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Temperature Sequence of Eggs from Oviposition Through Distribution: Production—Part 1

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Abstract

During Egg Safety Action Plan hearings in Washington, DC, many questions were raised concerning the egg temperature (T) used in the risk assessment model. Therefore, a national study was initiated to determine the T of eggs from oviposition through distribution. In part 1; researchers gathered data on internal and surface egg T from commercial egg production facilities. An infrared thermometer was used to rapidly measure surface T, and internal T was determined by probing individual eggs. The main effects were geographic region (state) and season evaluated in a factorial design. Egg T data were recorded in the production facilities in standardized comparisons. Regression analysis ($P < 0.0001$) showed that the R^2 (0.952) between infrared egg surface T and internal T was very high, and validated further use of the infrared thermometer. Hen house egg surface and internal T were significantly influenced by state, season, and the state × season interaction. Mean hen house egg surface T was 27.3 and 23.8°C for summer and winter, respectively, with 29.2 and 26.2°C for egg internal T ($P < 0.0001$). Hen house eggs from California had the lowest surface and internal T in winter among all the states ($P < 0.0001$), whereas the highest egg surface T were recorded during summer in North Carolina, Georgia, and Texas, and the highest internal T were recorded from Texas and Georgia. Cooling of warm eggs following oviposition was significantly influenced by season, state, and their interaction. Egg internal T when 3/4 cool was higher in summer vs. winter and higher in North Carolina and Pennsylvania compared with Iowa. The time required to 3/4 cool eggs was greater in winter than summer and greater in Iowa than in other states. These findings showed seasonal and state impacts on ambient T in the hen house that ultimately influenced egg surface and internal T. More important, they showed opportunities to influence cooling rate to improve internal and microbial egg quality.

Keywords

egg production, egg temperature, shell egg

Disciplines

Agriculture | Animal Sciences | Meat Science | Poultry or Avian Science

Comments

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Temperature Sequence of Eggs from Oviposition Through Distribution: Production—Part 1

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ABSTRACT During Egg Safety Action Plan hearings in Washington, DC, many questions were raised concerning the egg temperature (T) used in the risk assessment model. Therefore, a national study was initiated to determine the T of eggs from oviposition through distribution. In part 1; researchers gathered data on internal and surface egg T from commercial egg production facilities. An infrared thermometer was used to rapidly measure surface T, and internal T was determined by probing individual eggs. The main effects were geographic region (state) and season evaluated in a factorial design. Egg T data were recorded in the production facilities in standardized comparisons. Regression analysis ($P < 0.0001$) showed that the R^2 (0.952) between infrared egg surface T and internal T was very high, and validated further use of the infrared thermometer. Hen house egg surface and internal T were significantly influenced by state, season, and the state × season interaction. Mean hen house egg surface T was 27.3 and 23.8°C for summer and winter, respectively, with 29.2 and 26.2°C for egg internal T ($P < 0.0001$). Hen house eggs from California had the lowest surface and internal T in winter among all the states ($P < 0.0001$), whereas the highest egg surface T were recorded during summer in North Carolina, Georgia, and Texas, and the highest internal T were recorded from Texas and Georgia. Cooling of warm eggs following oviposition was significantly influenced by season, state, and their interaction. Egg internal T when 3/4 cool was higher in summer vs. winter and higher in North Carolina and Pennsylvania compared with Iowa. The time required to 3/4 cool eggs was greater in winter than summer and greater in Iowa than in other states. These findings showed seasonal and state impacts on ambient T in the hen house that ultimately influenced egg surface and internal T. More important, they showed opportunities to influence cooling rate to improve internal and microbial egg quality.

Key words: egg production, egg temperature, shell egg

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INTRODUCTION

Rapid cooling of table eggs is advantageous for several reasons. Lower storage temperatures (**T**) better maintain albumen height, Haugh units, and egg specific gravity while reducing air cell size and albumen pH (Williams, 1992; Samli et al., 2005). If eggs are exposed to *Salmonella* Enteritidis, either by natural or artificial means, their subsequent penetration of the shell and growth is accelerated by higher T and length of storage (Humphrey, 1994; Miyamoto et al., 1998; Gast and Holt, 2000). During the egg safety risk assessment hearings held in Washington, DC, questions were raised by USDA and US Food and Drug Administration officials regarding egg T and time relationships during the various stages of production, processing, and marketing that may influence the microbiological safety of eggs (USDA-Food Safety Inspection Service, 1998). Research in this area has focused mainly on egg surface T during washing and grading. Anderson (1993) showed that egg T increased by 6.7°C during processing before packaging. Anderson et al. (1992) looked at internal egg T postprocessing, whereas Czarick and Savage (1992) examined egg surface T postprocessing with different packaging and pallet orientations in the cooler, and Damron et al. (1994) examined the ambient T in transport trucks during distribution and their ability to meet regulations. Little work has been done to document the internal egg

