# Drinking Water Temperature Effects on Laying Hens Subjected to Warm Cyclic Environments

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**ABSTRACT** Two experiments were conducted to evaluate the effects of drinking water temperature ($T_w$) on laying hens subjected to warm cyclic air temperature ($T_a$) conditions. Each experiment consisted of a 1-wk acclimation under thermoneutrality (TN) ($T_a = T_w = 21$ C), a 4-wk heat exposure or treatment period, and a 2-wk recovery under TN. Each experiment involved 24 individually caged hens at the initial age of 29 wk (Experiment 1) or 30 wk (Experiment 2). In Experiment 1, $T_w$ of 18 or 27 C was provided to 12 birds per $T_w$ regimen under a diurnal $T_a$ of 27 to 35 C (daily mean of 31 C). In Experiment 2, $T_w$ of 15, 19, 23, or 27 C was provided to six birds per $T_w$ regimen under a diurnal $T_a$ of 27 to 38 C (daily mean of 32.5 C). Experiment 1 showed that $T_w$ of 18 C enhanced hourly and daily feed and water intake during the first 2 wk of heat exposure, as compared with $T_w$ of 27 C. Experiment 2 showed that daily feed and water intake were greatest for hens in the 23 C $T_w$ regimen and least for hens in the coolest or warmest $T_w$ regimens. Reduction in daily feed intake with increase in daily mean $T_a$ ranged from 2.0 ~ 3.2 g/C-day (first week of heat exposure) to 1.1 ~ 1.9 g/C-day (fourth week of heat exposure). Water to feed intake ratio was 1.8 ~ 2.0 during acclimation and recovery, but increased to 3.0 ~ 3.4 during heat exposure. Internal egg quality parameters were in general unaffected by $T_w$. The two warmer $T_w$ regimens in Experiment 2 had less reduction in egg size than did the two cooler $T_w$. In both experiments, hens displayed anticipatory increase in feed and water intake 2 to 3 h prior to lights-off. However, the stimulus of lights-on did not elicit a strong return to feed and water consumption as typically seen in broilers. The results revealed the potential existence of an optimal $T_w$ range (near 23 C) for heat-challenged laying hens. Larger-scale tests are warranted to further verify the findings.

(*Key words*: laying hen, production performance, heat stress relief, hen well-being)

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## INTRODUCTION

Factors influencing feed and water consumption and, thereby, meat and egg production of poultry are of economic importance. Although ample information exists in the literature about environmental effects on feed and water intake of broilers (May and Lott, 1992a,b, 1994; Xin et al., 1993, 1994; May et al., 1997), less information is available for modern laying hens. Daily feed use of White Leghorn chickens has been reported to decrease from 130 to 70 g/bird when the maximum house air temperature ($T_a$) increased from 4.4 to 37.8 C, yielding a daily feed-use reduction rate of 1.8 g/bird per C increase in $T_a$ (Poultry Times Supplement, 1999). At the same time, daily water use increased from 182 to 590 mL/bird for these $T_a$, or 12.2 g/bird per C increase in $T_a$. Decreased feed consumption during hot weather affects the intake of calcium and other nutrients essential for strong shells. High $T_a$ results in reduced shell quality and decreased shell thickness (North and Bell, 1990; Yamamoto et al., 1997).

The benefit of providing cooled drinking water to birds, in terms of body heat loss used to warm the water, is insignificant (less than 0.2 W assuming 10 C cooler water and 300 g daily water intake). Yet, if cool water can induce additional water intake, thereby ensuring ample moisture supply for respiratory (panting) heat loss, the benefit can be substantial (Brody, 1945). Further, we hypothesize that providing cooler drinking water promotes feed consumption and thus eggshell quality.



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**Abbreviation Key:** BM = body mass of the hen; DFI = daily feed intake; DWI = daily water intake; ES = egg size; EP = egg production; FC = feed conversion ratio; HFI = hourly feed intake; HU = Haugh unit; HWI = hourly water intake; $T_a$ = air temperature; $T_w$ = water temperature; TN = thermoneutrality; WFR = water to feed ratio.

