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Temperature Sequence of Eggs from Oviposition Through Distribution: Processing—Part 2

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Abstract
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Keywords
egg processing, 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: Processing—Part 2

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ABSTRACT The Egg Safety Action Plan released in 1999 raised questions concerning egg temperature used in the risk assessment model. Therefore, a national study was initiated to determine the internal and external temperature sequence of eggs from oviposition through distribution. Researchers gathered data from commercial egg production, shell egg processing, and distribution facilities. The experimental design was a mixed model with 2 random effects for season and geographic region and a fixed effect for operation type (inline or offline). For this report, internal and external egg temperature data were recorded at specific points during shell egg processing in the winter and summer months. In addition, internal egg temperatures were recorded in pre- and postshell egg processing cooler areas. There was a significant season × geographic region interaction ($P < 0.05$) for both surface and internal temperatures. Egg temperatures were lower in the winter vs. summer, but eggs gained in temperature from the accumulator to the postshell egg processing cooler. During shell egg processing, summer egg surface and internal temperatures were greater ($P < 0.05$) than during the winter. When examining the effect of shell egg processing time and conditions, it was found that 2.4 and 3.8°C were added to egg surface temperatures, and 3.3 and 6.0°C were added to internal temperatures in the summer and winter, respectively. Internal egg temperatures were higher ($P < 0.05$) in the preshell egg processing cooler area during the summer vs. winter, and internal egg temperatures were higher ($P < 0.05$) in the summer when eggs were ¾ cool (temperature change required to meet USDA-Agricultural Marketing Service storage regulation of 7.2°C) in the postshell egg processing area. However, the cooling rate was not different ($P > 0.05$) for eggs in the postshell egg processing cooler area in the summer vs. winter. Therefore, these data suggest that season of year and geographic location can affect the temperature of eggs during shell egg processing and should be a component in future assessments of egg safety.

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INTRODUCTION

During the egg safety risk assessment hearings held in Washington, DC, June 12, 1998, questions were raised by the USDA, Agricultural Marketing Service, USDA Food Safety Inspection Service, and the US Food and Drug Administration officials regarding egg temperatures at the various stages in the marketing chain and the effect that temperature has on the safety of eggs. Gwin (1952) determined that normal commercial egg-marketing practices offer limited opportunities to obtain reasonably accurate measures of quality. Today's shell egg processing plants keep accurate egg-quality records but have incomplete records for storage and delivery egg temperatures. This is primarily due to the volume and speed at which eggs move through the distribution system. Research in this area has focused mainly on the egg surface temperature during washing and grading (Anderson, 1993) and showed that egg temperatures increased by 6.7°C during shell egg processing before packaging. Although Anderson et al. (1992) looked at internal egg temperatures postshell egg processing, Czarick and Savage (1992) ex-

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Table 1. Mean ambient preshell egg processing cooler and internal egg temperatures for offline eggs processed during seasons, for 3 states[1]

Item	Ambient air temperature	Internal egg temperature
	(°C)	
Season		
Summer	13.3 ± 1.7[a]	13.4 ± 0.2[a]
Winter	11.1 ± 1.3[a]	13.0 ± 0.1[b]
State		
California	NA	NA
Georgia	11.4 ± 2.1[a]	13.3 ± 0.3[b]
Illinois	11.6 ± 1.8[a]	12.1 ± 0.1[c]
Iowa	NA	NA
North Carolina	13.6 ± 1.6[a]	14.1 ± 0.2[a]
Pennsylvania	NA	NA
Texas	NA	NA

[a–c]Means within a column comparing seasons and states with seasons combined with no common superscripts differ significantly ($P < 0.05$).

