

Effect of incubator tray location on broiler chicken growth performance, carcass part yields, and the meat quality defects wooden breast and white striping

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ABSTRACT Large variations in hatching egg incubation temperatures have been previously shown to negatively impact posthatch growth in broiler chickens. The objective was to determine whether small incubation temperature variations owing to incubator tray location (**LOC**) could alter posthatch female and male broiler growth performance and carcass characteristics. Broiler hatching eggs were obtained from a 40-week-old commercial broiler breeder flock and incubated in trays placed in the bottom (**BOT**), middle (**MID**), and top (**TOP**) thirds of the racks ($n = 4$ racks per incubator tray **LOC**) in a single-stage incubator in a commercial hatchery. Chicks hatched from the 3 **LOC** ($n = 720$ per **LOC**) were vent sexed, vaccinated, and separate-sex reared with 12 birds per pen in a floor-pen facility and fed a common corn and soybean meal-based diet for 41 d. At day 41, all birds ($n = 720$) were processed to determine carcass and carcass part yields and incidence and

severity of the meat quality defects wooden breast (**WB**) and white striping (**WS**). No **LOC** \times Sex interactions were observed ($P > 0.05$). Growth performance and incidence and severity of **WB** and **WS** were similar among **LOC** ($P > 0.05$). However, broilers from **BOT** trays had heavier tender and breast weights than broilers from warmer **MID** trays ($P < 0.05$). Broilers from the **BOT** trays had higher breast meat yield as a proportion of carcass weight (25.00%) than warmer **MID** (24.54%) broilers ($P < 0.05$). However, broilers from warmer **MID** trays had greater carcass yield than those from cooler **TOP** trays ($P < 0.05$). As expected, male broilers had heavier carcass, breast, tender, wings, drumsticks and thighs weights and were more severely affected by **WB** than females ($P < 0.05$). Overall, these data indicate that the inherent differences in environmental factors among incubation **LOC** can impact broiler carcass and breast meat yields.

Key words: incubation, broiler chicken, carcass yield, wooden breast, white striping

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INTRODUCTION

Incubation temperature is the most influential physical factor during chicken embryogenesis because it determines embryonic and posthatch growth, metabolism, and developmental characteristics (Sozcu and Ipek, 2015). However, achieving consistent internal egg temperature to cover the embryonic requirements thorough incubation is a challenge in the current broiler industry, and even when machinery is set to provide adequate conditions, most of the time, those conditions are not met (Gigli et al., 2009). Significant changes in incubation temperature during embryonic phases,

generally lead to cumulative negative impacts on the posthatch growth (Tong et al., 2013).

During embryogenesis, striated skeletal muscle development is achieved mainly by hyperplasia. Once the egg is fertilized, myogenesis begins around the 48th h of incubation with the formation of the somatic cells (Bellairs and Osmond, 1998). Cells from the somites will, posteriorly, be committed into the muscle lineage to form primary and secondary myofibers. In chickens, the first wave of myogenesis takes place from embryonic day (**ED**) 4 to 7 of incubation by the fusion of embryonic myoblasts and results in the formation of primary myofibers. Posteriorly, the second wave of myogenesis occurs from **ED** 8 to 12 of incubation by the fusion of fetal myoblasts and results in the formation of secondary myofibers (Crow and Stockdale, 1986; Al-Musawi et al., 2011). The primary myofibers serve as a scaffold for the formation of the secondary myofibers. Therefore, the number and size of primary myotubes can influence the total number of myofibers present at hatch (Zhang and McLennan,

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1999). The secondary myofibers are known to be more susceptible to environmental changes compared with primary myofibers. In chickens, it is known that primary and secondary myogenesis are completed by ED 12 (Yablonka-Reuveni, 1995). Primary and secondary myogenesis are the most important myogenic developmental windows and can be altered by incubation temperature. Hammond et al. (2007) demonstrated that stimulation of embryonic movement through egg incubation temperature results in muscle fiber hyperplasia and muscle growth in ovo by induction of myogenic factors. In addition, during the period of incubation, the chicken's embryo undergoes a series of physiological and thermoregulatory transitions from a poikilothermic to a homeothermic status, which must be considered when adjusting incubator settings (Lourens et al., 2006). Indeed, it is known that significant metabolic activity and heat production begins around day 4 of incubation (Black and Burggren, 2004; Hulet et al., 2007). Therefore, recent attention has focused on understanding chick embryonic development and the adequate temperature that must accompany those changes to ensure maximum growth potential. Recent studies have shown that extremely low temperatures during different stages of the incubation period result in lower metabolism and higher mortality, whereas high incubation temperatures result in shortening of the incubation period, malnutrition, and embryonic mortality (Suarez et al., 1996; Leksrisonpong et al., 2007; Willemsem et al., 2010). Although numerous reports indicate that large variations in incubation temperature, to either direction, can heavily impact embryonic developmental trajectory and therefore growth after hatch, limited formal research has been conducted to determine the effect of subtle changes of incubation temperature during key stages of myogenesis. Therefore, an experiment was conducted to determine the effects of incubator tray location (LOC) on both male and female broiler growth performance, carcass part yields, and incidence and severity of the meat quality defects wooden breast (WB) and white striping (WS).