Largely unknown is the relationship between feed and water consumption over the course of diurnal heat stress. For example, if birds could be induced to drink more during the hottest portion of a day, they may alter their feeding behavior as well.

Puma et al. (2001), using a newly developed feeding and drinking monitoring system, reported that when provided cooler drinking water (20, 22, or 27 C vs. 32 C), broilers tended to maintain feed and water intake under a warm (35 C) environment. Little published information is available regarding the effects of drinking water temperature on modern layers during heat exposure, even though flushing water lines during hot weather has been practiced by some commercial poultry operations. Scientific studies to quantify the effects and operational strategies of controlling drinking water temperature are warranted.

The objectives of this research were (1) to evaluate the effects of drinking water temperature ($T_w$) on production responses of laying hens subjected to warm/hot cyclic air temperature ($T_a$), (2) to determine whether an optimal $T_w$ or range exists during heat exposure, and (3) to determine if or how $T_w$ affects dynamic feeding and drinking patterns of the heat-challenged hen.

## MATERIALS AND METHODS

### Experimental Hens and Procedure

Two experiments were conducted at the Livestock Environment and Animal Physiology Laboratory at Iowa State University, Ames, Iowa. For each experiment, 30 Hy-line W-36 laying hens with similar body masses (BM) were obtained from a commercial egg facility in Iowa and transported to the laboratory. The hens had an initial age of 29 wk (Experiment 1) or 30 wk (Experiment 2) and BM of 1.57 to 1.58 kg or 1.61 to 1.67 kg, respectively. The hens were housed in individual wire-mesh cages (25-cm width × 46-cm depth × 46-cm height) that were located in two adjacent environmental chambers (2.4-m width × 2.4-m depth × 3.0-m height), 12 hens per chamber. They were provided with a photoperiod of 16 h (0500 to 2100 h) light and 8 h darkness, as practiced on the commercial farm, feeding ad libitum of a commercial diet containing 19% CP, 4.2% Ca, and 0.8% P. Feed and water were replenished daily.

Hens were held for 5 d under thermoneutrality (TN), followed by selection of 24 hens with similar BM and egg production histories for further testing. A 1-wk acclimation (Week 0) was then initiated with $T_a$ and $T_w$ at 21 C. After acclimation, a warm diurnal $T_a$ was applied to both chambers, and $T_w$ was controlled to achieve respective target values. In Experiment 1, 12 hens (six in each chamber) were randomly assigned to a warm $T_w$ of 27 C and the other 12 to a cool $T_w$ of 18 C; $T_a$ varied diurnally from 27 to 35 C (mean of 31 C). In Experiment 2, four $T_w$ of 15, 19, 23, and 27 C were randomly assigned to six hens per regimen (three per chamber); $T_a$ varied diurnally from 27 to 38 C (mean of 32.5 C). Selection of the four $T_w$ levels in Experiment 2 was based on the positive effects of cooler $T_w$ on hens as revealed in Experiment 1, and was to evaluate the potential existence of an optimal $T_w$ or range during the heat exposure. In both experiments, $T_a$ was programmed to reach the highest at 1800 h and the lowest at 0600 h. Hens were subjected to this environment for 4 wk, followed by a 2-wk recovery period during which both $T_a$ and $T_w$ returned to the acclimation TN condition of 21 C. The target values were maintained within 0.3 to 0.5 C for $T_a$ and 0.1 to 0.2 C for $T_w$. Humidifiers were used to maintain relative humidity between 45 and 60% in the environmental chambers.

### Measurement of Response Variables

Each individual birdcage was equipped with a feeding and drinking station whose signal outputs were transmitted to a central data acquisition personal computer. The specially designed drinking devices achieved the target $T_w$ by controlling the temperature of a water jacket surrounding the water reservoir column. Puma et al. (2001) provided a detailed description on the design and operation of the measurement and control system. Monitoring of feeding and drinking started with the acclimation period and continued throughout the experiment. Data for the transition days, i.e., from acclimation to treatment (Days 13 and 14) and from treatment to recovery (Day 41), were excluded from the analysis because of the time required for $T_w$ to reach stabilized target values.

