Broiler incubation. 2. Interaction of incubation and brooding temperatures on broiler chick feed consumption and growth[1]

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ABSTRACT The effect of either hot or cool brooding litter temperature on feed consumption, BW, and mortality of broiler chicks that had been exposed to either normal or high temperature during latter stages of incubation was studied in 2 experiments. The duration of experiments 1 and 2 was 14 and 21 d, respectively, with BW and feed consumption determined at 2, 5, 7, and 14 d of age in experiment 1 and at 7, 14, and 21 d of age in experiment 2. High incubator temperature after embryonic d 16 decreased chick feed consumption and BW at all ages in both experiments. Hot brooding litter temperature increased feed consumption at 2 and 5 d in experiment 1 and at 7 d in experiment 2 but decreased feed consumption at 14 and 21 d in experiment 2. Feed consumption was also influenced by the incubation temperature × brooding litter temperature interaction. From 0 to 2 d or 0 to 7 d in experiments 1 and 2, respectively, the highest to lowest feed consumption was exhibited by the normal-hot, high-hot, normal-cool, and high-cool interaction groups but the order changed to normal-cool, normal-hot≈high-cool, and high-hot from 7 to 14 and 14 to 21 d in experiment 2. Significant effects on mortality were observed in experiment 2 only where males exhibited greater mortality that was most evident in the combination of high temperature incubation followed by cool brooding. Excessive (high) eggshell temperature during the latter stages of incubation reduced feed consumption and BW through 21 d of age. However, the results showed that the hot brooding litter temperature supported increased feed consumption during the first few days of brooding even for the chicks that had been subjected to high incubation temperature. Hot brooding also reduced male mortality in experiment 2. Nonetheless, hot brooding litter temperatures should be limited as extending beyond a few days eventually decreased feed consumption.

Key words: incubation, brooding, chick quality, feed consumption, livability

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INTRODUCTION

There is a point where an increase in incubation temperatures above the optimal not only accelerates growth rates of avian embryos (Romanoff, 1960; Christensen et al., 1999) but has also been reported to begin to negatively affect hatchability, feed conversion, BW, and general posthatch chick performance (Michels et al., 1974; Decuypere, 1979; Gladys et al., 2000). Evidence has shown that high embryo temperatures during incubation can lead to reduced chick growth during the subsequent brooding period due to heat-stressed chicks being less alert and more sensitive to poor posthatch brooding conditions. These chicks also had an abnormal appearance (Thompson et al., 1976; Leksrisompong et al., 2007). Nonstandard incubation temperatures have also been shown to adversely affect major organ development (Shafey, 2004; Leksrisompong et al., 2007), which may account for some of the aforementioned signs and problems. Observation of commercial incubators by the present authors has generally revealed an elevated egg temperature beginning from about embryonic d (**E**)16 of incubation that reached 39 to 41°C by E19 of incubation.

Brooding, the provision of a warm place for the young chick, has long been known to be a critical aspect of management that may determine subsequent performance of the broiler chicken (Osbaldiston and Sainsbury, 1963). Chick quality problems and behavior

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have been shown to be influenced by brooding conditions at placement. Chicks that had survived exposure to high incubation temperatures consumed less feed, grew slower than normal, and had a greater chance of dying when compared with those that were exposed to lower incubation temperatures after arrival at a farm and placement at normal thermal conditions (Ernst et al., 1984; Henken et al., 1987). Scott and Washburn (1985) suggested that during the first 5 d of the brooding period, the temperature should be around 32.0°C, even though the thermoregulatory mechanism of the chickens was expected to develop very rapidly, to have competitive broiler production results. The most important management factor was to have the chicks move and eat during the first 2 d of the brooding period. The present authors had observed that chicks that had been exposed to elevated temperatures during late incubation often exhibited cool feet, which may have contributed to poor mobility and reduced feed consumption. According to Moraes et al. (2002), development during the first week of life of a chick was important to their future performance because physiological processes such as cell hyperplasia and hypertrophy, maturation of the thermoregulatory and immunological systems, as well as growth and differentiation of the gastrointestinal tract would subsequently influence BW and feed conversion until market age. Thus, the logic of the present research was that a chick that had been compromised metabolically by high incubation temperatures might benefit from elevated brooding litter temperature that would promote feed intake and subsequent growth.