MATERIALS AND METHODS

All procedures regarding live birds were approved by the Auburn University Institutional Animal Care and Use Committee (PRN 2015-2770).

Experimental Design

To evaluate the impact of incubator tray LOC and sex on broiler posthatch growth performance, carcass part yields, and incidence and severity of the meat quality defects WB and WS, a randomized complete block design experiment with a 3×2 factorial treatment structure was conducted. The 3 incubator tray LOC were designated based on the position of the egg trays (LOC) within an incubator rack (bottom 1/3 = **BOT**; middle 1/3 = **MID**; top 1/3 = **TOP**), while the 2 sexes of

broilers were (female = F; male = M; SEX) determined by vent sexing at hatch.

Hatchery Conditions

Hatching eggs from a 40-week-old commercial broiler breeder flock were incubated in a Cumberland 576 (Chick Master, Medina, OH) single-stage, 12-rack, 57,600-egg capacity incubator housed in a commercial hatchery running a temperature profile with an initial 4-hour pre-heat temperature of 31.11°C, an initial set point of 38.17°C, and an ending set point of 36.94°C with a 50% RH target. Incubator air temperature (Figure 1) was measured using the hatchery's wireless digital monitoring system (0.05°C accuracy). A total temperature differential among LOC of 0.25°C was achieved as mean air temperatures in the BOT, MID, and TOP trays were 38.09°C, 38.24°C, and 37.99°C, respectively ($P < 0.0001$). The air temperatures achieved for this experiment were considered typical for these LOC within the collaborating commercial hatchery. Eggs from a single 32-tray rack (150 eggs per tray) placed in the center of the completely full incubator were used for the experiment. The incubator rack tray LOC were designated as follows: trays 1, 3, 4, and 5 = BOT; trays 6, 7, 8, and 10 = MID; and trays 12, 13, 14, and 16 = TOP. Internal egg/embryo temperatures were measured by insertion of a thermometer probe accurate to $\pm 0.05^\circ\text{C}$ into the center of 4 randomly selected eggs as per tray LOC from day 2 to 13 of incubation. Internal egg temperatures are shown for the 3 tray LOC are shown in Figure 2. The room the incubator door opened to was maintained at 37°C and the door was kept open for as little time as possible while internal egg temperatures were measured to minimize temperature changes within the incubator.

Eggs were turned hourly before transfer to the hatcher on ED 18. Owing to logistical limitations in the collaborating commercial hatchery, neither starting egg weights nor O₂ and CO₂ concentrations were measured before or during incubation, respectively. On incubation day 18, all eggs were transferred to a Cumberland 192 (128 baskets; 19,200 egg-capacity) hatcher (Chick Master) maintaining incubation tray LOC until hatch. Logistical limitations prevented collection of egg residue break out data collection on an individual tray basis and, therefore, precluded statistical analysis of these data. However, percent moisture loss, percent fertility, and percent hatch of fertile were determined by the hatchery personnel on a tray LOC basis. The average moisture loss for eggs incubated in BOT, MID, and TOP incubator trays was 10.15, 10.46, and 10.25%, respectively. The fertility of eggs incubated in BOT, MID, and TOP incubator trays was 5.33, 6.00, and 4.67%, respectively. The hatchability of eggs incubated in BOT, MID, and TOP incubator trays was 92, 88.67, and 88.67%, respectively. The overall hatch of fertile for each tray LOC as obtained from available hatchery reports was 97.18, 94.33, and 93.01% for eggs incubated in BOT, MID, and TOP trays, respectively.