Eggs were collected and recorded daily, cleaned, weighed and stored at 4 C, and analyzed weekly for the following parameters: yolk, albumen, shell weight, yolk to white ratio, and Haugh units. Yolk was weighed after separating albumen and chalaza from the yolk. Chalaza was removed with a pair of forceps. For Experiment 1, shell weight was measured after removing any residual albumen from the inner eggshell surface with a vacuum. For Experiment 2, shell weight, including that of the membrane, was determined after drying for 24 h at 85 C. Albumen weight was calculated by subtracting yolk and shell weights from total egg weight. Albumen heights (to nearest 0.1 mm) were measured with a dial caliper device.[2] In both experiments, feed conversion (FC)—the ratio of feed intake to egg production—was determined for each hen for various periods.

### Data Processing and Statistical Analysis

***Feed and Water Consumption.*** Feed and water intake were determined from the time-series recordings (4 or 30 s intervals) of feeder and waterer weight for each hen. These data were checked for spurious readings and synthesized into hourly and daily values for each hen. Daily feed intake (DFI) and daily water intake

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(DWI) were also directly measured from the feeder and waterer weight readings at the start and end of each 24 h cycle. Daily values for each hen were further averaged into weekly intervals.

***Egg Production.*** Egg size (ES, g/hen), egg production (EP, eggs/hen-day), and FC were determined on weekly basis. In Experiment 1, eggs were pooled by treatment, whereas in Experiment 2, hen identity was preserved. Each egg was weighed to the nearest 0.1 g.

***Internal Egg Quality Parameters.*** In Experiment 1, eggs were pooled by $T_w$ treatment each week. In Experiment 2, eggs were analyzed on a per hen basis each week, with four eggs/hen used for yolk/white ratio determination and the remaining eggs for Haugh unit (HU) determination.

HU was calculated according to the following equation (Stadelman and Cotterill, 1977):

$$HU = 100 \log [H - 32.2^{1/2} (30\ EW^{0.37} - 100)/100 + 1.9] \quad [1]$$

where H = albumen height (mm), and EW = egg weight (g).

Egg weighing and measurement of albumen height were done just after taking the eggs from the cold storage (4 C). The temperature of the eggs during sampling was slightly higher than 4 C.

***Statistical Analysis.*** Response variables were tested for treatment effects as follows. For Experiment 1, an independent *t*-test was performed, using means by treatment for each week, with hen as the experimental unit. For Experiment 2, some differences between treatment groups during acclimation were observed; thus, means of bird responses for each week were subtracted from values for the acclimation period, and a percentage change with respect to the acclimation value was computed. Treatment effects were tested with analysis of variance, using weekly periods as repeated measures (SAS, 1999). Significant main effects were separated by least-squares means. A significance level of $P < 0.1$ was used for testing treatment effects in both experiments. Although the significance level of $P < 0.1$ is greater than the typical level of $P < 0.05$, it was considered to be adequate for this study because of the inherent nature of variation among the individual birds and the relatively small sample sizes.

## RESULTS AND DISCUSSION

### Feed and Water Consumption

For Experiment 1, DFI of hens on the $T_w$ regimens was similar at 105 and 106 g/hen-day during acclimation (Table 1) and decreased significantly during heat exposure. During the first 2-wk heat exposure, DFI for the cool $T_w$ (82 g for Week 1 and 86 g for Week 2) were significantly higher than those for the warm $T_w$ (77 g for Week 1 and 81 g for Week 2). During the last 2-wk heat exposure and the recovery period, DFI appeared unaffected by treatment. DFI for both $T_w$ regimens showed a similar compensatory gain during the recovery period, and stabilized at 114 g/hen-day. The rate of DFI reduction, with increase in daily mean $T_a$ on a weekly basis, averaged 2.8 g/C-d for Week 1 to 1.6 g/C-d for Week 4 of the warm $T_w$ regimen; and 2.4 g/C-d for Week 1 to 1.9 g/C-d for Week 4 of the cool $T_w$ regimen. These values compared well with the literature report of 1.8 g/C-d reduction rate (Poultry Times Supplement, 1999). The gradual rebound of the DFI reduction rate was presumably the result of adaptation of the hens to the increased temperature.