MATERIALS AND METHODS

General

Experimentation was approved by the Institutional Animal Care and Use Committee. Broiler hatching eggs produced by a resident Ross 344 × Ross 308 flock (Aviagen, Huntsville, AL) were collected during a 2 to 3 d period and stored at 16.0°C and 65% RH for less than 5 d before setting in each experiment. The incubators were initially operated at 37.4°C. Automatic controllers maintained 53% RH throughout incubation. Eggshell temperatures during incubation were determined daily with a Braun Thermoscan thermometer (Type 6012, The Gillette Company, Boston, MA) as described previously (Leksrisompong et al., 2007). The machine controls were adjusted to maintain the eggshell temperature in the 37.5 to 37.7°C range with egg rotation every 30 min (experiment 1) or hourly (experiment 2) from setting until experimental treatments began at E16 of incubation. Proper machine operation was verified by insertion of an ASTM mercury thermometer (Fisher Scientific, Hampton, NH) and an electronic humidity stick (Testo 605-H1, Testo Inc., Flanders, NJ) each day.

The eggs were transferred to hatching baskets and returned to the same machine at the end of E19 in each experiment where the temperature treatments were continued. At E21.5 of incubation, the chicks that had completed the hatching process were removed from the trays, counted, weighed, sexed using the feather-sexing method, permanently identified with neck tags, and placed in floor pens on new wood litter shavings. Hatchability was determined. During the first 5 d, there was a gallon chick font provided for supplemental water and half of a 30-egg paper flat was used for supplemental feed in each pen. The brooding facilities were preheated for 48 h before chick placement to achieve a stable and uniform litter temperature. Litter temperatures were determined with a Traceable infrared thermometer gun (Fisher Scientific, Control Company, Friendswood, TX) by randomly checking 2 dry spots in each pen at 1300 h each day during the brooding period. These litter temperatures were used to adjust the air temperature each day. Air temperatures were determined daily with maximum-minimum mercury recording thermometers hung at bird level in each brooding area. Chicks were observed twice daily for mortality and all dead chicks were weighed and recorded by sex. The chicks were exposed to 23 h of light daily in both experiments but the light intensity was 70 lx in experiment 1 and 25 lx in experiment 2.

Experiment 1

There were 1,440 eggs collected from a 48-wk-old broiler breeder flock set in a Natureform model NMC-2000 (Natureform International, Jacksonville, FL) incubator that held eleven 180-egg trays to E15 of incubation. There were 8 trays of experimental eggs placed in the machine with 1 tray of extra eggs placed above and 2 trays of extra eggs placed below the experimental eggs to ensure uniform airflow in the machine. There were 120 eggs numbered consecutively for subsequent daily temperature determination. At E15 of incubation, the eggs were transferred to 2 Natureform model NOM-45 incubators that held five 180-egg trays of chicken eggs each. A tray of extra eggs was placed in the lower position in each machine to maintain uniform air flow. Four trays were transferred to the incubator designated to reach a high temperature of greater than 39.4°C and the remaining trays were transferred to the incubator designated to incubate the eggs at a normal temperature of approximately 37.6°C (Figure 1). Determination of eggshell temperatures was discontinued once chicks began to hatch, but differences in machine temperatures that produced the eggshell differences shown in Figure 1 were maintained.

There were a total of 64 pens in 4 brooding rooms with 16 pens per room. Each 85.1 cm × 90.2 cm pen had two 13.5 cm × 36.3 cm × 26.7 cm feeders and 3 nipple drinkers to provide feed and water for ad libitum consumption. Two of the brooding rooms were operated at cool brooding litter temperatures with 28.5°C litter temperature at placement and 2 rooms were operated at hot brooding litter temperatures with 36.1°C

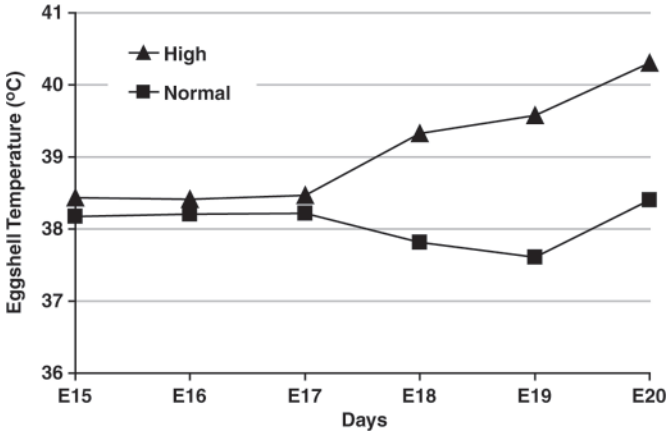

Figure 1. Eggshell temperatures as a result of high and normal air temperature incubation in experiment 1. The triangle symbols represent the high temperature eggs and the square symbols represent the normal temperature eggs. Differences in machine temperatures that produced these results were maintained through hatching at embryonic d (E) 21.5.

litter temperature at placement (Figure 2). There were 14 male and 14 female chicks from the 2 incubation regimens allocated equally and sex separate to 8 pens within each brooding treatment room for a total of 896 chicks. Chicks were group-weighed by sex and pen at placement (0 d) and at 2, 5, 7, and 14 d of age. Feed consumption was determined at 2, 5, 7, and 14 d of age.