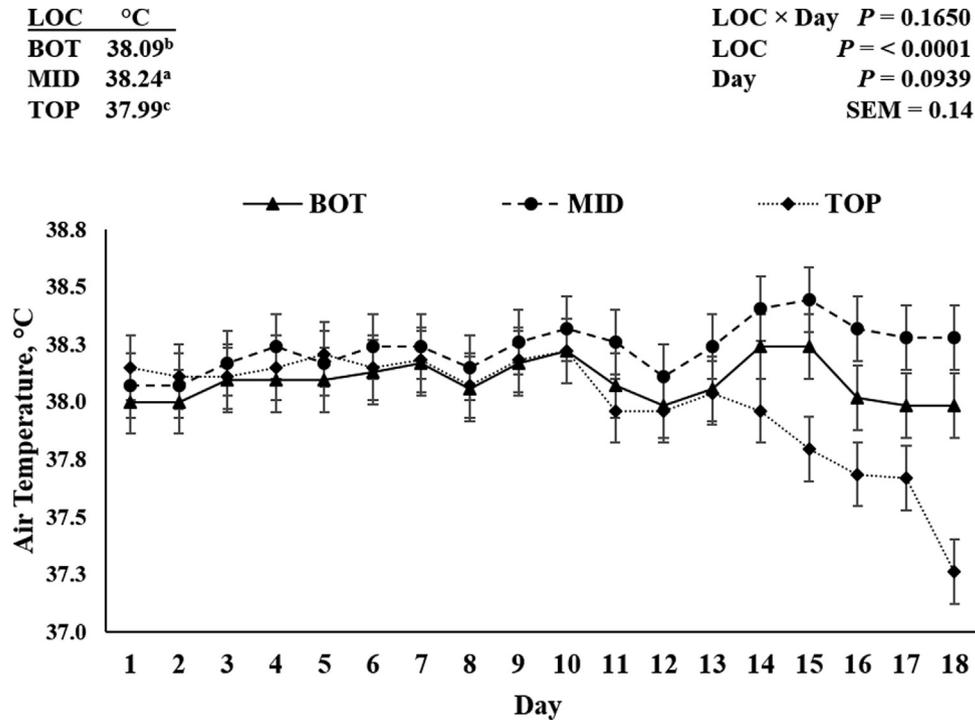


Figure 1. Incubator air temperature from eggs incubated in bottom (BOT), middle (MID), and top (TOP) trays from incubation day 1 to 18 measured using a digital wireless incubator temperature monitoring system. The mean air temperature from day 1 to 18 on the BOT, MID, and TOP trays were 38.09°C, 38.24°C, and 37.99°C, respectively ($P < 0.0001$). Abbreviation: SEM = pooled standard error of the LOC × D mean comparison. ^{a-c}Means within a column with different superscripts differ ($P < 0.05$).

Broiler Husbandry

Chicks hatched from the 3 different incubator tray LOC (240 per LOC; total $n = 720$) were vaccinated for Marek's disease, Newcastle disease, and infectious bronchitis, vent sexed, and transported to the Auburn University Poultry Science Research Unit in Auburn, AL. Chicks were randomly placed into floor pens ($n = 60$) equipped with hanging feeders and nipple drinker lines, bedded with new wood shavings ($n = 12$ birds per pen; 0.21 m^2 per bird) and sex-separated and reared for 41 d. Both water and feed were provided on an ad libitum basis. All birds were fed a common corn and soybean meal-based diet fed in 3 phases: starter (crumble) from day 1 to day 13, grower (pelleted) from day 14 to day 33, and finisher (pelleted) from day 34 to day 41. Diets were formulated based on common commercial broiler dietary nutrient recommendations (Table 1). Ambient temperature set points consisted of 33°C at placement with lowering in temperature based on bird comfort to reach a final temperature of 20°C. Birds were exposed to 23L:1D from 0 to 7 d of age, followed by 18L:6D for the remainder of the experiment. Light intensity was set at 30 lux from 0 to 7 d of age, 10 lux from 8 to 14 d of age, and 5 lux from 15 to 41 d of age.

Broiler Posthatch Growth Performance and Carcass Part Yields

Mortality was recorded on a daily basis, and pen feed intake and individual bird BW were determined

on day 13, 33, and 41 for the determination of mortality-corrected feed intake, BW gain, and feed conversion ratio (feed intake:BW gain; Table 2). On day 41, all birds ($n = 720$) were processed at the Auburn University Pilot Processing Plant after a 6-hour fast. Carcasses were static ice water bath chilled for 3 h before determination of chilled carcass and abdominal fat pad weights. The following day, the carcasses were deboned by professional commercial deboners, and the weights of the following carcass parts were determined: boneless and skinless breast (*pectoralis major* muscles); tenders (*pectoralis minor* muscles); bone-in, skin-on wings; bone-in, skin-on drums; and boneless, skinless thighs. Chilled carcass yield was calculated relative to day 41 fasted live BW. Carcass part yields were calculated as proportions of chilled carcass weights.

Meat Quality Defect (WB and WS) Scoring

Breast fillets were visually evaluated, palpated, and scored on a 4-point scale (0 = normal; 1 = mild; 2 = moderate; 3 = severe) for WB and WS. Fillets assigned WB and WS scores of 0 were considered normal and exhibited complete absence of the defect. Score 1 fillets were mildly affected (up to one-third of the fillet was affected), score 2 fillets were moderately affected (up to two-thirds of the fillet was affected), and score 3 were severely affected (the entire fillet was affected). All fillets were scored by the same trained and experienced evaluator.