[1]States with an NA did not collect data due to the nonavailability of offline eggs to process. Values are least square means ± SE, n = 319.

amined egg surface temperatures postshell egg processing in relation to different packaging and pallet orientation in the postshell egg processing cooler. They showed that eggs cool at different rates depended on their location in the pallet. Damron et al. (1994) examined transport trucks during partial phases of distribution and their ability to maintain the ambient temperature to meet regulations. Internal egg temperature can enhance the growth of potentially harmful microorganisms (Gast and Holt, 2000). Thus, researchers and food safety regulators have indicated the need to determine internal egg temperatures from point of lay to retail to improve the risk assessment model. However, research has been limited that documents the complete time and temperature changes from production throughout all phases of egg distribution on the internal egg temperatures. Therefore, the objectives of this study, reported in 3 parts, were to determine the relationship between the ambient air temperatures and internal temperature of eggs from production to retail and to identify the variables associated with shell egg processing that influence the temperature sequence that eggs are exposed.

MATERIALS AND METHODS

General

Researchers from California, Connecticut, Iowa, Illinois, North Carolina, Pennsylvania, and Texas and USDA-Agricultural Research Service in Georgia gathered data on egg internal and surface temperatures along with ambient temperatures from shell egg processing facilities. For the entire study, data were collected on egg temperatures in egg production houses, shell egg processing facilities, storage areas, and during transportation to distribution warehouses and retail outlets. This information was recorded over the course of 2 seasons. Winter was defined as November through February, and the summer months encompassed June through September. The procedure was for each state to gather data from a minimum of 3 different production-shell egg processing facilities sampled during the winter and the same plants resampled in the summer. It should be noted that not all states were able to compile complete data sets due to the particular practices of the processor and problems beyond our control. The data presented exclude states that had outbreaks of exotic Newcastle and avian influenza, which resulted in curtailment of the field investigation phase of the study due to biosecurity concerns; thus, a fewer number of data points were obtained.

This portion of the study encompasses the shell egg processing component (i.e., the temperature of eggs associated with different locations throughout a shell egg processing facility; see Anderson et al., 2008 and Patterson et al., 2008 for the transportation and production segments of the report). This report also presents data on the temperature of eggs in the preshell egg processing cooler area and immediately after shell egg processing (i.e., in the postshell egg processing cooler area). The shell egg processing plants sampled a combination of inline and offline plants from all states cooperating in the study. In some cases, the processor would not allow the eggs to be destroyed to capture internal egg temperatures. In this case, the researcher took what temperatures he could. During shell egg processing, random samples of 20 eggs were collected from each of the accumulator, postwash, postcandling, and packer head areas of the shell egg processing machine for surface and internal egg temperatures. To obtain the most accurate temperature recordings, subsets of 5 eggs were collected, and the egg surface temperature was measured immediately using an Omega Technologies Infrared Thermometer (Omega Engineering Inc., Stamford, CT). Then, a small hole was pierced (approximately 5.1 mm in diameter) in each egg at the large end using an external K-type thermocouple probe from Omega Technologies and placed such that the thermocouple measuring the internal egg temperature was in the approximate geometric center of the egg (approximately 25.4-mm deep, which would result in the probe being placed within the yolk). The temperature was recorded using an Omega Technologies Supermet Temperature Recorder (Omega Engineering Inc.). This was repeated until full sets of 20 eggs were sampled at each sampling location.

Egg temperatures were also recorded in the pre- and postshell egg processing coolers. Once again, 20 egg samples were made from specific lots of eggs that had a known cooler dwell time (the known time that eggs were in the cooler). The egg temperatures were recorded immediately before and after shell egg processing, from eggs that were either from offline storage or an inline facility. This was done to determine the effect of offline storage temperatures before processing eggs compared with inline ambient air temperature before processing those eggs. The egg internal temperatures were recorded for the pre- and postshell egg processing cooler areas as previously stated in the shell egg processing area.