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T and hen house climate, which can enhance the growth of potentially harmful microorganisms (Gast and Holt, 2000). Researchers and food safety regulators have indicated the need to determine internal egg T from point of lay to the retail establishment to improve the risk assessment model. However, research has been limited documenting the complete time and T picture throughout all phases of egg production and distribution and their impact on the internal egg T. Therefore, the objectives of the production part of the study were to determine the relationship between the ambient T in the hen house on the T of eggs and some of the variables that influence these T. For further information concerning the impact of processing and transportation on egg T, see Koelkebeck et al. (2008) and Anderson et al. (2008).

MATERIALS AND METHODS

General

Researchers from California (CA), Connecticut (CT), Iowa (IA), Illinois (IL), North Carolina (NC), Pennsylvania (PA), and Texas (TX), and from the USDA-Agricultural Research Service in Georgia (GA) gathered data on egg internal and surface T along with ambient T from 19 egg production facilities. Most farms were in-line complexes (86.5%) with 4 to 13 hen houses per complex. Complex populations ranged from 225,000 to 1,600,000 hens. Data from 111 hen houses were used for the current study. Fifteen houses were off-line, single hen houses (13.5%). Most hen houses were 2-story high-rise structures with manure accumulated in the lower story. These were closed, environmentally controlled houses with mechanical ventilation; however, in northern CA and TX there were both open and curtain-sided houses (n = 33) with either passive or tunnel ventilation. Temperature information was recorded over the course of 2 seasons. Winter was defined as November through February and summer encompassed June through August. It should be noted that not all states were able to compile complete data sets because of problems beyond our control. The data presented exclude states that had outbreaks of exotic Newcastle disease or avian influenza, which resulted in curtailment of this field investigation phase of the study because of biosecurity concerns; thus, fewer numbers of data points were obtained.

Production

This portion of the study encompassed the egg production component. The procedures used to record egg and environmental data were as follows. On arrival at the production facility in the morning, Cox Tracer temperature data loggers (CT-1E-DC-4-C, Sensitech, Beverly, MA) were placed inside the production house on the egg belts to gather ambient T conditions for the eggs. The hen house egg monitoring followed the change in T from oviposition in the house until the internal T equilibrated with the ambient T. This was accomplished by using 2 methods.

Method 1. The first method was an acute measure of T with eggs that were randomly selected from the egg belts at various locations within the production facility, thereby representing different levels, sides, or ends of the production house. These measurements were made in 6 states on 19 farms. These eggs were sampled for surface T by using an Omega Technologies (Omega Engineering Inc., Stamford, CT) infrared thermometer. Egg internal T was then determined by piercing a small hole (approximately 4.8 mm) in the large end, placing an external K-type thermocouple probe from Omega Technologies inside the hole, and pushing it to the approximate geometric center of the egg (25.4 mm). Egg surface and internal egg T were recorded in degrees Celsius, with an accuracy of 2% and ±0.1°C, respectively.

Method 2. The second procedure took a time-elapsed measure of internal T from individual freshly laid eggs that were sampled from the egg belt immediately after oviposition. The initial internal T of these eggs averaged 37.5°C (n = 38). These measurements were determined in 4 states with 15 farms. A small hole (approximately 0.48 cm) was pierced in the large end and an external probe from a Cox Tracer recorder (Sensitech) was placed such that the thermocouple measuring internal egg T was in the approximate geometric center of the egg (25.4 mm). The recorder was set to measure T at 15-s intervals for at least 1.5 h or until the egg equilibrated with the house T. Concurrently, ambient hen house T was logged every 15 s with the same Cox Tracer recorder to compare with egg internal T. Ambient and internal egg T were recorded in degrees Celsius, with an accuracy of ±0.1. Thus, this procedure allowed us to measure egg T changes from the point at which the egg was laid (oviposition) through to ambient T in the hen house.