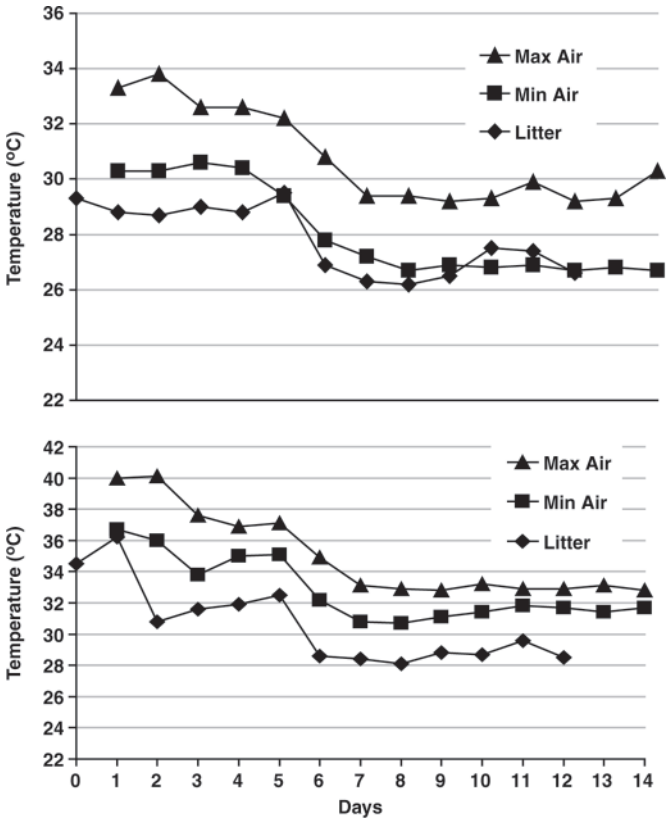

Figure 2. Daily maximum air, minimum air, and litter temperatures in the cool brooding (upper panel) or hot brooding (lower panel) rooms in experiment 1. The triangle symbols represent the daily maximum air (Max Air) temperature, the square symbols represent the daily minimum air (Min Air) temperature, and the diamond symbols represent the litter temperature taken at 1300 h each day.

Experiment 2

Eggs from the same broiler breeder flock at 52 wk of age were used. To add greater scope to this study, a Jamesway model 252B incubator (Butler Manufacturing Co., Ft. Atkinson, WI) that held fourteen 180-egg trays was used to set 2,520 eggs. There were 84 eggs numbered consecutively for subsequent daily monitoring of egg temperature. At E14 of incubation, half of the eggs were transferred to a second Jamesway machine designated to reach a high temperature of greater than 40.7°C by E19 of incubation and the original machine was designated to incubate the eggs at a normal temperature of approximately 37.5°C (Figure 3). Determination of eggshell temperatures became impossible once chicks began to hatch but differences in machine temperatures that produced the eggshell differences shown in Figure 3 were maintained through the completion of hatching.

To further increase the scope of this study, a different facility with 72 pens was divided into 2 brooding areas with 14 male plus 14 female chicks in each of 36 pens within each brooding area for a total of 1,008 chicks. Each pen had 2 tube feeders and one bell-type drinker to provide feed and water for ad libitum consumption. There was 1 supplemental chick font and 3 paper trays for supplemental feed used to 7 d of age in each pen. One of the brooding areas was operated at cool brooding litter temperatures near 25.9°C and the second was operated at hot brooding litter temperatures near 33.5°C (Figure 4) at placement. Mixed sex chicks were group-weighed by pen at placement (0 d) and at 7, 14, and 21 d of age. Feed consumption was determined at 7, 14, and 21 d.

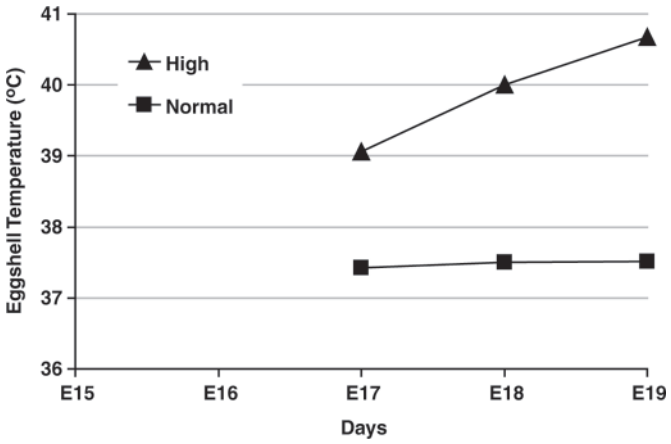

Figure 3. Eggshell temperatures as a result of high and normal air temperature incubation in experiment 2. The triangle symbols represent the high temperature eggs and the square symbols represent the normal temperature eggs. Differences in machine temperatures that produced these results were maintained through hatching at embryonic d (E) 21.5.