Table 2. Mean egg surface and internal egg temperatures recorded for inline eggs processed during the summer at the accumulator, postwash, postcandling, and packer head locations in shell egg processing plants[1]

State	Accumulator	Postwash	Postcandling	Packer head
	(°C)			
Egg surface temperatures				
California	13.9 ± 1.0[e]	19.6 ± 0.9[d]	NA	18.7 ± 0.9[f]
Georgia	24.9 ± 0.7[bc]	27.3 ± 0.6[c]	29.4 ± 0.8[b]	22.7 ± 0.6[e]
Illinois	23.2 ± 0.6[d]	27.6 ± 0.5[c]	25.7 ± 0.7[c]	26.7 ± 0.5[c]
Iowa	28.8 ± 0.7[a]	NA	NA	24.8 ± 0.6[d]
North Carolina	22.6 ± 0.7[d]	31.1 ± 0.6[a]	31.3 ± 0.8[a]	28.4 ± 0.5[b]
Pennsylvania	25.9 ± 0.6[b]	28.5 ± 0.5[b]	28.3 ± 0.7[b]	28.8 ± 0.5[b]
Texas	25.2 ± 0.8[bc]	NA	31.8 ± 0.9[a]	31.7 ± 0.7[a]
n	296	220	232	306
Internal egg temperatures				
California	15.1 ± 1.3[d]	22.2 ± 1.1[e]	NA	23.3 ± 1.2[d]
Georgia	24.9 ± 0.9[b]	28.3 ± 0.8[c]	29.1 ± 1.1[a]	28.8 ± 0.9[bc]
Illinois	25.6 ± 0.8[b]	29.5 ± 0.7[ab]	27.5 ± 0.9[b]	28.4 ± 0.7[c]
Iowa	NA	NA	NA	NA
North Carolina	24.9 ± 0.9[b]	30.2 ± 0.8[a]	29.8 ± 1.1[a]	29.6 ± 0.7[b]
Pennsylvania	23.2 ± 0.8[c]	26.6 ± 0.7[d]	26.4 ± 0.9[b]	23.2 ± 0.7[d]
Texas	27.5 ± 1.1[a]	28.8 ± 0.9[bc]	29.6 ± 1.2[a]	31.0 ± 1.0[a]
n	256	252	232	266

[a–f]Means within a column with no common superscript with either egg surface or internal egg temperatures differ significantly ($P < 0.05$).

[1]States with an NA did not collect data due to the processor not allowing the collection of the data. Values are least square means ± SE.

The sampling locations for this report were defined as follows: a) accumulator – after eggs have exited the layer house and within 0.33 m of entry into the washer; b) postwash – within 0.33 m after sanitizer spray or last chamber wash, before entry into the air dryer; c) postcandling – within 0.33 m after exiting from the candling booth, before transfer to the crack detector or scales, etc.; and d) packer head – at a point where eggs are placed into a carton or flat. In addition to these 4 areas in the shell egg processing plant, egg temperatures were recorded in the postshell egg processing cooler area, before delivery.

Three-quarter cool is the point on the cooling curve when the eggs have reached ¾ of the desired temperature drop (7.2°C) according to USDA-Agricultural Marketing Service egg storage regulation. This ¾ cooling time is based on the fact that eggs will cool quickly at first, then cool more slowly as the egg temperature approaches that of ambient temperature. In other words, it is the time required to remove three-fourths (75%) of the temperature difference between the starting egg temperature and the temperature of the surrounding air. This process is based on the cooling of fruits and vegetables (Fraser, 1998). The following equation was used to calculate the ¾ cool point for each lot of eggs sampled.

$$\tfrac{3}{4}\text{ cool} = \text{initial egg temperature} - [(\text{initial egg temperature} - 7.2^\circ\text{C}) \times 0.75].$$

This is a standard point on the product cooling curve, which allows for a comparison of product cooling rates (Fraser, 1998).

Statistical Analysis

For the shell egg processing segment of this research, the main effects were the state the data were collected (CA, GA, IL, IA, 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 temperature measurements taken with the Omega Technologies Infrared Thermometer or ambient and internal egg temperature data streams taken with the Omega Technologies Supermet Temperature Recorder. The relationship between the egg surface and internal temperatures was analyzed by a CORR procedure at each of the sampling locations in the plants. A separate analysis was conducted to compare inline vs. offline shell egg processing plants. All data were analyzed utilizing the SAS GLM procedure for ANOVA (SAS Institute, 1998), and the least square means that were significantly different were separated by PDIFF.