DWI for both $T_w$ regimens were similar (194 and 193 g/hen-day for the warm and cool $T_w$, respectively) during the acclimation period, and increased to 262 and 278 g/hen-day, respectively, during the first week of the treatment period. During the recovery period, DWI returned to almost the same levels as during the acclimation period, and there was no significant difference between the two regimens. As expected, DWI during the heat exposure was significantly higher than that during TN condition (i.e., acclimation or recovery), being 33% higher for the warm $T_w$ and 44% higher for the cool $T_w$.

Water to feed ratio (WFR) was not significantly different between the two $T_w$ regimens during the acclimation period (1.9 vs 1.8 for the warm and cool $T_w$, respectively). WFR increased during heat exposure, averaging 3.1 and 3.2, respectively, but showed no treatment effect (Table 1). WFR returned to the acclimation levels during the recovery period.

Suppression of DFI during 4-wk heat exposure was also noted in Experiment 2, averaging 31, 25, 23, and 17 g/hen-day across $T_w$ regimens for Weeks 1 to 4, respectively (i.e., mean weekly DFI increased 4.4 g/hen-day as birds acclimated to the temperature increase) (Table 2). As in Experiment 1, DFI in Experiment 2 also showed a compensatory gain during the recovery period (102 g/hen-day during acclimation vs. 109 and 111 g/hen-day for recovery Weeks 1 and 2, respectively). Hens in the 23 C $T_w$ regimen had a significantly lower percentage reduction in DFI than hens in the other three $T_w$ regimens during the first and second weeks of heat exposure (Figure 1). These hens also had significantly lower percentage reduction in DFI than hens in 19 C and 27 C $T_w$ regimens during the third week, and hens in 15 C and 27 C $T_w$ regimens during the fourth week of heat exposure. The rates of DFI reduction with increase in daily mean $T_a$ for 15, 19, 23, and 27 C $T_w$ regimens were, respectively, 2.6, 3.2, 2.0, and 2.8 g/C-d during the first week of heat exposure, and 1.7, 1.5, 1.1, and 1.6 g/C-d during the fourth week of heat exposure.

The temporal increase in overall DWI during the 4-wk heat exposure in Experiment 2 averaged 44, 41, 53, and 58 g/hen-day for Weeks 1, 2, 3, and 4, respectively. Upon return to TN, hens maintained an elevated water intake (190 g/hen-day during acclimation vs. 211 and 207 g/hen-day for recovery Weeks 1 and 2, respectively). Treatment effects on DWI were noted during heat exposure and recovery periods (Figure 2 and Table 2). During