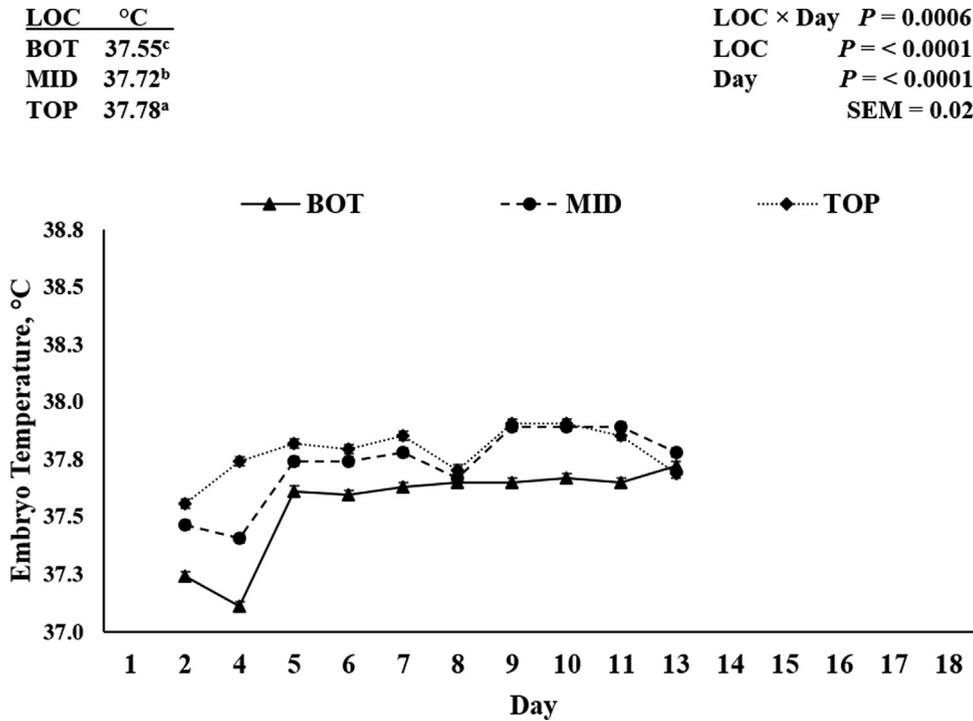


Figure 2. Internal embryo (egg) temperature from the bottom (BOT), middle (MID), and top (TOP) trays from incubation day 2 to 11 as per incubator tray location (LOC). Internal embryo temperature was measured (n = 4 per LOC per d) using a digital thermometer inserted into the center of 1 randomly selected egg per tray per location per d. The mean internal embryo temperature on the BOT, MID, and TOP trays were 37.55°C, 37.72°C, and 37.78°C, respectively (*P* < 0.0001). Abbreviation: SEM = pooled standard error of the LOC × D mean comparison. ^{a-c}Means within a column with different superscripts differ (*P* < 0.05).

Statistical Analysis

The experimental treatment structure was a 3 × 2 factorial arrangement consisting of 3 incubator LOC (BOT, MID, TOP) and 2 sexes (F and M). Each of the 6 resulting treatments was represented by 10 replicate pens each containing 12 birds that were incubated in 1 of 4 different trays per LOC. Data collected from the individual birds from each pen were pooled to generate an overall pen mean. All experimental data were analyzed with pen serving as the experimental unit and incubation LOC and pen LOC as the blocking factors with LOC and SEX serving as the fixed effects. Incubation air and embryo temperatures were not used as covariates as their variation was part of the incubation LOC treatment. Data were subjected to ANOVA using PROC GLIMMIX of SAS 9.4 using the following model:

$$Y_{ij} = \mu + \pi_i + \alpha_j + \pi\alpha_{ij} + \varepsilon_{ij}$$

where μ is the grand mean; π_i is independently normally distributed random block effect with mean 0 and variance σ^2_a ; α_j is the mean factor level analogous to the *j*th treatment such that $\sum \alpha_j = 0$; $\pi\alpha_{ij}$ is the interaction between the fixed factors levels and the treatments with mean 0 and variance σ^2_b ; and finally, ε_{ij} is an independently and identically distributed random error with mean 0 and variance σ . Satterthwaite adjustment was used to correct the degrees of freedom.

Proportional data (carcass part yields and WB and WS incidence) were analyzed using the events/

experiments syntax with a R-side covariance structure. For all hypothesis tests, treatment means were separated using the PDIF option and declared different when *P* < 0.05.

RESULTS AND DISCUSSION

Posthatch Broiler Growth Performance

No significant interactions among LOC and SEX were observed (*P* > 0.05). Therefore, only the main effects, LOC and SEX, are reported. Incubator tray LOC did not impact feed intake, feed conversion ratio, BW gain, or mortality of broilers reared to 41 d (*P* > 0.05; Table 2). This is in contrast to that of the studies by Leksrisomp et al. (2007) and Molenaar et al. (2011) who reported that broilers from eggs exposed to higher eggshell temperatures (39.5°C and 38.9°C, respectively) during the last third of the incubation period had lower BW during the grow out period because high temperatures reduced the yolk-free body mass and organ weights at hatch, causing subsequent impairments in the rearing period. In addition, it is known that chicks that survive semi-lethal high incubation temperatures consume less feed, grow slower, and have greater mortality when compared with normal treatments (Ernst et al., 1984). Other studies have shown that eggs exposed to lower air temperatures (34.6°C) can grow slower than those exposed to higher temperatures; however, their embryonic growth and development is the similar to those

Table 1. Ingredients and calculated nutrient composition of the common diets fed to broiler chickens incubated in different tray locations and reared to 41 d of age.