Statistical Analyses

Pen was the experimental unit in both experiments. In experiment 1, a split-plot design was utilized taking brooding litter temperature as the main plot, whereas incubation temperature, sex, and all the interactions were in the subplot. In experiment 2, a split-plot design was also utilized taking brooding litter temperature as the main factor, whereas incubation temperature and the interactions were in the subplot for feed consumption and BW. Mortality was analyzed as for experiment 1. Analyses of variance using the PROC MIXED procedure were employed to evaluate the data and the LS MEANS procedure was used to partition means (SAS Institute, 1998). Unless otherwise stated, statements of statistical significance were based upon $P \leq 0.05$.

RESULTS

Experiment 1

Hatchability was not significantly affected (data not shown). The effect of incubation temperature, brooding litter temperature, sex, and the incubation temperature × brooding temperature interaction on feed consumption of male and female broilers to 14 d of age is shown in Table 1. Feed consumption was significantly decreased by increased incubation temperature at all ages, whereas hot brooding increased feed consumption during the 0 to 2 and 2 to 5 d periods. Males consumed less feed than did females during the 0 to 2 d period but consumed more feed during the 7 to 14 d period. The incubation temperature × brooding litter temperature interaction at 0 to 2 d was largely due to chicks initially consuming less feed after they had been incubated at the high temperature followed by cool brooding, whereas chicks incubated at normal temperature followed by hot brooding consumed the most feed. However, this did not produce an interaction effect with respect to BW at 2 d of age (data not shown for brevity).

The effect of incubation temperature, brooding litter temperature, and sex on BW of male and female broilers to 14 d of age is shown in Table 2. Body weight was significantly decreased by increased incubation temperature at all ages, whereas hot brooding litter temperature numerically increased BW at 2 d only. Males exhibited heavier BW than did females at 0, 5, 7, and 14 d of age.

Mortality was generally low and there were no significant effects observed. These data were omitted for brevity.

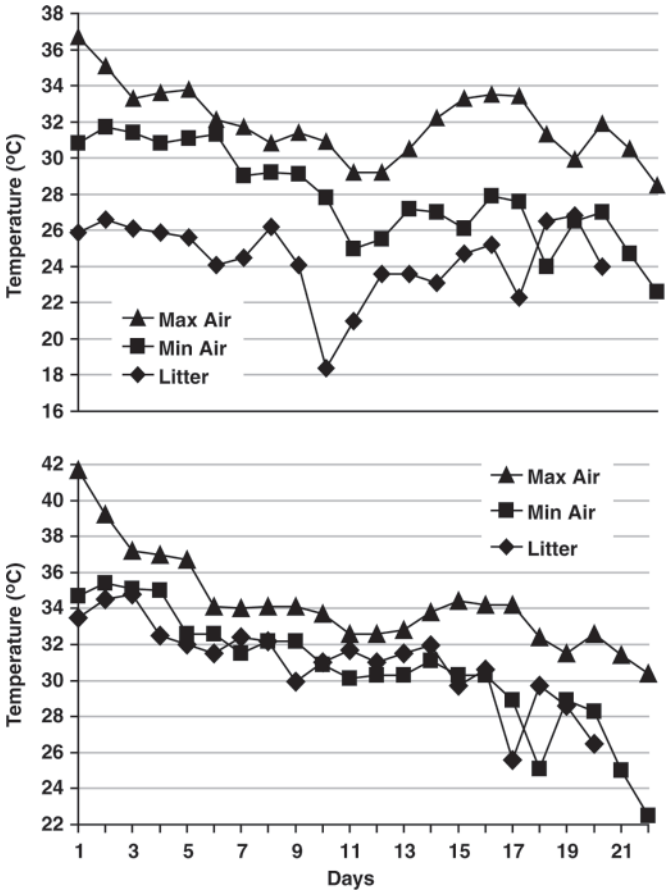

Figure 4. Daily maximum air, daily minimum air, and litter temperatures in the cool brooding (upper panel) or hot brooding (lower panel) rooms in experiment 2. The triangle symbols represent the daily maximum air (Max Air) temperature, the square symbols represent the daily minimum air (Min Air) temperature, and the diamond symbols represent the litter temperature taken at 1300 h each day.

