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Temperature Sequence of Eggs from Oviposition Through Distribution: Transportation—Part 3

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Abstract
The Egg Safety Action Plan released in 1999 raised many questions concerning egg temperature used in the risk assessment model. Therefore, a national study by researchers in California, Connecticut, Georgia, Iowa, Illinois, North Carolina, Pennsylvania, and Texas was initiated to determine the internal and external temperature sequence of eggs from oviposition through distribution. Researchers gathered data from commercial egg production, processing, and distribution facilities. The experimental design was a mixed model with random effects for season and a fixed effect for duration of the transport period (long or short haul). It was determined that processors used refrigerated transport trucks (REFER) as short-term storage (STS) in both the winter and summer. Therefore, this summary of data obtained from REFER also examines the impact of their use as STS. Egg temperature data were recorded for specific loads of eggs during transport to point of resale or distribution to retailers. To standardize data comparisons between loads, they were segregated between long and short hauls. The summer egg temperatures were higher in the STS and during delivery. Egg temperature was not significantly reduced during the STS phase. Egg temperature decreases were less ($P < 0.0001$) during short delivery hauls 0.6°C than during long hauls 7.8°C. There was a significant season × delivery interaction ($P < 0.05$) for the change in the temperature differences between the egg and ambient temperature indicated as the cooling potential. This indicated that the ambient temperature during long winter deliveries had the potential to increase egg temperature. The REFER used as STS did not appreciably reduce internal egg temperature. These data suggest that the season of year affects the temperature of eggs during transport. Eggs are appreciably cooled on the truck, during the delivery phase, which was contrary to the original supposition that egg temperatures would remain static during refrigerated transport. These data indicate that refrigerated transport should be a component in future assessments of egg safety.

Keywords
egg transport, egg temperature, shell egg

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INTRODUCTION

During the Egg Safety Risk Assessment hearings held in Washington, DC, June 12, 1998, questions were raised by USDA-Agriculture Marketing Service and Food Safety Inspection Service and Food and Drug Administration officials regarding egg temperatures at the various stages in the marketing chain and the impact that temperature has on the microbiological safety of eggs. Gwin (1952) determined that normal commercial egg marketing practices offer limited opportunities to obtain reasonably accurate measures of egg quality throughout the chain. Even today, processing plants have accurate egg quality records readily available, but incomplete records for storage temperatures and delivery continue to be problematic. This is primarily due to the volume and speed at which eggs move through the distribution system and grading and candling of specific lots of eggs at destination. Research in this area has focused mainly on egg surface temperature during washing and grading (Anderson, 1993) and has shown that temperatures increased 6.7°C during processing before packaging. Although Anderson et al. (1992) looked at internal egg temperatures postprocessing, Czarick and Savage (1992) examined egg surface temperatures postprocessing and different packaging and pallet arrangements in the postprocessing cooler. Anderson et al. (1992) and Czarick and Savage (1992) determined that eggs cool at different rates de-

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pending on their location in the pallet. Damron et al. (1994) examined egg transport trucks during phases of distribution and their ability to maintain the ambient temperature in the refrigerated trailers to meet regulations proposed at the time of 7.2°C (45°F). Internal egg temperatures greater than 7°C 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 the retail point of sale to improve the risk assessment model. However, research measuring internal egg temperatures that document the complete time and temperature changes from production throughout all phases of egg distribution has been limited. Therefore, the objectives of this phase of the study were to determine the relationship between the ambient transport temperatures and internal temperature of eggs from point of lay (oviposition) to the retail outlet and to identify the variables associated with transport that influence the time and temperature to which eggs are exposed.

MATERIALS AND METHODS

General

Researchers from universities in California, Connecticut, Iowa, Illinois, North Carolina, Pennsylvania, and Texas and the USDA-Agricultural Research Service in Georgia gathered data on egg internal and surface temperatures, along with ambient temperatures, during their transport and distribution to warehouses and retail outlets from commercial processing plants (Koelkebeck et al., 2008; Patterson et al., 2008). 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 goal was for each state to gather data from a minimum of 3 production-processing facilities during both winter and summer seasons. It should be noted that not all states were able to compile complete data sets due to the processor practices and challenges beyond their control. Therefore, the data presented excludes states that had outbreaks of exotic Newcastle disease and avian influenza, which resulted in curtailment of the field investigation phase of the study due to biosecurity concerns; thus, fewer number of data points were obtained.