Variable	Starter	Grower	Finisher
	(day 1–13)	(day 14–33)	(day 34–41)
Ingredient (%)			
Corn	57.65	61.09	68.16
Soybean meal (48% CP)	35.15	31.66	25.61
Poultry oil ¹	3.06	3.00	2.98
Salt	0.45	0.45	0.46
Dicalcium phosphate	1.72	1.48	1.38
Limestone	1.28	1.18	1.00
DL-Methionine	0.31	0.89	0.16
L-Lysine, 98%	0.13	–	–
Vitamin premix ²	0.10	0.05	0.05
Mineral premix ³	0.10	0.10	0.10
Choline chloride (60%)	0.05	0.05	0.05
Total	100.00	100.00	100.00
Calculated values			
AME _n (kcal/kg)	3,064	3,090	3,182
CP, %	21.50	20.30	17.50
Methionine + Cysteine, %	1.00	1.50	0.75
Lysine, %	1.30	1.10	0.93
Calcium, %	0.95	0.85	0.75
Available phosphorus, %	0.45	0.40	0.38

¹Poultry oil was added as follows: 1% in the mixer and 2% spray-applied after pelleting.

²Vitamin premix provided the following per kilogram of diet: vitamin A (vitamin A acetate), 9,370 IU; vitamin D (cholecalciferol), 3,300 IU; vitamin E (DL-alpha tocopheryl acetate), 33 IU; menadione (menadione sodium bisulfate complex), 2 mg; vitamin B12 (cyanocobalamin), 0.02 mg; folacin (folic acid), 1.3 mg; D-pantothenic acid (calcium pantothenate), 15 mg; riboflavin (riboflavin), 11 mg; niacin (niacinamide), 44 mg; thiamin (thiamin mononitrate), 2.7 mg; D-biotin (biotin), 0.09 mg; and pyridoxine (pyridoxine hydrochloride), 3.8 mg.

³Mineral premix provided the following per kg of diet: Mn (manganese sulfate), 120 mg; Zn (zinc sulfate), 100 mg; Fe (iron sulfate monohydrate), 30 mg; Cu (tri-basic copper chloride), 8 mg; I (stabilized ethylenediamine dihydriodide), 1.4 mg; Se (sodium selenite), 0.3 mg.

eggs exposed to standard temperatures (Willemsen et al., 2010). This is also supported by Maatjens et al. (2017) who showed that even though the embryos with an eggshell temperature of 36.7°C during the last third of incubation have a delayed hatching process, their development and growth are the similar or even improved when compared with eggshell temperatures 37.8°C and 38.9°C, resulting in higher quality chicks with greater BW during the first week of the grow out period. This improvement was not caused by an increase in the feed intake, therefore the feed efficiency of such broilers was increased.

Our results suggest that subtle changes such as 0.25°C in incubation temperature among tray LOC may not be severe enough to have detectable effects in the overall growth performance during posthatch period. These results may also be due the inherent temperature resilience of avian embryos. It is known that intermittent changes in temperature have differential effects on embryonic metabolism without affecting embryonic growth or hatchability (Willemsen et al., 2011). Therefore, embryos are capable of enduring small changes in incubation temperature and maintain a steady state throughout incubation not allowing major physiological changes that can impair the subsequent posthatch growth. However, it is important to underscore that

Table 2. Effect of incubator tray location on post-hatch growth performance of broiler chickens reared to 41 d of age.

Variable ¹	Incubator tray location			SEM	P-value
	Bottom	Middle	Top		
FI, g	4,937	4,939	4,927	68	0.991
BWG, g	3,269	3,290	3,300	51	0.906
FCR	1.513	1.515	1.511	0.026	0.993
Mortality, %	5.0	3.7	3.3	0.014	0.668

Abbreviations: BWG, mortality-corrected BW gain; FI, mortality-corrected feed intake; FCR, mortality-corrected feed conversion ratio; SEM, largest pooled standard error of the pairwise mean comparisons.

¹Broilers from eggs incubated in different incubator tray locations all received a common corn and soybean meal-based diet provided in 3 phases: starter (day 1–13), grower (day 14–33), and finisher (day 34–41). Pen served as the experimental unit with 20 replicate pens (12 birds per pen) per treatment.

larger variations in incubation temperature have direct effects on embryonic growth and metabolism as seen in other studies (Lourens et al., 2006; Molenaar et al., 2011; Maatjens et al., 2016). Finally, it is known that in large-scale chicken egg incubation, most of the time, it is likely to find differences up to 5°C in incubation temperature owing to structural and physical factors intrinsic to the incubator that last for the entire period of incubation and can really have a harmful effect on embryonic development and subsequently that might affect growth performance (Gigli et al., 2009).

