenge, the effect of the best initial physical quality and use of the residual yolk could ensure that chicks do not exhibit worse performance results.

The percentage of yolk-free body weight in relation to egg weight was also lower in MS. According to Meijerhof

Table 7. Performance of male and female broilers from incubation on multistage (MS) and single-stage (SS) systems during the period of 1 to 7 d and 1 to 14 d.

		1 to 7 d					
		Incubator type					
Performance	Sex	MS	SS	Mean	*P**	*P***	*P****
Initial body weight (g)	Male	41.96[a,B]	43.09[a,A]	42.52			
	Female	41.95[a,A]	41.46[b,A]	41.71	0.001	0.151	0.001
	Mean	41.96	42.27				
Final body weight (g)	Male	183.93[a]	187.36[a]	185.65			
	Female	179.17[b]	179.50[b]	179.33	0.038	0.516	0.592
	Mean	181.55	183.43				
Body weight gain (g)	Male	141.97	144.27	143.12			
	Female	137.21	138.04	137.63	0.055	0.569	0.787
	Mean	139.59	141.16				
Feed intake (g)	Male	193.87	214.96	204.42			
	Female	205.37	213.57	209.47	0.549	0.093	0.447
	Mean	199.62	214.26				
Feed conversion ratio (g/g)	Male	1.376	1.491	1.433			
	Female	1.495	1.547	1.521	0.139	0.158	0.584
	Mean	1.435	1.519				
Mortality (%)[1]	Male	1.33	0.00	0.67			
	Female	0.00	0.00	0.00	0.329	0.329	0.329
	Mean	0.67	0.00				

		1 to 14 d					
		Incubator type					
Performance	Sex	MS	SS	Mean	*P**	*P***	*P****
Final body weight (g)	Male	511.81[a]	514.74[a]	513.28			
	Female	466.20[b]	465.42[b]	465.81	<0.001	0.927	0.899
	Mean	489.01	490.08				
Body weight gain (g)	Male	469.85	471.65	470.75			
	Female	424.25	423.96	424.10	0.055	0.569	0.787
	Mean	447.05	447.81				
Feed intake (g)	Male	637.52	666.80	652.16			
	Female	655.03	640.22	647.63	0.808	0.698	0.244
	Mean	646.28	653.51				
Feed conversion ratio (g/g)	Male	1.365[b]	1.416[b]	1.390			
	Female	1.548[a]	1.515[a]	1.531	0.007	0.857	0.386
	Mean	1.456	1.465				
Mortality (%)[1]	Male	1.33	0.67	1.00			
	Female	0.00	0.67	0.33	0.423	1.000	0.423
	Mean	0.67	0.67				

[a–b]Means in a column not sharing a common superscript are significantly different ($P < 0.05$) by Tukey's test.

Abbreviations: MS, multistage; SS, single-stage.

**P*-value of the analysis of variance of the variable sex.

***P*-value of the analysis of variance of the variable incubator.

****P*-value of the analysis of variance of the Interaction between sex and incubator.

[1]Mortality was transformed into ASEN(RAIZ((%MORT/100) + 0.05)) before ANOVA.

(2010), relative percentage of chick weight and egg weight also shows embryo development and body mass synthesis. A lower ratio of chick weight to egg weight indicates that less residual yolk was used during incubation, resulting in less developed chicks. The difference observed for chick weight loss between hatching and pulling reflected average weight in pulling. This weight loss can be attributed to water loss during the prolonged stay inside the hatchery.

Physical evaluation of chick quality considered aspects of appearance, activity, navel, eyes, and legs (Tona et al., 2003). The average score for chick quality for chicks incubated in SS was higher than those in MS, as was the number of chicks with scores above 96.00 points. Chicks with scores of 96.00 to 100.00 points are considered to be of excellent quality and without any physical quality that would compromise posthatch development.

Parameters of the physical quality of hatching chicks have been correlated with broiler chick performance. Because chick body weight includes not only their body mass, but also the amount of residual yolk present and their state of hydration, to compare chick weight, it is necessary to not only analyze body weight but also yolk-free body weight, which is the best indicator of chick development (Tona et al., 2004).

The results indicated that SS improved chick length and physical quality. These results are consistent with the studies of Araújo et al. (2016) and Villanueva et al. (2016), who also found that larger chicks were achieved when eggs were incubated in SS. Chick length may be positively correlated with poultry performance during the posthatch phase (Mukhtar et al., 2013). Thus, the grater length indicates that there was a greater transformation of nutritive material into body mass. So, again, it

Table 8. Performance of male and female broilers from incubation on multistage (MS) and single-stage (SS) systems during the period of 1 to 21 d and 1 to 28 d.