This portion of the study encompasses the transportation component that begins with the distribution of eggs from the postprocessing coolers at the loading docks. This is followed by the direct nonstop transport of the eggs by refrigerated transport trucks (**REFER**) to the distribution center or retail outlet. Temperature data logger probes, for the collection of egg and ambient temperatures, were placed so they integrated into the packaging materials utilized by the processor, to prevent damage or displacement during transport. The eggs were packaged in foam cartons then placed in plastic open-sided baskets or corrugated cardboard close-sided cases with the data loggers being placed in the order the egg shipment was assembled and prepared for shipment under the oversight of the plant manager. The sampling was done using the same egg size and egg mass where possible in accordance with the sampling methods the processors would allow for any given shipment. Normally, this minimized the eggs destroyed for sampling loss and allowed for easy retrieval of the data loggers at the final destination. This may have contributed to the variation in the study. Typically, the researcher retrieved the logger, or in some cases, the delivery driver retrieved the data logger from the shipment and returned it to the processing plant where it was picked up and returned to the laboratory.

Egg Temperatures and Environmental Condition Determination

For the delivery sampling locations, internal egg and ambient temperatures were measured with a Cox Tracer (CT-1E-DC-4-C, Sensitech, Beverly, MA) data logger equipped with an internal and external probe. The internal probe was a thermocouple built into the tracer body. The external probe was a stainless steel pointed probe 8 cm long (4-mm diameter) and a temperature range of –40 to 70°C. The Tracer was capable of storing 8,000 readings. A 4-mm hole was made in the egg shell in the center of the large end. The external probe was inserted in the egg and thus inside the yolk at a depth of about 2.5 cm, the approximate geometric center of the egg. The probe utilized the entire opening in the shell, which prevented contents from leaking out and mitigated the need to seal the hole as used by Curtis et al. (1995). The probed egg was then placed in a carton or flat that was located in the approximate center of a shipping container (basket or case). The Tracer was then activated and placed in the container where the internal probe recorded the case temperature concurrently with the internal egg temperature from the external probe. The data logger was programmed to simultaneously record internal egg and ambient case temperatures every 15 min. The case was then integrated into the lot of eggs being shipped by the processor and labeled so that the data logger with the probe could be easily retrieved at destination by the researcher or the truck driver. Another Cox Tracer (CT-HS-B-16, Sensitech) data logger for monitoring REFER ambient temperature and relative humidity was placed on top of the pallets with the egg shipment. Some processors were using the REFER for short-term storage (**STS**) of the egg shipments for up to 30 h before delivery to the warehouse, distribution center, or retail store. The REFER ambient temperature and humidity were monitored throughout the transport period, which was initiated when the eggs were loaded into the REFER. All of the egg shipments that were monitored were direct deliveries to destination so that once the eggs were loaded for storage through the delivery, the REFER were not opened until point of delivery. All external and internal egg temperatures were recorded in degrees Celsius with an accuracy of ±0.3°C. Cooling potentials, defined as the temperature differences between the internal egg temperature and ambient tem-

Table 1. Mean case, internal egg, and ambient temperature when using refrigerated transport trucks as short-term storage predelivery[1]

Source	Number of loads	Duration (h)	Mean case temperature (°C)	Mean internal egg temperature[2] (°C)	Mean ambient temperature (°C)
Season (S)					
Summer	15	24.1	22.9 ± 2.6*	23.1 ± 2.7*	6.9 ± 1.6
Winter	14	18.4	14.1 ± 2.0	14.6 ± 2.0	11.4 ± 1.2*
Storage (STS)					
Long[3]	22	>12	19.8 ± 1.5	19.6 ± 1.5	10.6 ± 1.0
Short[4]	7	<12	17.3 ± 2.9	18.0 ± 2.9	7.6 ± 1.8
S × STS			NS	NS	NS

[1]Data are the least squares means ± SEM, n = 29.

[2]Represents the average of start and ending egg temperatures.

[3]Long storage time (>12 h).

[4]Short storage time (<12 h).