In this study, the major differences observed in broiler growth performance were primarily due to SEX. As expected, based on the primary breeder performance objectives, M broilers had higher feed intake ($P < 0.004$), greater BW gain ($P < 0.0001$), and lower feed conversion ratio ($P < 0.006$) than F through the 41-day rearing period (Table 3). It has been previously reported that M broilers can consume up to 13% more feed, gain 22% more weight, and improve 7.3% feed efficiency when exposed to the same environmental conditions and fed the same diet compared with F (Howlider and Rose, 1992).

Broiler Carcass Characteristics

No significant interactions between LOC and SEX were observed for carcass part weights. Therefore, only the main effects, LOC and SEX, are reported and discussed. Incubator tray LOC did not affect whole carcass, abdominal fat pad, wing, drum, and thigh weights ($P > 0.05$; Table 4). However, broilers from BOT trays had heavier breast ($P < 0.05$) and tender muscle weights ($P < 0.05$) than those from MID trays (Table 4). This is in contrast with previous studies that have shown that increases in incubation temperature during late embryogenesis, when satellite cells are being formed, can stimulate satellite cell proliferation, leading to higher potential for posthatch skeletal muscle hypertrophic growth (Piestun et al., 2009). However, it is known that warmer temperatures during early or late incubation can impact carcass part weights and yields negatively by affecting the embryonic developmental trajectory. The continuous exposure of eggs to high temperature generally

Table 3. Effect of sex on post-hatch growth performance of broiler chickens reared to 41 d of age.

Variable ¹	Sex		SEM	P-value
	Female	Male		
FI, g	4,707	5,162	56	<0.001
BWG, g	2,975	3,597	42	<0.001
FCR	1.583	1.440	0.021	<0.001
Mortality, %	3.1	4.9	0.012	0.252

Abbreviations: BWG, mortality corrected BW gain; FCR, mortality-corrected feed conversion ratio; FI, mortality-corrected feed intake; SEM, largest pooled standard error of the pairwise mean comparisons.

¹All birds received a common corn and soybean-meal based diet provided in 3 phases: starter (day 1–13), grower (day 14–33), and finisher (day 34–41). Pen served as the experimental unit with 30 replicate pens (12 birds per pen) per treatment.

results in impairments in embryonic development and significantly inadequate carbohydrate and lipid metabolism. The inability of the embryo to use all the nutrients from the yolk causes the retardation and disability of the embryonic growth, resulting in poor performance during the grow out period (Willemssen et al., 2010). Clark et al. (2017) reported that broilers from eggs exposed to 12 h of higher air temperature (39.5°C) daily from ED 14 to ED 18 had lower breast weights than those from the eggs exposed to the same higher temperatures for just 3 h daily. Although different studies seem to contrast each other, it is important to underscore that eggs were exposed to the treatment temperature in different phases throughout embryogenesis. Therefore, the differences in the duration and magnitude of the temperature change and the period when they occurred help explain why these results differ.

In this study, abdominal fat pad, tender, wing, drum, and thigh yields were not affected by LOC ($P > 0.05$). Although broilers from MID trays had a lower breast and tender weight, they had a greater carcass yield as a proportion of day 41 BW than those from the TOP trays ($P < 0.05$). However, broilers from the MID trays

had significantly lower breast meat yield as a proportion of carcass weight (24.54%) than BOT (25.00%) broilers ($P < 0.05$). In contrast with these results, Molenaar et al. (2011) reported that broilers exposed to a higher eggshell temperature (38.9°C) from ED 7 onwards had 1% higher PM meat yield than those exposed to normal eggshell temperature (37.8°C). These results indicate that even subtle variations in incubation temperature can affect carcass composition when they are applied during important embryonic developmental periods. Similar to those results, Janisch et al. (2015) reported that broilers from eggs incubated at higher air temperatures (38.8°C) from ED 7 to ED 10 had heavier carcass and carcass parts than those from eggs exposed to lower air temperatures (36.8°C). However, their carcass and carcass part yields were lower than those from lower temperatures. In addition, previous studies demonstrated that posthatch performance of broilers from eggs exposed to high temperatures is impaired because of inadequate embryonic growth resulting in lower weights and higher mortality (Molenaar et al., 2011). This is likely because high temperatures have slightly negative impacts on the development of cellular components that lead to cumulative negative effects on adults (Watcharapong et al., 2016).