RESULTS AND DISCUSSION

The results presented herein represent partial data obtained for the entire study (i.e., the shell egg processing plant data). It should be pointed out at the outset that not all states were able to compile complete data information due to problems beyond our control, so there are missing data for some states. This was primarily due to the processor not allowing eggs to be destroyed to capture internal egg temperature. The emphasis is that we were working in commercial operations and could only sample what they would allow us to do. Overall, however, we believe that this data accurately represents the trends normally seen in egg temperature changes in the shell egg processing plant over time as affected by geographic region and season of the year. We feel confident that we collected most of the information we initially set out to obtain. In this part of the 3 reports, there is some missing data. We believe that

Table 3. Mean egg surface and internal egg temperatures recorded for inline eggs processed during the winter at the accumulator, postwash, postcandling, and packer head locations in shell egg processing plants[1]

State	Accumulator	Postwash	Postcandling	Packer head
	(°C)			
Egg surface temperatures				
California	11.7 ± 1.8[d]	21.0 ± 2.0[b]	NA	16.6 ± 0.2[f]
Georgia	16.8 ± 1.1[bc]	21.1 ± 1.2[b]	21.5 ± 0.6[c]	21.1 ± 0.7[de]
Illinois	15.7 ± 0.9[d]	21.6 ± 1.0[ab]	21.5 ± 0.6[c]	21.8 ± 0.7[cd]
Iowa	29.4 ± 1.8[a]	NA	NA	23.7 ± 1.2[ab]
North Carolina	12.6 ± 1.3[e]	23.5 ± 1.4[a]	23.6 ± 0.8[b]	22.5 ± 0.9[bc]
Pennsylvania	19.0 ± 0.6[c]	21.2 ± 0.7[b]	24.6 ± 0.4[b]	21.0 ± 0.4[e]
Texas	19.3 ± 1.0[b]	NA	26.4 ± 1.0[a]	24.1 ± 0.7[a]
n	469	380	430	446
Internal egg temperatures				
California	14.1 ± 1.6[c]	20.6 ± 1.4[de]	NA	21.9 ± 0.9[c]
Georgia	17.9 ± 0.9[b]	22.1 ± 0.8[cd]	23.0 ± 0.9[a]	24.1 ± 0.5[b]
Illinois	18.7 ± 0.8[b]	23.9 ± 0.7[ab]	23.4 ± 0.8[a]	24.4 ± 0.5[b]
Iowa	NA	NA	NA	NA
North Carolina	15.4 ± 1.1[c]	20.3 ± 1.0[e]	19.8 ± 1.1[b]	22.6 ± 0.6[c]
Pennsylvania	22.4 ± 0.9[a]	24.2 ± 0.8[a]	24.2 ± 0.9[a]	24.9 ± 0.5[b]
Texas	21.2 ± 1.0[a]	22.9 ± 0.8[bc]	23.8 ± 1.0[a]	28.3 ± 0.5[a]
n	309	322	290	306

[a–f]Means within a column with no common superscript within either egg surface or internal egg temperatures differ significantly ($P < 0.05$).

[1]States with an NA did not collect data due to the processor not allowing the collection of the data. Values are least square means ± SE.

enough data were collected to accurately represent the shell egg processing results.

Before eggs entered the shell egg processing plants from offline sites, data were taken on the ambient temperature and internal egg temperatures of eggs in the preshell egg processing cooler area in 3 states in both summer and winter time (Table 1). The states of Georgia, Illinois, and North Carolina were the only ones that had offline facilities to sample from. There were no significant differences ($P > 0.05$) in ambient air temperatures in the summer or winter or between the plants located in Georgia, Illinois, or North Carolina. However, internal egg temperatures were higher ($P < 0.05$) in preshell egg processed eggs during the summer vs. winter. In addition, internal egg temperatures were highest in North Carolina plants. These data suggest that internal egg temperatures start out higher in the summer vs. winter before shell egg processing. This is probably because ambient air temperature of the preprocessing coolers was higher in the summer vs. winter, although not significantly.