*Mean case, egg, and ambient temperatures within a column comparing seasons differ significantly ($P < 0.05$).

peratures, were calculated at the start (**SCP**) and end (**ECP**) of STS and delivery phases through the transportation system. The change in the cooling potential (**ΔCP**) represented by the formula (ECP – SCP = ΔCP) represents the potential for the egg to dissipate heat at the given point in the transport system.

Statistical Analysis

For the transportation segment of this research, the main effects evaluated were season of the year, duration of REFER use for storage, and egg delivery time. The storage periods were divided into short (<12 h) and long (>12 h) durations and the delivery periods similarly with durations of <10 h, short, and >10-h long. The distinct phases of long and short durations in the storage and delivery were determined by the natural break points in the data sets, corresponding to notations made by the researchers. The experiment was set up as a factorial design with season and duration of the storage or delivery period as the main effects. The experimental units were the random lots of eggs assembled for shipment. Short-term storage and delivery were analyzed separately. All data were analyzed utilizing the SAS GLM procedure for ANOVA and, when significantly different, the least squares means that were separated using PDIFF (SAS Institute, 1998).

RESULTS AND DISCUSSION

The transportation of shell eggs has several distinct phases, which were examined in this study. These phases are the predelivery loading of eggs, which includes using REFER as short-term storage, and the actual delivery of the eggs. Therefore, the transportation phases for this study have been divided into predelivery STS and delivery phases.

Predelivery STS Phase

Average internal shell egg temperatures were higher ($P < 0.05$) in the summer season than during the winter during the initial STS of the eggs before delivery (Table 1). This would be logical, because the eggs would be coming from a warmer production house in the summer and would still retain that temperature through processing. However, the ambient temperature in the REFER was higher ($P < 0.05$) in the winter than in the summer. The higher winter ambient temperature in the REFER may be the result of the refrigeration units not being set as low in the winter with a greater reliance on lower outdoor winter temperatures. The length of the STS greater or less than 12 h had no impact on the average egg or ambient temperatures.

Summer egg temperatures were 8.4°C warmer ($P < 0.05$) than in the winter at the beginning of the storage period and 8.9°C at the end (Table 2). This was surprising, because the summer and winter temperature differences between the egg and the ambient temperatures at the beginning of the storage period were 12.8 and 1.0°C, respectively. Even though the eggs were coming out of a 7.2°C postprocessing cooler, regardless of the season, the influence of the summer egg temperatures results in higher temperatures in the eggs coming out of the coolers. This may be the result of the minimal time eggs actually spend in the cooler of a plant. Based on the greater heat loss potential of the egg in the summer, it would be expected to have a greater egg temperature change occur. However, this shows that the season of the year had little impact on the internal egg temperature change. This is supported by the findings of Anderson et al. (1992) and Czarick and Savage (1992). They determined that egg temperatures changed very slowly when the eggs were packed and palletized.

The present study indicates that the REFER ambient temperature will decrease during the storage period and for long deliveries will get below the USDA storage temperature requirements of 7.2°C (45°F). Surprisingly, this only occurs in the summer. It appears that processing plants may be operating the refrigeration units at a lower capacity in the winter, which would allow for greater influence of egg temperature on the ambient temperature in the REFER. This would indicate that the cooling performance of the REFER is relatively constant throughout the year and would not have a difficult time maintaining the ambient temperature at or below 7.2°C in the warmer seasons, as was shown by Damron et al. (1994). The length

Table 2. Egg and ambient temperatures and temperature changes when using refrigerated transport trucks as short-term storage predelivery[1]

Source	Egg temperature start (°C)	Egg temperature end (°C)	Egg temperature change (°C)	Ambient temperature start (°C)	Ambient temperature end (°C)	Ambient temperature change (°C)
Season (S)						
Summer	24.1 ± 2.8*	22.3 ± 2.7*	1.8 ± 1.3	11.3 ± 2.1	6.3 ± 1.7	5.0 ± 1.4
Winter	15.7 ± 2.0	13.4 ± 2.0	2.3 ± 0.9	14.7 ± 1.5	9.2 ± 1.3	5.5 ± 1.1
Storage (STS)						
Long[2]	21.3 ± 1.6	18.3 ± 1.5	2.9 ± 0.7	13.7 ± 1.2	8.8 ± 1.0	4.8 ± 0.9
Short[3]	18.5 ± 3.0	17.4 ± 2.9	1.5 ± 1.4	12.4 ± 2.3	6.6 ± 1.8	5.7 ± 1.6
S × STS	NS	NS	NS	NS	NS	NS

[1]Data are the least squares means ± SEM, n = 29.