Eggs cool quickly at first and then more slowly as the egg T approaches that of the ambient T. Three-quarters cool is the point on the cooling curve where the eggs have reached 3/4 of the desired T drop (7.2°C) according to USDA-Agricultural Marketing Service egg storage regulations. The 3/4 cool time is a standard term that describes the time to remove 3/4 (75%) of the T difference between the starting egg internal T and the ambient T of the cooling medium (circulating air). It is a convenient and practical method of indicating when eggs have come close to the T of the cooling medium (Mitchell et al., 1972; Fraser, 1998), with the rate gradually declining toward equilibrium. The following equation was used to calculate the 3/4 cool point for the eggs:

$$3/4 \text{ cool} = \text{initial egg T} - [(\text{initial egg T} - 7.2°\text{C}) \times 0.75].$$

Statistical Analysis

For the production segment of this research, the main effects were the state in which the data were collected (CA, GA, IL, NC, PA, and TX) and season of the year (winter vs. summer). The experiment was set up as a factorial design, with state and season as the main effects. The experimental units were single-surface and internal mea-

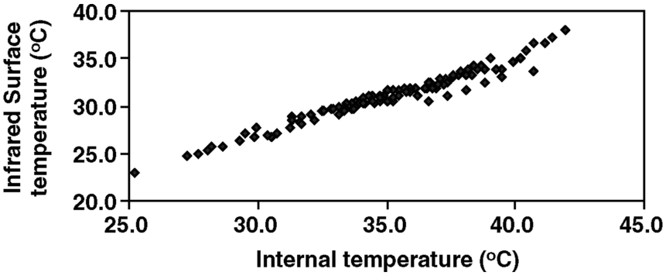

Figure 1. Egg infrared surface temperature vs. internal temperature (°C). Regression analysis ($P < 0.0001$) showed the $R^2 = 0.9521$; n = 101.

surements taken with the infrared unit with probe or ambient and internal egg T data streams taken with data loggers. Each data set was analyzed separately by using the SAS GLM procedure for ANOVA, and when significant differences were detected ($P < 0.05$), the LS means were separated by using PDIFF (SAS Institute, 1998).

RESULTS AND DISCUSSION

Egg Surface T (Infrared) vs. Internal T

Internal egg T can vary considerably depending on ambient T, time since oviposition, and the conducting surfaces to which the eggs are exposed. In the hen house, the ambient T can vary greatly from summer to winter, across egg belts, down deescalators, and across rod conveyers to the packing equipment or processing plant in the case of in-line facilities. Infrared thermometers are a rapid, easy-to-use means of assessing egg surface T anywhere in the hen house and are much easier than probing eggs and waiting for an internal T. One would anticipate egg surface and internal T to be different but highly correlated. In the hen house, preliminary regression analysis of T from 101 eggs over a range of internal (41.9 to 25.2°C) and surface T (38.0 to 23.1°C) showed them to be significantly related ($R^2 = 0.9521$, $P < 0.0001$; Figure 1). In the hen house, egg surface T was most often lower than internal T, or equal if enough time had allowed internal T to equilibrate with ambient T. As shown in this series of experiments, this will not always be the case in other thermal settings to which the eggs are exposed. For example, surface warming such as that encountered during egg washing could reverse the relationship and could change again as warm eggs are placed in refrigeration.

Egg Surface T (Method 1)

Hen house egg surface T summarized by sample states were highest in GA and NC, intermediate in TX, PA, and IL, and lowest in CA ($P < 0.0001$). Surface T in summer averaged 27.3°C, with a range from 25.0 to 29.6°C among the states (Table 1). Mean surface T in winter was 23.8°C, with a range of 17.8 to 27.0°C. Winter T was significantly less than summer (3.5°C) and also showed differences among the states. The highest summer egg surface T were measured in NC, GA, and TX, and T were significantly lower in PA, IL, and CA, with a difference of nearly 4°C. In winter, surface T were again high in GA and low in CA, with more than 9°C difference ($P < 0.0001$). Egg surface T in CA showed the greatest seasonal variation (winter to summer, 17.8 to 26.0°C). This may be influenced in part by the northern CA location of the houses, and additionally by the open-sided, passive ventilation. Eggs from GA, IL, NC, and TX also showed significant seasonal T differences. However, egg surface T in PA was not significantly influenced by season and showed the most consistent winter to summer T, at 25.1 to 25.0°C, respectively. Although these observations may suggest geographic factors influencing environmental T and egg surface T, it is more likely housing, equipment, and management practices that influenced seasonal egg surface T.