There was a significant season × geographic region interaction ($P < 0.05$) for both surface and internal egg temperatures. For the individual states, surface and internal egg temperatures varied by season at the various shell egg processing plant locations. Table 2 depicts surface and internal egg temperatures recorded at various locations in shell egg processing plants during the summer months. The highest egg surface temperatures recorded at the accumulator, postwash, postcandling, and packer head were plants in Iowa, North Carolina, Texas, and Texas, respectively. Egg surface temperatures recorded at the accumulator, postwash, and packer head area were lowest ($P < 0.05$) for eggs sampled from California, whereas those sampled from Illinois were lowest during postcandling. For internal egg temperatures, the highest temperatures recorded for the accumulator, postwash, postcandling and packer head areas were Texas, North Carolina, North Carolina, and Texas, respectively. Similar to egg surface temperature, internal temperatures were lowest ($P < 0.05$) for eggs sampled from California at the accumulator and postwash area. As expected, egg surface and internal egg temperatures recorded in each state showed an increase in temperature from the accumulator phase to immediately after the postwash phase. This agrees with the findings of Anderson et al. (1992), because the wash water used to wash eggs was warmer than the eggs.

In addition to egg temperature data, egg wash and rinse water temperatures were also recorded. During the summer months, wash water averaged 45.4°C, whereas rinse water averaged 46.5°C for all states combined. During the winter, wash and rinse water averaged 44.2 and 45.3°C, respectively, for all states combined (data not shown). As might be expected, this data indicates that summer wash and rinse water were slightly higher than during the winter. In both seasons, the temperature of rinse water was higher than wash water. This is consistent with the requirement of the USDA regarding rinse and wash water temperature.

The temperatures recorded for both egg surface and internal egg contents in the winter showed a similar trend as that during the summer (Table 3). The absolute temperature recordings were somewhat lower in the winter vs. summer as might be expected. Except for egg surface temperature at the accumulator, slightly higher temperatures were recorded for plants in Texas. It is interesting to note that egg surface temperatures were

Table 4. Mean egg surface and internal egg temperatures recorded for inline eggs processed at the accumulator, postwash, postcandling, and packer head locations in shell egg processing plants for summer and winter combined[1]

State	Accumulator	Postwash	Postcandling	Packer head
	(°C)			
Egg surface temperatures				
California	12.8 ± 1.5^{e}	20.3 ± 1.5^{d}	NA	17.6 ± 1.1^{e}
Georgia	20.0 ± 0.9^{bc}	23.6 ± 0.9^{bc}	24.7 ± 0.7^{b}	21.7 ± 0.7^{d}
Illinois	18.9 ± 0.8^{cd}	24.2 ± 0.8^{b}	23.3 ± 0.6^{c}	24.2 ± 0.6^{b}
Iowa	29.0 ± 1.2^{a}	NA	NA	24.4 ± 0.9^{b}
North Carolina	17.8 ± 1.0^{d}	27.3 ± 1.1^{a}	27.4 ± 0.8^{b}	25.9 ± 0.7^{a}
Pennsylvania	20.7 ± 0.6^{b}	23.1 ± 0.6^{c}	25.4 ± 0.5^{b}	22.9 ± 0.4^{c}
Texas	21.2 ± 0.9^{b}	NA	28.1 ± 0.7^{a}	26.6 ± 0.7^{a}
n	765	600	662	752
Internal egg temperatures				
California	14.6 ± 1.4^{d}	21.4 ± 1.2^{d}	NA	22.6 ± 1.0^{d}
Georgia	20.7 ± 0.9^{c}	24.6 ± 0.8^{c}	25.5 ± 0.9^{a}	26.0 ± 0.6^{b}
Illinois	21.7 ± 0.7^{bc}	26.3 ± 0.7^{a}	25.2 ± 0.7^{a}	26.4 ± 0.6^{b}
Iowa	NA	NA	NA	NA
North Carolina	20.4 ± 1.0^{c}	25.2 ± 0.9^{abc}	24.8 ± 1.0^{a}	26.6 ± 0.6^{b}
Pennsylvania	22.8 ± 0.8^{ab}	25.4 ± 0.7^{ab}	25.3 ± 0.8^{a}	24.0 ± 0.6^{c}
Texas	23.7 ± 1.0^{a}	24.9 ± 0.8^{bc}	26.1 ± 0.9^{a}	29.2 ± 0.6^{a}
n	565	574	522	572

[a–e]Means within a column with no common superscript within either egg surface or internal egg temperatures differ significantly ($P < 0.05$).