[2]Long storage time (>12 h).

[3]Short storage time (<12 h).

*Mean egg temperatures start and end within a column comparing seasons differ significantly ($P < 0.05$).

of the predelivery storage phase had no significant influence on the ending internal egg or ambient temperatures. Both the egg and ambient temperatures changed in similar ways during postprocessing and pretransport storage and during transport phases. There were no significant interactions during the predelivery storage phase between season and storage.

Delivery Phase

The season of the year continued to have a significant impact on the case and egg temperature (Table 3). Consistently, the case ($P < 0.05$) and egg temperatures ($P < 0.01$) were higher in summer than in winter by 4.7°C. This is logical, because the eggs coming in from the production facilities and through processing have the potential of being warmer due to higher ambient temperatures during summer. The case temperature indicates environmental conditions to which the eggs are immediately in contact. These temperatures were lower than the egg and higher than the REFER ambient temperatures. This reflects the insulative value that packaging can have on the egg (Czarick and Savage, 1992). There was a significant ($P < 0.05$) interaction of season by delivery for the mean egg temperature (Figure 1). In the winter there were no internal egg temperature differences between the long and short deliveries; however, in the summer, the internal egg temperatures were higher after the short deliveries. This indicates that under summer conditions and short duration delivery, eggs do not have adequate time or exposure to cold temperatures to affect a significant lowering of the egg temperature. This is indicated by a continuing cooling of eggs from predelivery storage through delivery in the REFER as shown between Tables 1 and 3.

The summer egg temperatures at the start and end of delivery were significantly ($P < 0.01$) warmer than in the winter (Table 4). The relative change in egg temperature at destination of the delivery phase was not significantly different when comparing winter and summer at 3.2 and 4.5°C, respectively. There was no season effect on ambient temperature observed (Table 4). However, in both seasons, eggs never reached an internal temperature of 7.2°C that would significantly reduce the replication of most organisms (Rhorer, 1991) responsible for foodborne diseases. Short-term deliveries resulted in higher ($P < 0.0001$) egg temperatures vs. long. This is due to the fact that the eggs did not have sufficient exposure time (<10 h) to the cool ambient environment to achieve effective heat loss.

Table 3. Mean case, internal egg, and ambient temperature when using refrigerated transport trucks for deliveries[1]

Source	Number of loads	Duration (h)	Mean case temperature (°C)	Mean egg temperature (°C)	Mean ambient temperature (°C)
Season (S)					
Summer	23	25.4	16.6 ± 1.4*	16.9 ± 1.3**	8.5 ± 1.4
Winter	28	20.6	11.9 ± 1.4	12.2 ± 1.2	11.1 ± 1.3
Delivery (D)					
Long[2]	23	>10	11.0 ± 1.5	11.1 ± 1.3	8.0 ± 1.0
Short[3]	28	<10	17.6 ± 1.4**	18.0 ± 1.2***	8.7 ± 0.9
S × D			NS	*	NS

[1]Data are the least squares means ± SEM, n = 51.

[2]Long delivery time (>10 h).

[3]Short delivery time (<10 h).

*Mean case temperature within a column comparing seasons differ significantly ($P < 0.05$).

*Mean egg temperature season × delivery interaction was significantly different ($P < 0.05$).

**Means egg and case temperatures within a column comparing seasons and delivery duration, respectively, differ significantly ($P < 0.01$).

***Mean egg temperature within a column comparing delivery duration differ significantly ($P < 0.001$).

Table 4. Egg and ambient temperatures and temperature changes when using refrigerated transport trucks for delivery[1]

Source	Egg temperature start (°C)	Egg temperature end (°C)	Egg temperature change (°C)	Ambient temperature start (°C)	Ambient temperature end (°C)	Ambient temperature change (°C)
Season (S)						
Summer	20.7 ± 1.4**	16.2 ± 1.3**	4.5 ± 1.1	9.8 ± 1.1	7.2 ± 0.9	2.6 ± 1.1
Winter	14.4 ± 1.3	11.2 ± 1.2	3.2 ± 1.0	11.8 ± 1.0	8.5 ± 0.9	3.3 ± 1.0
Delivery (D)						
Long[2]	16.8 ± 1.4	9.7 ± 1.3	7.1 ± 1.0***	14.4 ± 1.2***	8.9 ± 1.0	5.5 ± 1.1**
Short[3]	18.3 ± 1.3	17.7 ± 1.2***	0.6 ± 1.0	7.2 ± 1.0	6.8 ± 0.8	0.4 ± 0.9
S × D	NS	*	NS	NS	NS	NS

[1]Data are the least squares means ± SEM, n = 51.