Experiment 2

Hatchability was not significantly affected (data not shown).The effect of incubation temperature, brooding litter temperature, and the incubation temperature × brooding litter temperature interaction on feed consumption of mixed sex broilers to 21 d of age is shown in Table 3. Feed consumption was significantly decreased by increased incubation temperature at all ages. Feed consumption was increased by increased brooding litter temperature during the 0 to 7 d period but decreased during the 7 to 14 and 14 to 21 d periods. Feed consumption was significantly affected by the incubation temperature × brooding litter temperature interaction during all periods. Hot-brooded chicks that had been incubated in the normal incubator consumed the most feed, whereas cool-brooded chicks that had been incubated in the hot incubator consumed the least amount of feed during the 0 to 7 d period. Cool-brooded chicks that had been incubated in the normal incubator consumed the most feed, whereas hot-brooded chicks that had been incubated in the high incubator consumed the least amount of feed during the 7 to 14 and 14 to 21 d periods. The other 2 groups responded similarly during the latter 2 time periods.

The effect of incubation temperature, brooding litter temperature, and the incubation temperature × brooding litter temperature interaction on BW of broilers to 21 d of age is shown in Table 4. The BW was significantly decreased by increased incubation temperature at all ages and by increased brooding litter temperature

Table 1. Feed consumption of broilers as affected by incubation temperature, brooding temperature, sex, and the incubation temperature × brooding temperature interaction in experiment 1

	Feed consumption for ages shown (g)				
Item	0 to 2 d	2 to 5 d	5 to 7 d	0 to 7 d	7 to 14 d
Incubation[1] temperature					
High	27.6^{B}	78.4^{B}	79.5^{b}	185.5^{B}	425.0^{b}
Normal	30.4^{A}	85.8^{A}	86.2^{a}	202.5^{A}	462.8^{a}
SEM	0.8	1.8	2.3	4.0	19.1
Brooding[2] temperature					
Hot	31.7^{a}	85.5^{x}	83.8	201.1	434.5
Cool	26.2^{b}	78.7^{y}	82.0	187.0	453.3
SEM	1.0	1.8	2.5	4.6	25.1
Sex					
Male	28.2^{b}	81.8	83.6	194.4	463.6^{A}
Female	29.7^{a}	82.5	82.2	193.7	424.2^{B}
SEM	0.8	1.8	2.3	4.0	19.1
Incubation temperature/brooding temperature					
High/hot	30.9^{ab}	80.9	78.6	190.6	416.3
Normal/hot	32.5^{a}	90.1	89.0	211.7	452.7
High/cool	24.0^{c}	75.9	80.5	180.5	433.7
Normal/cool	28.3^{b}	81.5	83.5	193.4	472.8
SEM	1.1	2.6	3.6	5.7	27.0

$^{a–c}$Means in columns that possess different superscripts differ significantly ($P \leq 0.05$).

^{x,y}Means in columns that possess different superscripts approach significance ($P \leq 0.10$).

^{A,B}Means in columns that possess different superscripts differ significantly ($P \leq 0.01$).

[1]High incubation eggs were 39.5°C and normal incubation eggs were 37.6°C at embryonic d 19 as shown in Figure 1.

[2]Hot brooding room litter was 36.1°C at placement and cool brooding room litter was 28.5°C at placement as shown in Figure 2.

at 7 and 14 d of age. There was a significant incubation × brooding interaction at 7 d because cool brooding increased BW more than did hot brooding for normal incubated chicks, whereas the high incubated chicks were not affected by brooding. By 14 d, the high incubation-hot brooding combination chicks were smaller than all other groups, whereas the normal incubated-cool brooded chicks were larger than all other groups.

The effect of incubation temperature, brooding litter temperature, sex, and incubation temperature × brooding temperature × sex interaction on percentage mortality of male and female broilers to 21 d of age is shown in Table 5. Mortality was increased for the 0 to 7, 0 to 14, and 0 to 21 d periods by increased incubation temperature. Cool brooding numerically ($P < 0.10$) increased mortality during the 0 to 14 and 0 to 21 d periods. Male chicks exhibited significantly greater mortality during the 0 to 7, 7 to 14, 0 to 14, and 0 to 21 d periods. There were significant 2-way interactions (data not shown for brevity), but the highly significant 3-way incubation temperature × brooding temperature × sex interaction during the 0 to 7, 0 to 14, and 0 to

Table 2. Body weight of broiler chickens as affected by incubation temperature, brooding temperature, and sex in experiment 1

	BW for ages shown (g)				
Item	0 d	2 d	5 d	7 d	14 d
Incubation[1] temperature					
High	45.6^{B}	79.2^{B}	149.2^{B}	206.7^{B}	494.2^{B}
Normal	46.7^{A}	80.8^{A}	152.4^{A}	211.4^{A}	508.5^{A}
SEM	0.2	0.4	0.9	1.7	7.2
Brooding[2] temperature					
Hot	46.2	80.7^{x}	151.0	208.7	498.9
Cool	46.0	79.3^{y}	150.6	209.4	503.7
SEM	0.2	0.4	1.1	2.1	9.7
Sex					
Male	46.6^{A}	80.1	152.8^{A}	213.5^{A}	522.9^{A}
Female	45.7^{B}	79.9	148.8^{B}	204.6^{B}	479.8^{B}
SEM	0.2	0.4	0.9	1.2	7.2

^{x,y}Means in columns that possess different superscripts approach significance ($P \leq 0.10$).