		1 to 21 d					
		Incubator type					
Performance	Sex	MS	SS	Mean	*P**	*P***	*P****
Final body weight (g)	Male	841.15	857.37	849.26[a]			
	Female	791.60	800.44	796.02[b]	<0.001	0.293	0.801
	Mean	816.37	828.90				
Body weight gain (g)	Male	799.19	814.29	806.74			
	Female	749.65	758.98	754.31	0.179	0.626	0.284
	Mean	744.41	786.63				
Feed intake (g)	Male	1,220.48	1,250.35	1,235.42			
	Female	1,215.03	1,203.68	1,209.36	0.808	0.698	0.244
	Mean	1,217.75	1,227.01				
Feed conversion ratio (g/g)	Male	1.536	1.546	1.541[b]			
	Female	1.622	1.592	1.607[a]	0.030	0.715	0.491
	Mean	1.579	1.569				
Mortality (%)[1]	Male	2.67	2.06	2.36			
	Female	0.00	1.33	0.67	0.077	0.683	0.312
	Mean	1.33	1.70				
		1 to 28 d					
		Incubator type					
Performance	Sex	MS	SS	Mean	P*	P**	P***
Final body weight (g)	Male	1,558.45	1,596.87	1,577.61[a]			
	Female	1,385.01	1,411.54	1,398.27[b]	<0.001	0.101	0.787
	Mean	1,471.73	1,504.20				
Body weight gain (g)	Male	1,516.49	1,553.78	1,535.14[a]			
	Female	1,343.06	1,370.08	1,356.57[b]	0.037	0.665	0.998
	Mean	1,429.78	1,461.93				
Feed intake (g)	Male	2,266.07	2,282.33	2,274.20			
	Female	2,183.92	2,199.98	2,191.95	0.808	0.698	0.244
	Mean	2,224.99	2,241.15				
Feed conversion ratio (g/g)	Male	1.503	1.485	1.494[b]			
	Female	1.625	1.617	1.621[a]	<0.001	0.673	0.865
	Mean	1.564	1.551				
Mortality (%)[1]	Male	2.67	2.72	2.70			
	Female	1.33	2.00	1.67	0.366	0.740	0.803
	Mean	2.00	2.36				

[a–b]Means in a column not sharing a common superscript are significantly different ($P < 0.05$) by Tukey's test.
Abbrevitions: MS, multistage; SS, single-stage.
*P-value of the analysis of variance of the variable sex.
**P-value of the analysis of variance of the variable incubator.
***P-value of the analysis of variance of the interaction between sex and incubator.
[1]Mortality was transformed into ASEN(RAIZ((%MORT/100) + 0.05)) before ANOVA.

can be confirmed that SS allows better embryonic development resulting chicks with better physical quality than MS.

It is known that SS systems allow for more precise control of the physical factors involved in incubation, especially temperature, thus attending more precisely to the physiological requirements of the embryo and, thus, better nutrient utilization and organ maturation (Araújo et al., 2016). As observed in the present study, SS provided a significant improvement over MS in the physical quality of neonatal chicks as reflected in yolk-free body weight, chick length, and quality score.

Results for hatchability consistently demonstrated better hatching in SS than in MS. Similar results were also observed by Mauldin (2006) in a comparative study of incubation yield in SS and MS. The better hatchability obtained in SS can be explained by the more efficient control of temperature, RH and ventilation. In addition, because eggs from the same batch are usually incubated together in SS, differences in eggshell weight, eggshell quality, and egg health are minimized. This, in turn, allows physical factors to be adjusted to the requirements of embryos, thereby more accurately guaranteeing the maintenance of homeostasis and consequently better development and quality. Despite the improved hatching rates, an economic analysis needs to be performed regarding the implementation and management of SS.

Later hatching in MS can be explained by the affirmations of Araújo et al. (2016) and Oviedo-Rondón et al. (2009) that heat exchange between old and young embryos does not occur efficiently in MS, such that young embryos are kept colder than that accepted by the scientific community, resulting in delayed embryo development. The control of hatch window is an important indicator of chick uniformity and of broiler performance.