[2]Long delivery time (>10 h).

[3]Short delivery time (<10 h).

*Egg temperature end season × delivery interaction was significantly different ($P < 0.05$).

**Mean egg temperature start and end within a column comparing seasons differ significantly, and mean ambient temperature in a column comparing delivery duration differ significantly ($P < 0.01$).

***Mean egg temperature end, change, and ambient temperature start within a column comparing delivery duration differ significantly ($P < 0.0001$).

This is shown by the 6.5°C greater ($P < 0.0001$) temperature change during long vs. short deliveries (Table 4). This is further illustrated by the significant ($P < 0.05$) interaction of season and delivery duration as shown in Figure 2. During the summer, indications are that eggs do not cool significantly during a short delivery. This results in eggs not having achieved an internal temperature of 7.2°C or below at destination but rather at least 9°C (16.2°C – 7.2°C) higher than the internal target temperature. Egg temperatures were lower at the beginning of the delivery phase after a short period of storage in the REFER. This indicates that using the REFER as storage before delivery for long or short time periods resulted in a 3.0 to 1.1°C respective drop in egg temperature. However, the initial egg temperatures at the start of the delivery phase shown in Table 4 were 1.5 to 0.3°C cooler than at the end of the STS shown in Table 2. This would suggest that the eggs cooled faster in the postprocessing cooler than eggs held short-term in the REFER before delivery.

Some customers stipulate in their HACCP/Quality Assurance programs that the internal egg temperature reach 7.2°C or below within 4 h after delivery. This would mean the summer eggs herein could be out of compliance at point of delivery. Although it is not clear why ambient starting temperature was greater for longer deliveries, the start to end change in ambient temperature was significantly greater for longer than shorter deliveries (5.5 vs. 0.4°C), which makes intuitive sense, because there was more cooling time available in the long hauls with a greater probability that the eggs could reach the prescribed internal temperature.

One concern during transport is the change in ΔCP. This means that the ΔCP between the egg and ambient temperature from the start needs to be maintained in a positive status where the egg temperature will decrease. A worst-case scenario is that when a negative ΔCP occurs, the potential that the egg may increase in temperature exists. Figure 3 indicates that there was no effect of season with the ΔCP during the STS phase. However, during the winter STS, there was a negative ΔCP at the start and end of storage, which translates into conditions in which the egg could increase in temperature. However, this was not the case in the delivery phase, in which the interaction ($P < 0.05$) of season and delivery duration (Figure 4) shows that the ambient temperature can increase. In this study, during long hauls in the winter, the egg temperature

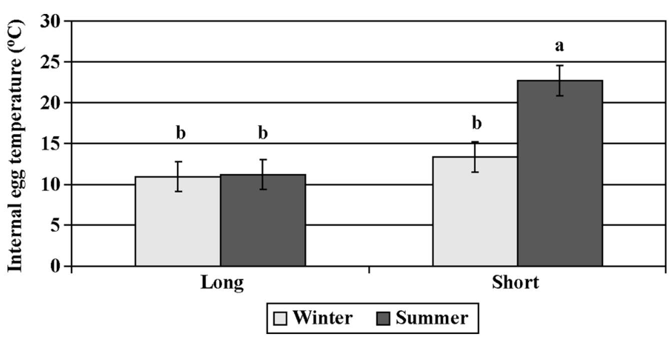

Figure 1. Interaction of season and long delivery time (>10 h) and short delivery time (<10 h) on average internal egg temperatures. Data are the least squares means ± SEM, n = 45. [a,b]Means with different letters are significantly different ($P < 0.05$).