[1]States with an NA did not collect data due to the processor not allowing the collection of the data. Values are least square means ± SE.

highest ($P < 0.05$) for eggs at the accumulator in Iowa plants. Table 4 depicts the egg surface and internal egg temperatures for each state sampled when season of the year was combined. This data show that, for the most part, eggs tend to gain in temperature when they go from the accumulator to the packer head in both the summer and winter seasons. It is unclear as to why egg surface temperatures declined for plants sampled in Iowa.

When the data for all states were averaged, a definite difference was seen in summer and winter egg surface and internal egg temperatures (Table 5). During all 4 phases of processing, egg surface and internal egg temperatures were markedly greater during the summer vs. winter months ($P < 0.05$). When examining the effect of shell egg processing (time and conditions), it was noted that 2.4 and 3.8°C were added to egg surface temperatures from the accumulator to the packer head during the summer vs. winter, respectively. The total difference in internal egg temperatures recorded from the accumulator to packer head was 3.3 and 6.0°C in summer vs. winter conditions, respectively. These trends in surface and internal egg temperatures are probably a result of the temperature of eggs exiting the layer facility in the summer vs. winter.

It was of interest to also record the surface and internal egg temperatures of eggs coming into the shell egg processing plant from inline vs. offline configurations (Table 6). Offline, eggs would be collected from a production facility away from the shell egg processing plant and

Table 5. Mean egg surface and internal egg temperatures recorded for inline eggs processed at the accumulator, postwash, postcandling, and packer head locations in shell egg processing plants for summer and winter for all states[1]

Season	Accumulator	Postwash	Postcandling	Packer head	Accumulator to packer head difference
	(°C)				
Egg surface temperatures					
Summer	24.2 ± 0.5^{a}	27.7 ± 0.6^{a}	28.8 ± 0.4^{a}	26.6 ± 0.4^{a}	+2.4
Winter	17.8 ± 0.4^{b}	21.5 ± 0.4^{b}	23.7 ± 0.3^{b}	21.6 ± 0.3^{b}	+3.8
n	765	600	662	752	
Internal egg temperatures					
Summer	24.2 ± 0.5^{a}	28.1 ± 0.4^{a}	28.2 ± 0.5^{a}	27.5 ± 0.4^{a}	+3.3
Winter	18.9 ± 0.5^{b}	22.8 ± 0.4^{b}	23.1 ± 0.4^{b}	24.9 ± 0.4^{b}	+6.0
n	565	574	522	572	

[a,b]Means within a column for egg surface or internal egg temperatures with no common superscript differ significantly ($P < 0.05$).

[1]Values are least square means ± SE.

Table 6. Mean egg surface and internal egg temperatures recorded at the accumulator, postwash, postcandling, and packer head locations in shell egg processing plants for all inline and offline eggs in the summer and winter for all states[1]

Processing configuration[2]	Accumulator	Postwash	Postcandling	Packer head
	(°C)			
Egg surface temperatures				
Inline	19.6 ± 0.6[a]	23.7 ± 0.4[a]	23.4 ± 0.3[a]	23.2 ± 0.6[a]
Offline	12.0 ± 0.8[b]	21.2 ± 0.5[b]	20.7 ± 0.4[b]	19.0 ± 1.0[b]
Internal egg temperatures				
Inline	21.8 ± 0.5[a]	24.9 ± 0.6[a]	24.9 ± 0.6[a]	25.1 ± 0.4[a]
Offline	13.5 ± 0.6[b]	19.3 ± 0.8[b]	18.3 ± 0.7[b]	20.0 ± 0.7[b]

[a,b]Means within a column for egg surface or internal egg temperatures with no common superscript differ significantly ($P < 0.05$).