^{A,B}Means in columns that possess different superscripts differ significantly ($P \leq 0.01$).

[1]High incubation eggs were 39.5°C and normal incubation eggs were 37.6°C at embryonic d 19 as shown in Figure 1.

[2]Hot brooding room litter was 36.1°C at placement and cool brooding room litter was 28.5°C at placement as shown in Figure 2.

Table 3. Feed consumption of broiler chickens as affected by incubation temperature, brooding temperature, and the incubation temperature × brooding temperature interaction in experiment 2

	Feed consumption for ages shown (g)		
Item	0 to 7 d	7 to 14 d	14 to 21 d
Incubation temperature[1]			
High	119.9^{B}	302.8^{B}	498.3^{B}
Normal	138.9^{A}	337.0^{A}	538.1^{A}
SEM	1.7	2.1	5.7
Brooding temperature[2]			
Hot	137.4^{a}	302.7^{B}	498.9^{y}
Cool	121.4^{b}	337.1^{A}	537.5^{x}
SEM	1.7	2.3	7.4
Incubation temperature/brooding temperature			
High/hot	132.0^{B}	287.9^{y}	484.2^{c}
Normal/hot	142.7^{A}	317.4^{xy}	513.5^{b}
High/cool	107.8^{C}	317.7^{xy}	512.3^{b}
Normal/cool	135.0^{B}	356.6^{x}	562.7^{a}
SEM	2.3	3.0	8.1

$^{a–c}$Means in columns that possess different superscripts differ significantly ($P \leq 0.05$).

^{x,y}Means in columns that possess different superscripts approach significance ($P \leq 0.10$).

$^{A–C}$Means in columns that possess different superscripts differ significantly ($P \leq 0.01$).

[1]High incubation eggs were 40.6°C and normal incubation eggs were 37.7°C at embryonic d 19 as shown in Figure 3.

[2]Hot brooding room litter was 33.8°C at placement and cool brooding room litter was 26.0°C at placement as shown in Figure 4.

21 d periods best illustrates why male mortality was increased. Inspection of the interaction means clearly shows that the combination of high incubation temperature and cool brooding dramatically elevated the male mortality.

DISCUSSION

It has become clear that the incubator machine air temperature may not accurately reflect the internal egg temperature during the later stages of incubation (Meijerhof, 2000; Leksrisompong et al., 2007). This evidently has led to the unknowing production of chicks from eggs that experienced elevated internal egg temperatures during the latter stages of incubation. We chose to start our incubation treatments near E16 to mimic our practical observations. Our previous studies have shown that BW and weights of the heart, gizzard, proventriculus, and small intestines were frequently reduced under the influence of high incubation temperature (>39.5°C) during late incubation, but yolk sac weights were frequently larger (Leksrisompong et al.,

Table 4. Body weight of broiler chickens as affected by incubation temperature, brooding temperature, and the incubation temperature × brooding temperature interaction in experiment 2

	BW for ages shown (g)			
Item	0 d	7 d	14 d	21 d
Incubation temperature[1]				
High	43.7^{B}	138.8^{B}	380.7^{B}	722.8^{B}
Normal	45.5^{A}	150.7^{A}	411.5^{A}	777.0^{A}
SEM	0.1	0.9	2.9	5.6
Brooding temperature[2]				
Hot	44.6	141.9^{b}	384.5^{b}	721.9^{b}
Cool	44.6	147.7^{a}	407.8^{a}	775.7^{a}
SEM	0.1	1.0	3.2	6.2
Incubation temperature/brooding temperature				
High/hot	43.8	138.1^{C}	372.9^{c}	698.7
Normal/hot	45.4	145.7^{B}	396.1^{b}	745.0
High/cool	43.7	139.6^{C}	388.6^{b}	746.8
Normal/cool	45.6	155.7^{A}	427.0^{a}	809.0
SEM	0.1	1.6	4.0	7.9

$^{a–c}$Means in columns that possess different superscripts differ significantly ($P \leq 0.05$).

$^{A–C}$Means in columns that possess different superscripts differ significantly ($P \leq 0.01$).

[1]High incubation eggs were 40.6°C and normal incubation eggs were 37.7°C at embryonic d 19 as shown in Figure 3.

[2]Hot brooding room litter was 33.8°C at placement and cool brooding room litter was 26.0°C at placement as shown in Figure 4.