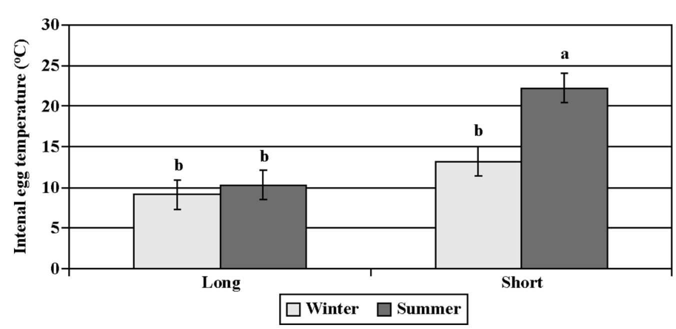

Figure 2. Interaction of season and long delivery time (>10 h) and short delivery time (<10 h) on the ending internal egg temperatures at the end of the delivery. Data are the least squares means ± SEM, n = 45. [a,b]Means with different letters are significantly different ($P < 0.05$).

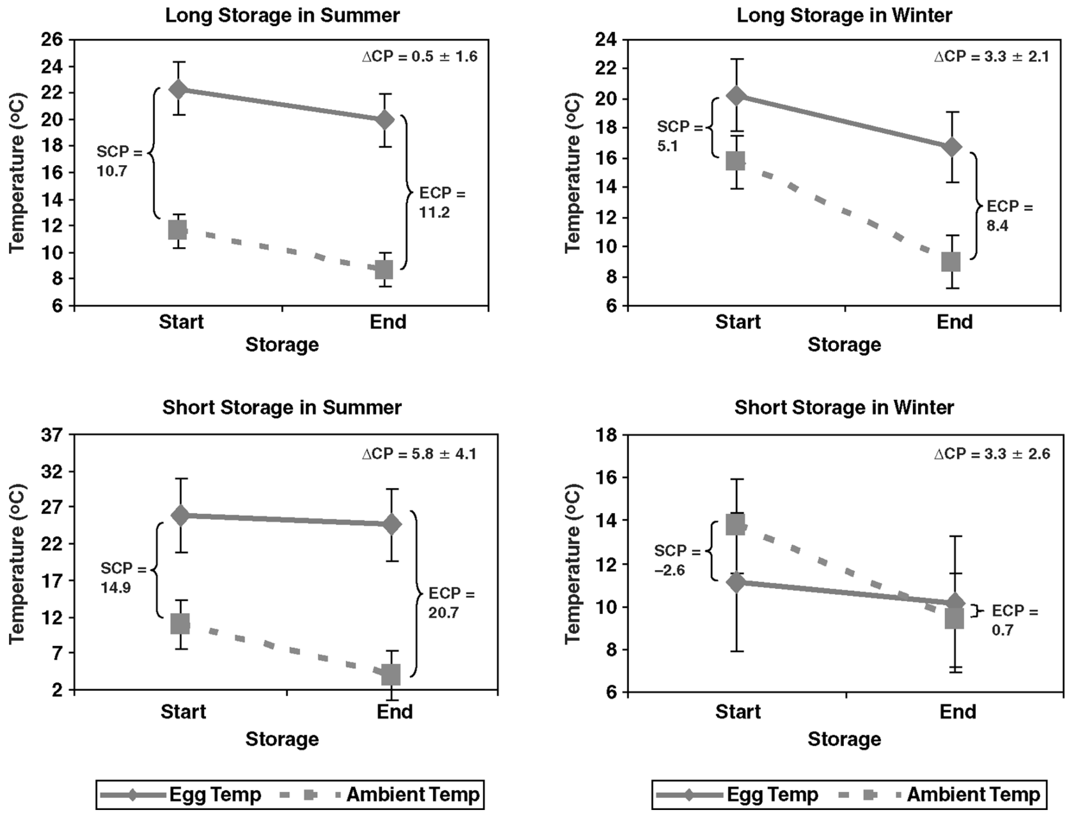

Figure 3. Interaction of season and long storage time (>12 h) and short storage time (<12 h) on the change in cooling potential (ΔCP = ECP – SCP). Data are the least squares means ± SEM, n = 29. SCP = starting cooling potential; ECP = ending cooling potential; Temp = temperature.