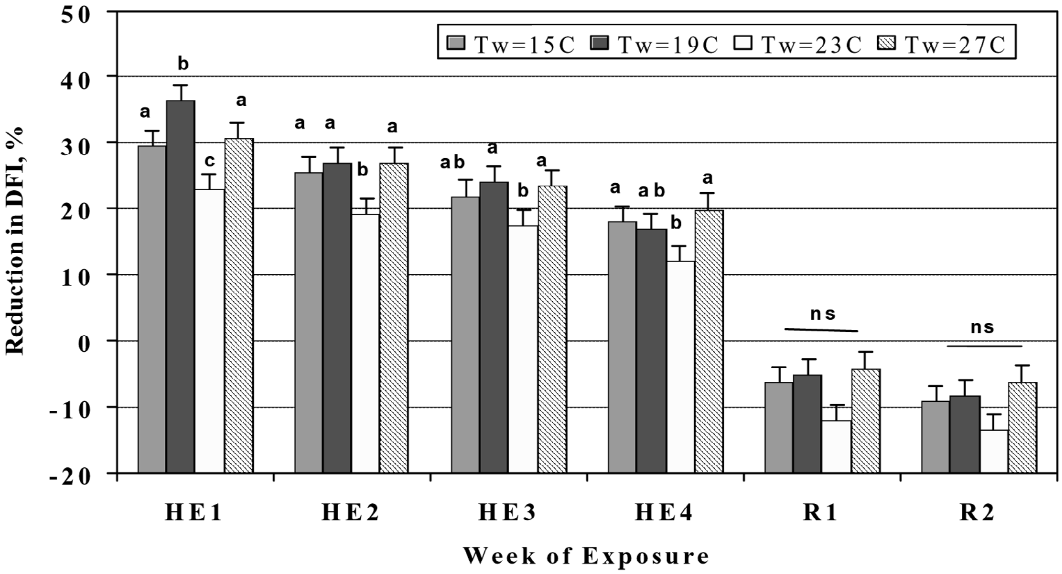


**FIGURE 1.** Effect of drinking water temperature ($T_w$) on change in daily feed intake (DFI), with reference to DFI during acclimation at thermoneutrality ($T_a$ and $T_w$ = 21 C), during 4 wk of heat exposure (HE) and 2 wk of recovery (R) at thermoneutrality. Means for each week with different letters were significantly different ($P < 0.1$).

the heat exposure period, hens receiving the 23 C $T_w$ had the highest percentage increase in DWI. Hens receiving the cooler $T_w$ (15 and 19 C) were intermediate, and those receiving the warmest $T_w$ (27 C) had the lowest percentage increase in DWI (Figure 2). During the recovery period, birds receiving 23 C $T_w$ maintained a significantly greater DWI.

WFR increased from 1.9 during acclimation to 3.4 during the first week of heat exposure, and then declined slightly to 3.0 by end of the fourth week of heat exposure. No treatment effects on WFR were observed during heat exposure. WFR returned to the acclimation level during recovery, 2.0 and 1.8, respectively, for Weeks 1 and 2 of recovery.

## Hourly Feeding and Drinking Patterns

Hourly feeding and drinking patterns of the hens for Experiment 1, during acclimation and the first and fourth weeks of heat exposure, are illustrated in Figures 3 and 4. The profiles are pooled hourly feed (HFI) and water (HWI) intakes over the 12 replicates and 1-wk period.

HFI or HWI was similar in patterns for both cool and warm $T_w$ regimens but different in magnitude. During the acclimation period, HFI remained quite constant from morning until late afternoon (Figure 3). HFI then increased during 3 h prior to lights off, suggesting anticipation of darkness by the hens. An implication of this

**TABLE 1. Daily feed and water intake (DFI, DWI, respectively), water to feed intake ratio (WFR), and body mass (BM) of W-36 laying hens for Experiment 1 (starting age = 29 wk) during acclimation, treatment, and recovery periods[1,2]**

| Trial week | DFI (g/hen-day) | | DWI (g/hen-day) | | WFR | | BM (kg) | |
|---|---|---|---|---|---|---|---|---|
| | $T_w$ = 27 C | $T_w$ = 18 C | $T_w$ = 27 C | $T_w$ = 18 C | $T_w$ = 27 C | $T_w$ = 18 C | $T_w$ = 27 C | $T_w$ = 18 C |
| Acclimation | | | | | | | | |
| 0 | $105^{a}$ (4) | $106^{a}$ (3) | $194^{a}$ (7) | $193^{a}$ (7) | $1.9^{a}$ (0.1) | $1.8^{a}$ (0.1) | $1.64^{a}$ (0.02) | $1.65^{a}$ (0.02) |
| Treatment | | | | | | | | |
| 1 | $77^{b}$ (2) | $82^{c}$ (3) | $262^{b}$ (13) | $278^{b}$ (24) | $3.4^{b}$ (0.2) | $3.4^{b}$ (0.2) | $1.56^{b}$ (0.02) | $1.58^{b}$ (0.02) |
| 2 | $81^{d}$ (1) | $86^{e}$ (1) | $260^{b}$ (13) | $277^{b}$ (24) | $3.2^{b}$ (0.2) | $3.2^{b}$ (0.3) | $1.53^{b}$ (0.02) | $1.56^{b}$ (0.02) |
| 3 | $90^{f}$ (3) | $91^{f}$ (3) | $257^{b}$ (15) | $274^{b}$ (24) | $2.9^{b}$ (0.2) | $3.0^{b}$ (0.3) | $1.54^{b}$ (0.02) | $1.56^{b}$ (0.02) |
| 4 | $89^{f}$ (2) | $91^{f}$ (3) | $264^{b}$ (13) | $287^{b}$ (27) | $3.0^{b}$ (0.1) | $3.2^{b}$ (0.3) | $1.54^{b}$ (0.02) | $1.56^{b}$ (0.02) |
| 1–4 | 84 (1) | 87 (1) | 261 (13) | 279 (23) | 3.1 (0.2) | 3.2 (0.3) | 1.54 (0.02) | 1.56 (0.02) |
| Recovery | | | | | | | | |
| 5 | $107^{a}$ (2) | $108^{a}$ (2) | $196^{a}$ (4) | $195^{a}$ (8) | $1.8^{a}$ (0.04) | $1.8^{a}$ (0.08) | $1.57^{b}$ (0.02) | $1.59^{b}$ (0.02) |
| 6 | $114^{g}$ (2) | $114^{g}$ (2) | $204^{a}$ (6) | $201^{a}$ (6) | $1.8^{a}$ (0.04) | $1.8^{a}$ (0.05) | $1.62^{a}$ (0.02) | $1.63^{a}$ (0.02) |