2007). These developmental problems may be associated with generally poor posthatch chick performance (Michels et al., 1974; Decuypere, 1979; Gladys et al., 2000) because such chicks may not be immediately ready to consume feed normally as shown in Tables 1 and 3 and, in fact, may never consume feed normally.

Elevated incubation temperature could also encourage early hatching and a longer waiting period in the hatchers (Romanoff, 1936). Wyatt et al. (1985) reported that the longer that chicks remained in the hatchers, the more that they suffered dehydration that negatively affected subsequent growth and mortality. Although this factor may have played some role in the lower feed consumption and higher mortality of experiment 2, the 200-g d 7 BW in experiment 1 indicated that chicks that had experienced elevated eggshell temperature during late incubation could grow well for the first 7 d in the presence of optimum management during the early brooding period. However, in spite of this excellent early growth, the negative effects of high incubation temperature on feed consumption and BW remained evident (Table 2). This demonstrates that achieving excellent average BW at 7 d does not exclude the possibility that incubation problems occurred.

It has long been known that chilled chicks (19.4°C) would huddle together for warmth and not eat or drink normally, whereas warm chicks (29.4°C) were more active and consumed more feed (USDA, 1955). As a result, chicks brooded at cooler temperatures during the first week of age have often been observed to exhibit depressed 1 to 7 d BW gain (Harris et al., 1975; Renwick and Washburn, 1982; Renwick et al., 1985; Scott and Washburn, 1985; Noy and Sklan, 1999). According to Scott and Washburn (1985), reduced growth rate caused by a low brooding temperature primarily occurred during the initial 24 to 48 h after placement in the brooding quarters. In a similar manner, cool brooding reduced feed consumption through 5 d in experiment 1 (Table 1) and through 7 d in experiment 2 (Table 3), which may somewhat explain the BW results of previous studies, although, with respect to brooding temperature, BW did not necessarily follow feed consumption in the present study. This may be explained because the facility and management used in experiment 1 promoted very high feed consumption with low mortality across all treatments, whereas the male mortality in the high incubation-low brooding temperature combination in experiment 2 eliminated several chicks before the 7 d BW was determined, which obviously affected the treatment averages. Nevertheless, once past the first 7 d, the cooler brooding temperature clearly promoted greater feed consumption in both experiments, irrespective of the variation in the infrastructure and equipment used.

Chicks brooded at cooler temperatures have often been observed to exhibit increased mortality (Renwick and Washburn, 1982). This was observed in experiment 2 (Table 5) but not in experiment 1 of the present study, which suggests that a specific combination of incubation conditions and brooding management may

Table 5. Percentage mortality (deaths) of broiler chickens as affected by incubation temperature, brooding temperature, sex, and the incubation temperature × brooding temperature × sex interaction in experiment 2

	Deaths for ages shown (%)				
Item	0 to 7 d	7 to 14 d	0 to 14 d	14 to 21 d	0 to 21 d
Incubation temperature[1]					
High	1.97^{a}	0.93	2.89^{a}	0.12	3.01^{x}
Normal	0.69^{b}	0.50	1.19^{b}	0.40	1.59^{y}
SEM	0.41	0.47	0.51	0.16	0.54
Brooding temperature[2]					
Hot	0.66	0.35	1.01^{y}	0.20	1.21^{y}
Cool	2.00	1.07	3.08^{x}	0.31	3.39^{x}
SEM	0.41	0.60	0.51	0.16	0.54
Sex					
Male	2.00^{a}	1.31^{A}	3.31^{A}	0.21	3.52^{A}
Female	0.66^{b}	0.10^{B}	0.76^{B}	0.20	0.96^{B}
SEM	0.41	0.47	0.52	0.14	0.54
Incubation temperature/brooding temperature/sex					
Normal/hot/male	0.79^{B}	0.40	1.19^{B}	0.40^{ab}	1.59^{B}
Normal/hot/female	0.00^{B}	0.00	0.00^{B}	0.00^{b}	0.00^{B}
Normal/cool/male	1.19^{B}	1.59	2.78^{B}	0.00^{b}	2.75^{B}
Normal/cool/female	0.79^{B}	0.40	1.19^{B}	0.79^{a}	1.98^{B}
Hot/hot/male	0.00^{B}	0.93	0.93^{B}	0.00^{b}	0.93^{B}
Hot/hot/female	1.85^{B}	0.00	1.85^{B}	0.00^{b}	1.85^{B}
Hot/cool/male	6.02^{A}	2.31	8.33^{A}	0.46^{ab}	8.80^{A}
Hot/cool/female	0.00^{B}	0.00	0.00^{B}	0.00^{b}	0.00^{B}
SEM	0.83	0.79	1.03	0.29	1.08

^{a,b}Means in columns that possess different superscripts differ significantly ($P \leq 0.05$).