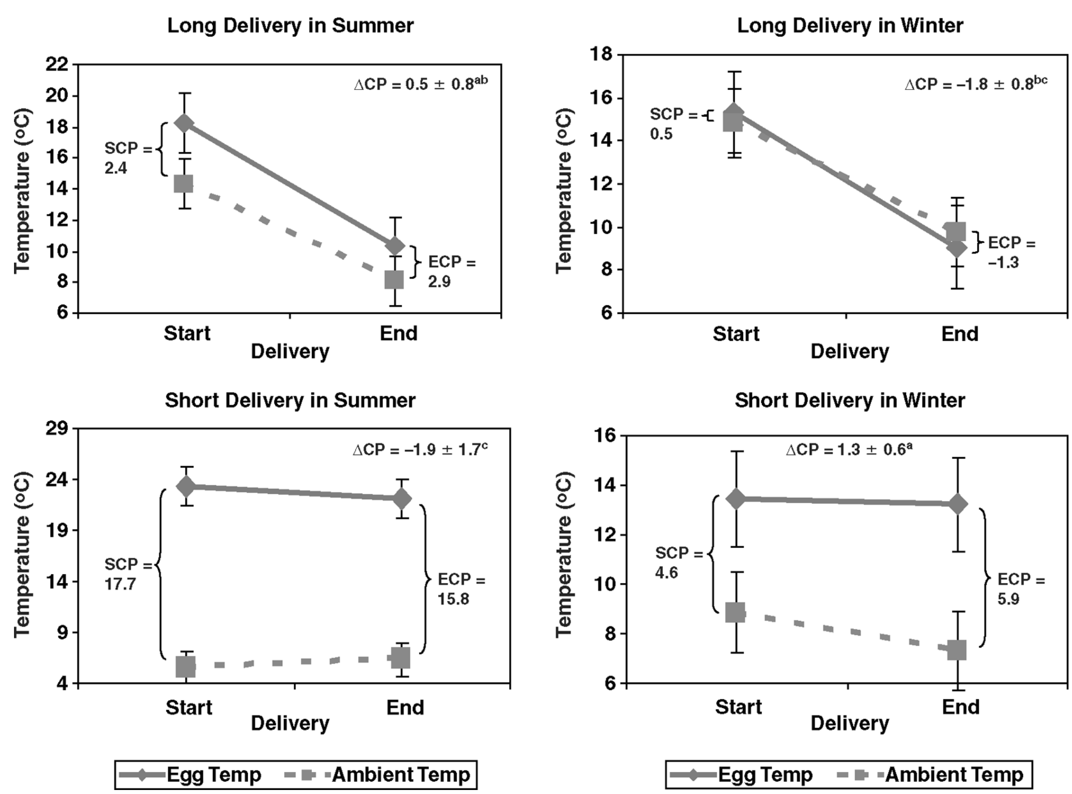

Figure 4. Interaction of season and long delivery time (>10 h) and short delivery time (<10 h) on the change in cooling potential (ΔCP = ECP – SCP). Data are the least squares means ± SEM, n = 45. [a–c]ΔCP with different superscripts are significantly different (P < 0.05). SCP = starting cooling potential; ECP = ending cooling potential; Temp = temperature.

actually had the potential to increase with a ΔCP of −1.8, in which the egg temperature dropped to a temperature lower than the ambient temperature at the end of the delivery. A negative ΔCP was also measured during summer short deliveries, when ambient temperature was increasing, resulting in a ΔCP of −1.9. In this summer scenario, the 17.7°C (SCP) to 15.8°C (ECP) temperature differences between the ambient and the egg temperature ensured that the eggs continued to cool. This component of the interaction may have been caused by the influence of the warmer summer egg internal temperature along with the mass of eggs causing the ambient temperature to rise due to the heat transfer from the eggs.

The data presented herein has shown that the duration of the STS phase did not impact the mean internal egg temperature or ambient temperature changes, whereas the season of the year impacted internal egg temperatures in the STS. During the delivery phase, both season and the duration of the delivery period influenced internal egg temperatures. However, only the long-duration deliveries (>10 h) resulted in significant changes in egg temperatures. Processors should implement management strategies to improve overall egg cooling and to eliminate possible ΔCP that could contribute to the warming of eggs during transport. At both points in this study, at the end of STS and delivery, the internal egg temperatures had not equilibrated with the ambient temperatures that are regulated at 7.2°C postprocessing.

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