[a–g]Row means for each response variable with different superscripts are significantly different ($P < 0.10$). Column means under each $T_w$ during different trial weeks with different superscripts are significantly different ($P < 0.10$).

[1]Drinking water temperature ($T_w$) and air temperature ($T_a$) were 21 C during the acclimation and recovery periods. During the treatment period, $T_w$ was 18 or 27 C, and $T_a$ varied diurnally from 27 to 35 C.

[2]Values in parentheses are standard errors of the means.

**TABLE 2. Daily feed and water intake (DFI, DWI, respectively), water to feed intake ratio (WFR), and body mass (BM) of W-36 laying hens for Experiment 2 (starting age = 30 wk) during acclimation, treatment, and recovery periods[1,2]**

| Trial week | DFI (g/hen-day) | | | | | DWI (g/hen-day) | | | | | WFR | BM (kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 15 | 19 | 23 | 27 | Overall | 15 | 19 | 23 | 27 | Overall | Overall | Overall |
| Acclimation | | | | | | | | | | | | |
| 0 | 103[a] | 101[a] | 101[a] | 102[a] | 102 (4) | 205[a] | 181[a] | 188[a] | 185[a] | 190 (8) | 1.9 (0.09) | 1.67 (0.01) |
| Treatment | | | | | | | | | | | | |
| 1 | 73[b] | 64[c] | 78[d] | 70[b] | 71 (4) | 246[b] | 216[c] | 257[c] | 218[b] | 234 (15) | 3.4 (0.28) | |
| 2 | 77[b] | 74[b] | 81[c] | 74[b] | 77 (4) | 244[be] | 223[bc] | 248[d] | 209[e] | 231 (13) | 3.1 (0.20) | 1.56 (0.02) |
| 3 | 80[bc] | 77[b] | 83[c] | 78[b] | 79 (3) | 258[b] | 234[bc] | 255[c] | 226[b] | 243 (1) | 3.1 (0.18) | |
| 4 | 84[b] | 84[b] | 89[c] | 84[b] | 85 (3) | 264[be] | 239[bc] | 267[d] | 228[e] | 248 (13) | 3.0 (0.18) | 1.56 (0.02) |
| Recovery | | | | | | | | | | | | |
| 5 | 109[ad] | 106[ad] | 113[d] | 108[ad] | 109 (3) | 220[b] | 204[bc] | 223[c] | 202[b] | 211 (8) | 2.0 (0.09) | 1.62 (0.02) |
| 6 | 112[ad] | 109[ad] | 114[d] | 111[ad] | 111 (3) | 213[b] | 203[bc] | 216[c] | 198[b] | 207 (8) | 1.8 (0.08) | 1.63 (0.02) |

[a–e]Row means with different superscripts are significantly different ($P < 0.10$) as determined by percentage change from acclimation level. Column means under each $T_w$ during different trial wk with different superscripts are significantly different ($P < 0.10$).