^{x,y}Means in columns that possess different superscripts approach significance ($P \leq 0.10$).

^{A,B}Means in columns that possess different superscripts differ significantly ($P \leq 0.01$).

[1]High incubation eggs were 40.6°C and normal incubation eggs were 37.7°C at embryonic d 19 as shown in Figure 3.

[2]Hot brooding room litter was 33.8°C at placement and cool brooding room litter was 26.0°C at placement as shown in Figure 4.

have been required to elicit this response. One factor that must be considered is that the machines used in experiment 1 exchanged greater volumes of air than did the machines used in experiment 2 and this factor could have created some difference in embryonic development in the presence of elevated incubation temperature. Nonetheless, in a manner similar to the effect observed for feed consumption, early hot litter temperature for brooding helped the male chicks recover from high incubation temperatures (0.0 versus 6.0% 7 d mortality; Table 5). It has also been reported that exposure of chicks to heat stress at an early posthatch age has led to chickens that were thermotolerant later in life (Arjona et al., 1988; Yahav and Hurwitz, 1996). Thus, there must be no obligatory problems associated with properly managed elevated brooding temperatures very early in life. The fact that the male chicks were most negatively affected in experiment 2 suggests that eggs with male embryos may have become hotter than eggs with female embryos when eggshell temperature was elevated late in incubation under the conditions of the present study. This could have also been related to the reduced 0 to 2 d feed consumption in the males of experiment 1 (Table 1).

Chick behavior may have influenced the results because previous researchers (Ernst et al., 1984; Henken et al., 1987) reported that chicks that were placed at normal thermal conditions but had been exposed to high incubation temperatures consumed less feed and grew slower than chicks that had been exposed to lower incubation temperatures. Chicks, especially males, must be very sensitive to cool brooding temperatures, even for short periods of time, if they had been exposed to high incubation conditions. In the present experiments, a hot brooding litter temperature at placement apparently encouraged chicks from both high and normal incubation environments to move and consume feed more normally (Tables 1 and 3). This effect must have been more evident with males as demonstrated by the pattern of mortality shown in the interaction means of Table 5.

These behaviors may have been initially determined during incubation because the preoptic anterior hypothalamus contains temperature-sensitive neurons (Boulant, 1996) that may be influenced by the incubation temperature during embryogensis (Nichelmann et al., 1999; Tzschentke et al., 2001). Changing the sensitivity of the warm- or cold-sensitive neurons, or both, located in the preoptic anterior hypothalamus may change the threshold for heat production or heat loss, or both, of an animal. As an example, exposing broiler embryos to a higher-than-standard incubation temperature resulted in a significant decline in the metabolic rate of the posthatch chicks that was accompanied by a reduction in energy expenditure for maintenance (Yahav et al., 2004a,b; Piestun et al., 2008). Exposure of these chicks to a low brooding litter temperature immediately after hatching apparently prevented the chicks from consuming sufficient feed to maintain energy balance presumably as a result of reduced activity. Reduced feed consumption may have also influenced livability in experiment 2.

Nonetheless, the extent of the posthatch effects observed in experiments 1 and 2 may have also been dependent upon the arrangement of the infrastructure of the brooding facility (i.e., convenience of access to feed and water and sufficient light intensity). As an example, the chicks hatched in the older Jamesway incubators with a lower ventilation rate and brooded in the larger and darker pens of experiment 2 exhibited reduced overall feed intake and BW even though the general effects of incubation and brooding temperatures as well as of sex mirrored those of experiment 1. These differences between the 2 experiments indicated that the present data could be broadly applied across a wide range of management and infrastructure, the detailed effects of which remain to be delineated.

One general recommendation that can be drawn from our data was that litter temperatures should reach >34.0°C at the time of placement and be decreased to 32.2°C or slightly below by the second day of the brooding period to achieve maximum feed consumption, irrespective of incubation temperature. The brooding temperature should be further reduced to about 27°C during the second week to maintain a high level of feed consumption and growth. Further, in a manner similar to how incubator air temperature does not reflect eggshell temperature (Meijerhof, 2000; Leksrisompong et al., 2007), our data showed that the air temperature during brooding was not equivalent to litter temperature and that the difference between air and litter temperature was within the range of 2.7 to 5.5°C. We suggest that initial brooding conditions should be adjusted based upon the litter temperature rather than the air temperature because the temperature that chicks experienced through their contact with the litter (feet) probably determined activity patterns and feed intake. Appropriate management of litter temperature may be utilized to encourage early feed intake in broilers, which may be a useful means to ameliorate the detrimental effects of excessive eggshell temperature during the latter stages of incubation while not risking compromise of the vitality of chicks that hatched from eggs incubated at normal temperatures.

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