Males had heavier carcass and carcass parts weights, except for abdominal fat pad when compared with F ($P < 0.001$; Table 5). It is known that M and F broilers have distinctively different developmental trajectories that are led by changes in molecular and gene expression profile. Males had greater carcass yield as a proportion of BW as well as greater drum and thigh yields as proportions of chilled carcass when compared with F ($P < 0.01$; Table 5). Females had greater proportions of fat pad and tenders as proportions of chilled carcass than M, though in this study, breast yield as a proportion of chilled carcass weight was similar among SEX ($P < 0.05$; Table 5). Overall, these results are in alignment with

Table 4. Effect of incubator tray location on carcass part weights and yields of broiler chickens reared to 41 d of age.

Variable	Incubator tray location			SEM	P-value
	Bottom	Middle	Top		
Carcass weight, g	2,361	2,337	2,328	13.7	0.158
Abdominal fat pad, g	45.35	44.82	43.65	0.8	0.297
Breast (boneless, skinless), g	590 ^a	573 ^b	578 ^{a,b}	4.8	0.035
Tenders, g	130 ^a	127 ^b	128 ^{a,b}	1.1	0.046
Wings (bone-in), g	264	261	260	1.6	0.155
Drums (bone-in), g	298	298	296	2.1	0.737
Thighs (boneless, skinless), g	323	319	322	3.1	0.549
Proportion of carcass parts ¹					
Chilled carcass, %	71.62 ^{a,b}	72.16 ^a	71.43 ^b	0.21	0.041
Abdominal fat pad, %	1.91	1.91	1.86	0.03	0.502
Breasts, %	25.00 ^a	24.54 ^b	24.88 ^{a,b}	0.13	0.029
Tenders, %	5.55	5.46	5.50	0.04	0.276
Wings, %	11.18	11.17	11.16	0.05	0.978
Drums, %	12.60	12.76	12.71	0.06	0.269
Thighs, %	13.67	13.65	13.86	0.10	0.269

^{a-b}Means within a row with different superscripts differ ($P < 0.05$).

Abbreviation: SEM, largest pooled standard error of the pairwise mean comparisons. Pen served as the experimental unit with 20 replicate pens (12 birds per pen) per treatment.

¹Chilled carcass yield as proportion of fasted live BW on d 41 and carcass part yields are proportions of chilled carcass weight.

Table 5. Effect of sex on carcass part weights and yields of broiler chickens reared to 41 d of age.

Variable	Sex		SEM	P-value
	Female	Male		
Carcass weight, g	2,138	2,546	10.4	<0.001
Abdominal fat pad, g	49.38	39.84	6.5	<0.001
Breast (boneless, skinless), g	532.8	628.3	3.9	<0.001
Tenders, g	122.5	134.7	0.9	<0.001
Wings (bone-in), g	239	284	1.3	<0.001
Drums (bone-in), g	264	331	1.7	<0.001
Thighs (boneless, skinless), g	290	353	2.5	<0.001
Proportion of carcass parts ¹				
Chilled carcass, %	71.42	72.04	0.17	0.011
Abdominal fat pad, %	2.3	1.56	0.02	<0.001
Breasts, %	24.92	24.69	0.11	0.113
Tenders, %	5.72	5.28	0.03	<0.001
Wings, %	11.18	11.16	0.04	0.740
Drums, %	12.36	13.02	0.06	<0.001
Thighs, %	13.58	13.88	0.08	0.011

Abbreviation: SEM, largest pooled standard error of the pairwise mean comparisons. Pen served as the experimental unit with 30 replicate pens (12 birds per pen) per treatment.

¹Chilled carcass yield as proportion of fasted live BW on d 41 and carcass part yields are proportions of chilled carcass weight.

other studies and commercial broiler performance guides that have previously demonstrated M broilers typically have heavier carcass and greater proportions of carcass and carcass parts when compared with F (Bogosavljevic-Boskovic et al., 2006; Tona et al., 2010).

Meat Quality Defects: WB and WS

The impact of incubation parameters on the development of the breast meat quality defects WB and WS has not been well studied and is poorly understood at this time. No interactions were observed among the main effects of LOC and SEX on the incidence and severity of the breast meat quality defects WB and WS ($P > 0.05$); therefore, only main effects will be discussed in the following text. Incubation LOC did not alter the incidence or severity of the meat quality defect WB (Table 6). However, M broilers were more severely affected by WB than F (Table 7). Females had greater incidence of WB score 1 and WB score 2 ($P < 0.02$), whereas the M broilers were more severely affected, exhibiting a greater incidence of WB score 3 than F ($P < 0.001$; Table 7). Incidence of the WS meat quality defect was unaffected by both LOC and SEX (Table 6). Previously, Clark et al. (2017) demonstrated that exposure to increased incubation air temperatures during late stage incubation reduced both breast weight and the severity of WB in broilers. These results combined with the current work warrant further investigation of the link between incubation conditions and their impact on embryonic muscle development and growth and the development and severity of WB and WS.