[1]Values are least square means ± SE, n = 160.

[2]The states of Georgia, Illinois, and North Carolina composed the offline processing data, whereas all states contributed to the inline processing data.

processed that day or stored in a preshell egg processing cooler before being processed. Inline eggs would be immediately processed after being conveyed by belts from the production house. The data depicted in Table 6 shows that egg surface and internal egg temperatures were higher ($P < 0.05$) for eggs being processed from inline vs. offline configurations. This should be expected, because the eggs processed inline come directly from the production house and are warmer at the start.

Over all of the temperatures taken, the surface temperature was slightly cooler than the internal temperature (Table 7). The correlation analysis comparing the egg surface to the internal temperatures indicated that these were highly correlated. However, postcandling, the surface temperatures were higher than the internal temperatures. This may have been due to the instantaneous nature of the heat generated by the candling lights resulting in a slight surface temperature elevation. Based upon these findings, the processors could utilize infrared temperatures to monitor the processing temperatures in the plant.

Tables 8 and 9 depict the data collected from 4 states in the postshell egg processing cooler area before eggs were transported to a distribution or retail center. The processor in the states of California, Georgia, and Iowa would not let the researcher collect this data, so they are not listed. There was no season × state interaction, so only the main effect means are shown. Ambient air temperature was surprisingly higher ($P < 0.05$) in the postshell egg processing cooler areas in Illinois, North Carolina, Pennsylvania, and Texas in the winter vs. summer (Table 8). This indicates that during the summer, overall building temperatures were probably kept cooler by air conditioning, which helped maintain cooler postshell egg processing cooler temperatures, or perhaps cooler use was less in the winter. Postshell egg processing cooler temperatures were the highest ($P < 0.05$) in North Carolina and Pennsylvania plants and lowest in Illinois plants when seasons were combined. The initial internal temperature of eggs entering the postshell egg processing coolers was much higher ($P < 0.05$) in the summer vs. winter. The higher ($P < 0.05$) summer and winter internal egg temperatures in Texas processing plants contributed significantly to the higher internal egg temperatures when the eggs entered the postshell egg processing cooler. The time that eggs spent in the postshell egg processing cooler was not different ($P > 0.05$) in the summer vs. winter; however, a wide range of time in the cooler was recorded for the 4 states. Most notably, the eggs spent more time ($P < 0.05$) in the postshell egg processing cooler in Illinois vs. Pennsylvania plants.

Table 8 also depicts the internal egg temperature at which eggs would be when they reached the ¾ cool point. This data represents the temperature change that is required to meet the 7.2°C storage regulation. This is the portion of the cooling curve that is most readily affected by temperature differences between ambient and egg temperature. This factor is also used in produce cooling as an indicator of cooling rates. This shows the

Table 7. Correlation of the mean egg surface and internal temperatures for inline eggs processed and recorded at the accumulator, postwash, postcandling, and packer head locations in shell egg processing plants[1]

Sampling location	Surface	Internal	R^2	*P*-value
	(°C)			
Accumulator	20.4 ± 6.1	21.3 ± 5.3	0.832	<0.0001
Postwash	24.1 ± 5.6	25.1 ± 4.5	0.659	<0.0001
Postcandling	25.6 ± 4.2	25.3 ± 4.8	0.636	<0.0001
Packer head	23.8 ± 4.4	26.1 ± 3.8	0.608	<0.0001

[1]Values are least square means ± SE, n = 80.

Table 8. Mean ambient postshell egg processing cooler temperatures, initial internal egg temperatures, time in cooler, and internal egg temperatures at ¾ cooling recorded for inline eggs processed during seasons and states with seasons combined[1]