Egg Internal T (Method 1)

The hen house egg internal T summarized by the states showed higher T in NC, TX, and GA, intermediate T in IL, and lower T in CA and PA ($P < 0.0001$). The internal T in summer averaged 29.2°C and was significantly greater than that in winter, at 26.2°C (Table 2). Summer and winter T ranged from 24.5 to 32.1°C and 21.3 to 29.5°C among the states, respectively. The highest summer internal egg T were measured in TX and GA, and the lowest were in PA, with a difference of more than 5°C. In winter the

Table 1. Mean hen house egg surface temperature (°C) by state, season, and state × season (method 1)[1]

		State						
Item	Season	CA	GA	IL	NC	PA	TX	P-value
State		21.9^d	28.0^a	24.7^c	27.6^a	25.0^c	26.1^b	<0.0001
Season								<0.0001
Summer	27.3^a							
Winter	23.8^b							
State × season								<0.0001
Summer		26.0^c	29.1^a	25.9^c	29.6^a	25.0^c	28.4^{ab}	
Winter		17.8^e	27.0^{bc}	23.5^d	25.5^c	25.1^c	23.8^d	

[a–e]Means comparing states, seasons, or state × season within a row or column with no common superscripts differ ($P < 0.05$). n = 2,686.

[1] Method 1: egg surface T determined by using an Omega Technologies infrared thermometer (Omega Engineering Inc., Stamford, CT).

Table 2. Mean hen house egg internal temperature (°C) by state, season, and state × season (method 1)[1]

Item	Season	CA	GA	IL	NC	PA	TX	*P*-value
		State						
State		25.3^{c}	29.2^{a}	27.8^{b}	29.7^{a}	24.4^{c}	29.7^{a}	<0.0001
Season								<0.0001
Summer	29.2^{a}							
Winter	26.2^{b}							
State × season								<0.0001
Summer		29.4^{bcd}	30.9^{ab}	28.4^{cde}	30.0^{b}	24.5^{f}	32.1^{a}	
Winter		21.3^{g}	27.5^{cde}	27.2^{e}	29.5^{bc}	24.4^{f}	27.3^{de}	

[a–g]Means comparing states, seasons, or state × season within a row or column with no common superscripts differ ($P < 0.05$). n = 953.

[1]Method 1: egg internal T determined by using an Omega Technologies type-K thermocouple probe (Omega Engineering Inc., Stamford, CT).

internal T were highest in NC and GA and lowest in CA, with more than 6°C difference. Seasonal extremes for internal T in TX, as in CA, were most likely influenced by their respective curtain-sided and open-house designs. Like egg surface T, egg internal T in northern CA showed the greatest seasonal variation from winter to summer (21.3 to 29.4°C), whereas PA showed the least variability (24.4 to 24.5°C, respectively). In addition to seasonal internal T differences in CA, they were also significantly different in TX and GA, but like PA, no measurable T differences were observed in NC or IL ($P > 0.05$). Although somewhat muted, the same seasonal and state differences observed for surface T were seen again in egg internal T, reflecting the impact of the hen house type and environment on core egg T.

Egg Cooling in the Hen House (Method 2)

Ambient hen house T was influenced by both the season and the state in which measurements were taken (Table 3). Like egg T, hen houses were significantly warmer in summer than in winter by more than 3°C. Hen houses were maintained at significantly higher T in NC and PA (>3.4°C) compared with IA, with IL falling in between. The interaction of season and state ($P = 0.0267$) indicated cooler winter T in general, with the exception of PA houses being warmer than the rest, and with the coolest house T in IA in either season.