In conclusion, we have demonstrated incubator tray LOC can impact broiler carcass yields. We observed that broilers from MID trays had a 0.46% lower breast yield compared with those from BOT trays. This difference in breast yield equates to 17 g of breast meat per broiler (Table 4). Using the 9 billion broilers harvested

Table 6. Effect of incubator tray location on the incidence and severity of wooden breast and white striping in breast fillets of broiler chickens reared to 41 d of age.

Variable ^{1, 2}	Incubator tray location			SEM	P-value
	Bottom	Middle	Top		
Wooden breast score 0, %	1.84	2.79	1.78	0.91	0.740
Wooden breast score 1, %	18.89	21.41	24.56	3.57	0.500
Wooden breast score 2, %	47.04	42.54	44.95	3.58	0.675
Wooden breast score 3, %	29.40	28.85	24.91	3.80	0.651
White striping score 0, %	32.72	34.14	39.23	4.02	0.479
White striping score 1, %	52.02	50.85	50.89	3.46	0.963
White striping score 2, %	13.99	14.36	9.37	2.82	0.339
White striping score 3, %	-	-	-	-	-

Abbreviation: SEM, largest pooled standard error of the pairwise mean comparisons.

¹Breast fillets of all birds ($n = 720$) were visually evaluated, palpated, and scored on a 4-point scale for each meat quality defect by the same evaluator where score 0 = normal; score 1 = mildly affected; score 2 = moderately affected; and score 3 = severely affected. Pen served as the experimental unit with 20 replicate pens (12 birds per pen) per treatment.

²Proportion of the total number of breasts scored per treatment.

in the United States per year as an example, these seemingly small changes in breast meat yield resulted in losses of 150 MT of breast meat per year for the poultry industry. These losses are not trivial, and this underscores the importance of careful incubator management, regardless of incubator type. It is not clear, however, what other factors such as ventilation (O₂ and CO₂ concentrations) and humidity in addition to the relatively small (0.25°C) changes in air and embryo temperatures influenced by LOC are impacting embryonic development in this study.

There is not a clear consensus in the scientific literature regarding the optimal incubation temperature, humidity, and ventilation parameters to produce the highest quality chicks capable of reaching their genetic potential for muscle growth and meat yield. Proper embryonic muscle development (myogenesis) requires the coordination of a myriad of cellular and molecular events within the embryos that must not be negatively

Table 7. Effect of sex on incidence and severity of wooden breast and white striping in breast fillets of broiler chickens reared to 41 d of age.

Variable ^{1, 2}	Sex		SEM	P-value
	Female	Male		
Wooden breast score 0, %	2.01	2.18	0.86	0.882
Wooden breast score 1, %	32.45	13.55	2.98	<0.001
Wooden breast score 2, %	49.54	40.23	2.9	0.027
Wooden breast score 3, %	15.77	43.88	3.23	<0.001
White striping score 0, %	37.88	32.83	3.27	0.278
White striping score 1, %	48.21	54.29	2.84	0.130
White striping score 2, %	13.07	11.72	2.19	0.663
White striping score 3, %	-	-	-	-

Abbreviation: SEM, largest pooled standard error of the pairwise mean comparisons.

¹Breast fillets of all birds ($n = 720$) were visually evaluated, palpated, and scored on a 4-point scale for each meat quality defect by the same evaluator where score 0 = normal; score 1 = mildly affected; score 2 = moderately affected; and score 3 = severely affected. Pen served as the experimental unit with 30 replicate pens (12 birds per pen) per treatment.

²Proportion of the total number of breasts scored per treatment.

influenced by the incubation environment. Alterations in those physiological events can divert the normal course of muscle tissue formation, shifting the normal developmental trajectory curve to either direction based on the direction, duration, and magnitude of the change in incubation temperature. What is clear, though, is that many factors, including incubator tray LOC, can impact broiler carcass composition and yields.

In commercial broiler hatcheries, the management of incubation parameters such as temperature, humidity, and adequate ventilation is not simple and often seems to be specific to the different hatcheries, sexes, genetic lines of birds, breeder flock sources, and so on. Even when the incubation machines are set to meet embryonic requirements, many times those requirements are not actually met owing to a myriad of outside factors, leading to higher embryonic mortality, poor chick quality, and reduced growth efficiency and meat yields. The causes and mechanisms behind these changes in carcass composition and characteristics observed here are unclear and merit further investigation. Therefore, further investigation is needed to determine the impact of subtle changes in incubation temperature, humidity, and gas concentrations during critical muscle development windows on broiler muscle fiber number, myogenic stem cell populations, and skeletal muscle fiber growth characteristics. Future work in this area will provide a better understanding about effect of incubation conditions on embryonic muscle development, which can be used to improve the current management practices that will in turn improve broiler performance and yield, and possibly lower the incidence of meat quality defects such as WB and WS.

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DISCLOSURES

The authors declare no conflicts of interest.

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