Item	Ambient air temperature	Initial internal egg temperature[2]	Time eggs in cooler (h)	Internal egg temperature at ¾ cool[3] (°C)
	(°C)			
Season				
Summer	6.2 ± 0.2[b]	28.4 ± 1.3[a]	85.6 ± 21.3[a]	12.5 ± 0.3[a]
Winter	7.7 ± 0.2[a]	21.9 ± 1.0[b]	94.0 ± 16.5[a]	10.9 ± 0.3[b]
State				
California	NA	NA	NA	NA
Georgia	NA	NA	NA	NA
Illinois	5.7 ± 0.4[c]	24.3 ± 2.1[b]	137.2 ± 35.7[a]	11.5 ± 0.5[ab]
Iowa	NA	NA	NA	NA
North Carolina	7.7 ± 0.2[a]	24.4 ± 1.3[b]	84.3 ± 22.0[ab]	11.5 ± 0.3[b]
Pennsylvania	7.4 ± 0.3[ab]	23.3 ± 1.7[b]	42.1 ± 29.0[b]	11.2 ± 0.4[b]
Texas	6.9 ± 0.2[b]	28.9 ± 1.2[a]	95.6 ± 19.6[ab]	12.6 ± 0.3[a]

[a–c]Means within a column comparing seasons or states with seasons combined with no common superscripts differ significantly ($P < 0.05$).

[1]The processors in the states of California, Georgia, and Iowa would not allow for the collection of this data. Values are least square means ± SE, n = 35.

[2]Initial internal egg temperature when eggs entered the postprocessing cooler.

[3]Internal egg temperature at which eggs would be at when they reached ¾ cool (temperature change required to meet 7.2°C USDA-Agricultural Marketing Service storage regulation).

influence of initial egg temperature on ¾ cooled during the summer vs. winter months. This data, along with the higher internal egg temperatures at ¾ cool for Texas plants, are consistent with overall higher internal egg temperatures in summer and in Texas plants noted during the shell egg processing phase. The time required for eggs to reach their internal ¾ cool temperature target was not different ($P > 0.05$) in the summer vs. winter months or between the states of Illinois, North Carolina, Pennsylvania, or Texas (Table 9). Even though numerically it appeared that the time for eggs to reach ¾ cool was longer in the summer vs. winter and less in Texas vs. Illinois, North Carolina, and Pennsylvania plants, statistically there were no differences, probably due to large variability and a low number of samples. Finally, the internal egg temperature change (cooling rate of eggs from their initial internal egg temperature to ¾ cool) was not different ($P > 0.05$) during the summer vs. winter months or between states with seasons combined. Here again, a greater internal egg temperature (cooling rate) was noted in the winter vs. summer, but the variability in the data contributed to nonstatistical differences.

Table 9. Mean time it took for inline eggs processed to reach ¾ cool and internal temperature change (cooling rate) in the postshell egg processing cooler during seasons or states with seasons combined[1]

Item	Time eggs to ¾ cool[2] (h)	Internal temperature change[3] (°C change/h)
Season		
Summer	48.1 ± 12.8[NS]	0.27 ± 0.19[NS]
Winter	31.4 ± 6.3	0.51 ± 0.09
State		
California	NA	NA
Georgia	NA	NA
Illinois	45.8 ± 13.0[NS]	0.35 ± 0.19[NS]
Iowa	NA	NA
North Carolina	43.9 ± 7.7	0.46 ± 0.12
Pennsylvania	41.9 ± 17.1	0.09 ± 0.25
Texas	27.4 ± 11.3	0.66 ± 0.17

[NS]There were no significant differences ($P > 0.05$) between means within a column comparing seasons and states with seasons combined.

[1]The processors in the states of California, Georgia, and Iowa would not allow for the collection of this data. Values are least square means ± SE, n = 20.

[2]Time required by eggs to reach ¾ cool internal temperature.

[3]Internal temperature change (cooling rate) of eggs from initial internal egg temperature until they reached ¾ cool.

The data presented herein have shown that the season of the year and geographic region can affect egg surface and internal temperatures throughout commercial shell egg processing. It has been shown that during the processing of shell eggs, both the surface and internal egg temperatures are increased in the winter and summer months. Furthermore, it appears that temperature effects in the preshell egg processing cooler, processing phases, and postprocessing cooler affect the surface and internal egg temperatures differently in the summer vs. winter seasons. Therefore, the factors discussed herein should be included in future components of egg safety.

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