The same significant seasonal differences prevailed after warm eggs at oviposition (initial internal T = 37.5°C) had cooled (3/4 cool) to ambient hen house T (Table 3). Like

Table 3. Egg cooling rate: internal egg temperature vs. ambient hen house (method 2)[1]

Item	Hen house ambient T (°C)	Egg T at 3/4 cool (°C)	T change to 3/4 cool (°C)	Time to 3/4 cool (min)	T change (°C/min) to 3/4 cool
Overall	24.8	28.3	10.7	56.0	0.19
Summer	26.5	29.6	9.4	48.4	0.20
Winter	23.2	27.2	11.8	63.6	0.19
IA	22.7^{c}	26.8^{c}	12.2^{a}	67.5^{a}	0.18
IL	24.2^{bca}	28.0^{bc}	11.1^{ab}	54.1^{b}	0.21
NC	26.4^{a}	29.6^{a}	9.5^{c}	45.7^{c}	0.21
PA	26.1^{ab}	29.3^{ab}	9.7^{bc}	56.6^{b}	0.18
Summer					
IA	25.5^{bc}	28.9^{bc}	10.2^{bc}	53.0^{c}	0.19
IL	25.6^{bc}	29.0^{bc}	10.1^{bc}	52.3^{c}	0.19
NC	28.8^{a}	31.4^{a}	7.7^{d}	37.9^{d}	0.20
PA	26.0^{abc}	29.3^{ab}	9.8^{cd}	50.4^{c}	0.20
Winter					
IA	19.9^{d}	24.7^{d}	14.3^{a}	82.0^{a}	0.17
IL	22.9^{c}	26.9^{c}	12.1^{b}	55.9^{bc}	0.22
NC	23.9^{c}	27.7^{bc}	11.3^{bc}	53.6^{c}	0.22
PA	26.2^{abc}	29.4^{ab}	9.6^{cd}	62.8^{b}	0.15
P-value					
Season	<0.0001	<0.0001	<0.0001	<0.0001	0.6225
State	0.0004	0.0004	0.0004	<0.0001	0.0904
Season × state	0.0267	0.0255	0.0260	0.0009	0.1721

[a–d]Means comparing seasons, states, or state × season with no common superscripts differ ($P < 0.05$). n = 38.

[1]Method 2: egg internal T and ambient T determined by using a Cox Tracer data logger (Sensitech, Beverly, MA) equipped with internal and external thermocouple probes. Average initial egg internal T at oviposition was 37.5°C; n = 38.

ambient T, internal egg T at 3/4 cool followed the same pattern from state to state, with warmer hen houses maintaining higher egg T ($P = 0.0004$). The interaction of season and state indicated cooler winter egg T in general, with the exception of PA eggs running warmer than those in the other states in winter and IA houses having the coolest internal egg T in either season.

The egg T change from oviposition to 3/4 cool was significantly greater in winter than summer because of the greater T differential between the egg and ambient T (Table 3). Cooler house T in IA and IL resulted in greater egg T changes than in PA and NC. The season and state patterns of T change are seen in the significant interaction ($P = 0.0260$), indicating internal egg cooling of more than 14°C during winter and as little as 7°C during summer in the hen house.

The time required to 3/4 cool egg internal contents to ambient T was significantly greater in winter than summer by more than 15 min (Table 3). More time is required because of the greater T change from oviposition to ambient T in winter. States showed significant differences, with IA taking the most time to cool, corresponding with the lowest ambient and internal egg T. These extremes were shown in the season × state interaction, with IA eggs taking 82 min to decrease 14.32°C vs. 37.9 min for NC eggs to decrease 9.75°C ($P = 0.0009$).

The rate of T change in degrees per minute averaged 0.19, with no significant season effect, state effect, or season × state interactions. Most likely, the interval was too small to detect the significant T differences realized in the other measures with greater amounts of time.

Like the egg surface and internal T differences realized in Tables 1 and 2, seasonal and state ambient hen house T influenced the internal T of eggs, their T change during cooling, and their rate of cooling. Warmer houses sustained higher internal egg T (e.g., NC and PA in summer). Cooler houses result in cooler internal egg T at 3/4 cool (e.g., IA houses in winter), and the difference between these internal egg T from these states could be greater than 6°C (e.g., NC eggs in summer vs. IA eggs in winter). Although it may take more time to reach a lower internal egg T in IA during winter, the time required to reach the same internal T would be less because of the greater T differential between house ambient T and egg T at oviposition.

In summary, inferences about egg T in the hen house can be made by using either internal or surface T. However, the latter are much more readily determined, and the two are highly correlated. These findings clearly showed seasonal and regional impacts on ambient T in the hen house that ultimately influenced egg surface and internal T, and the time required to cool egg contents. In addition, hen house design and ventilation systems most likely influenced egg T extremes. More important, future opportunities to influence egg cooling rate for both interior and microbial quality can be realized by applying this information.

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