Commercial hatcheries usually use the entire 504 h incubation period, considering it to be sufficient to maximize hatching. However, a great number of chicks hatch in less than 504 h, and thus spend long periods

inside hatcheries until they are removed. Long hatch windows cause dehydration, malformation of the thermoregulatory system due to caloric stress in the hatchery and immaturity of the gastrointestinal system due to the delay in supplying food and water, resulting chicks with poor physical quality (Araújo et al., 2016). Gustin (2003) affirms that chicks that stay for more than 12 h within hatcheries are subject to stress due to increased production of body heat, conditioned by the high temperature inside the hatchery, and respond with higher production of corticosterone hormone. High levels of corticosterone promote a reduction of bursa and spleen weight and decrease protein levels in the blood. These factors reduce bird immunity and consequently affect development.

The present study found hatch window to be satisfactory in both incubation systems with averages under 24 h. Although hatch intervals were higher in SS, the difference in hours was relatively short and did not negatively influence chick physical quality, as confirmed by the findings of the quality evaluation with SS hatching chicks having greater yolk-free body weight, greater length, and higher average quality score.

The removal of hatching chicks from both incubators occurred at the same time in all trials. Because hatching was advanced in SS, hatching chicks should be removed earlier and not at the same time as for MS. Despite hindering the work routine in the commercial hatchery, it is presumed that removal at different times would allow even more satisfactory results, especially better chick physical quality.

Air flow inside the setters can be considered an important factor that influences the hatch distribution curve or total hatching time (Meijerhof, 2003). According to this author, setters must have efficient air circulation inside the machine to uniformly heat the eggs in the initial period of embryonic development and to remove excess heat produced by embryos from the 10th d of incubation onward.

According to Gonzales (2012), the main influences of the incidence of mortality in the final incubation period are high temperatures, low ventilation and bad positioning of the eggs. The higher percentage of mortality in the final incubation period for MS can be explained by Oviedo-Rondón et al. (2009), who mention that MS does not have enough capacity to dissipate the heat produced by embryos in the final stage of development, which causes embryonic temperature to remain above optimum physiological temperature. Thus, stress caused by high temperatures at the end of the incubation period resulted in higher mortality in the final incubation period. The occurrence of increased rates of cracked eggs in MS can be explained by the increased handling of incubation trolleys that occurs when new egg loads are placed and repositioned inside the machines, with the manual transfer of trays being necessary. Thus, another positive point that can be emphasized with SS is the absence of a need for handling incubation trolleys during the entire process.

The higher incidence of live and dead pipped eggs in MS can be explained by the delay that occurred in the hatching process, and at the time that incubation trolleys were removed from hatcheries, there was still the possibility of outbreaks. The incubation process exerts a great influence on broiler production because the productive performance of birds is directly related to the quality of day-old chicks (Decuypere et al., 2001). According to Wineland and Oviedo-Rondón (2010), incubation in SS allows the maintenance of homeostasis throughout the entirety of embryo development, thus ensuring better nutrient utilization, organ maturation and, consequently, better quality and viability of broilers. However, the results found in the present study were not reflected in the performance of broilers that were incubated in SS.

Chick weight at the moment that they are placed in chicken houses is an important factor that can have a significant effect on broiler performance (Nangsuay et al., 2017). The higher initial body weight of male chicks from SS at the time they were placed reflected the average weight of the same group in all the periods analyzed. Although the difference was not significant, a higher average weight was observed for male broilers incubated in SS, regardless of the sex of birds. This relationship between initial weight and better performance at the end of the broiler production cycle was also observed by Leandro et al. (2006).

The potential performance of each sex, with better performance results for males, can be can be attributed exclusively to differences observed between males and females for body weight, body weight gain, feed intake, and feed conversion. Han and Baker (1993) affirmed that viability and uniformity of broilers are highly influenced by sex. Creating batches with sex separation is possible and can help stimulate maximum development of broilers because the nutrients supplied can be changed to satisfy the specific requirements of the sexes. In addition, the cost of production can be reduced and waste of feed avoided by properly regulating equipment for each sex.

According to Tzschentke and Halle (2009), there is a large differential in body weight between sexes, as evidenced mainly from the last half of the broiler production cycle. These authors affirm that males reared under the same conditions as females have higher body weights. The results found in the present study support this statement, with males having greater weight than females, but in the present case, the difference was observed from the first week and not only in the final phase of the broiler production cycle.

CONCLUSION

Artificial incubation of fertile eggs from Cobb broiler breeders should be performed in single-stage incubators to obtain better productivity. The single-stage system not only enhanced hatchability results, it also improved chick quality. Under optimal conditions, the incubator system did not influence broiler performance.

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DISCLOSURES

The authors declare no conflicts of interest.

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