[1]Drinking water temperature ($T_w$) and air temperature ($T_a$) were 21 C during the acclimation and recovery periods. During the treatment period, $T_w$ was 15, 19, 23, or 27 C, $T_a$ varied diurnally from 27 to 38 C.

[2]Values in parentheses are standard errors of the means.

anticipatory behavior is the importance of sufficient feed supply to meet this increased feed intake before lights go off. The anticipatory ingestion behavior before the dark period exhibited by the hens had been reported also for 36-wk-old laying hens provided with a 14-h photoperiod (0400 to 1800) (Hughes and Black, 1977) and for broilers (May and Lott, 1994, 1992b; Savory, 1976). Broilers maintained on 12L:12D photoperiod anticipated darkness by increasing their feed consumption during the period preceding darkness (Savory, 1976). May and Lott (1992b) demonstrated that broilers were able to anticipate the period of feed unavailability when it coincided with darkness. They showed that periodically lighted broilers consumed more feed at the end than at the onset of the feeding period (which coincided with the light period).

During the treatment period, HFI gradually increased from the early morning cooler hours and peaked about 2 h before noontime. Feed intake then decreased as $T_a$ further increased during late afternoon. Minimum feed intake occurred just before the onset of maximum $T_a$, and increased again until the onset of dark period. Upon lights on at 0500 h, feed consumption resumed at a lower rate during the first hour and then increased. This behavior of hens differed from that of broilers in that onset of light generally stimulates HFI of broilers (Xin et al., 1993; May and Lott, 1994). HFI of the hens was much lower during heat exposure than during acclimation,

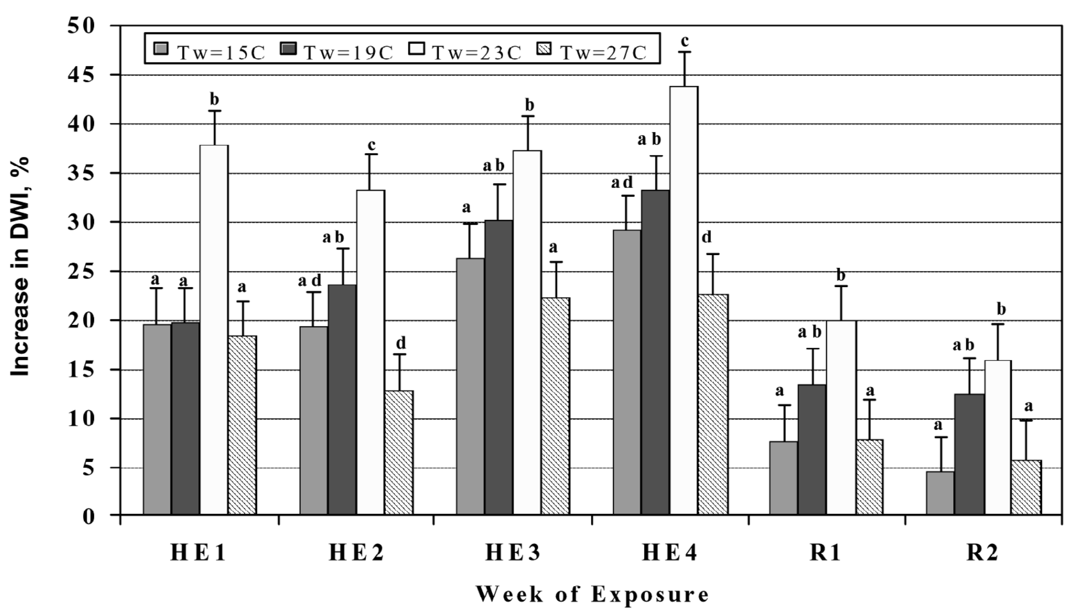


**FIGURE 2.** Effect of drinking water temperature ($T_w$) on change in daily water intake (DWI), with reference to DWI during acclimation at thermoneutrality ($T_a$ and $T_w$ = 21 C), during 4 wk of heat exposure (HE) and 2 wk of recovery (R) at thermoneutrality. Means for each week labeled with different letters were significantly different ($P < 0.1$).

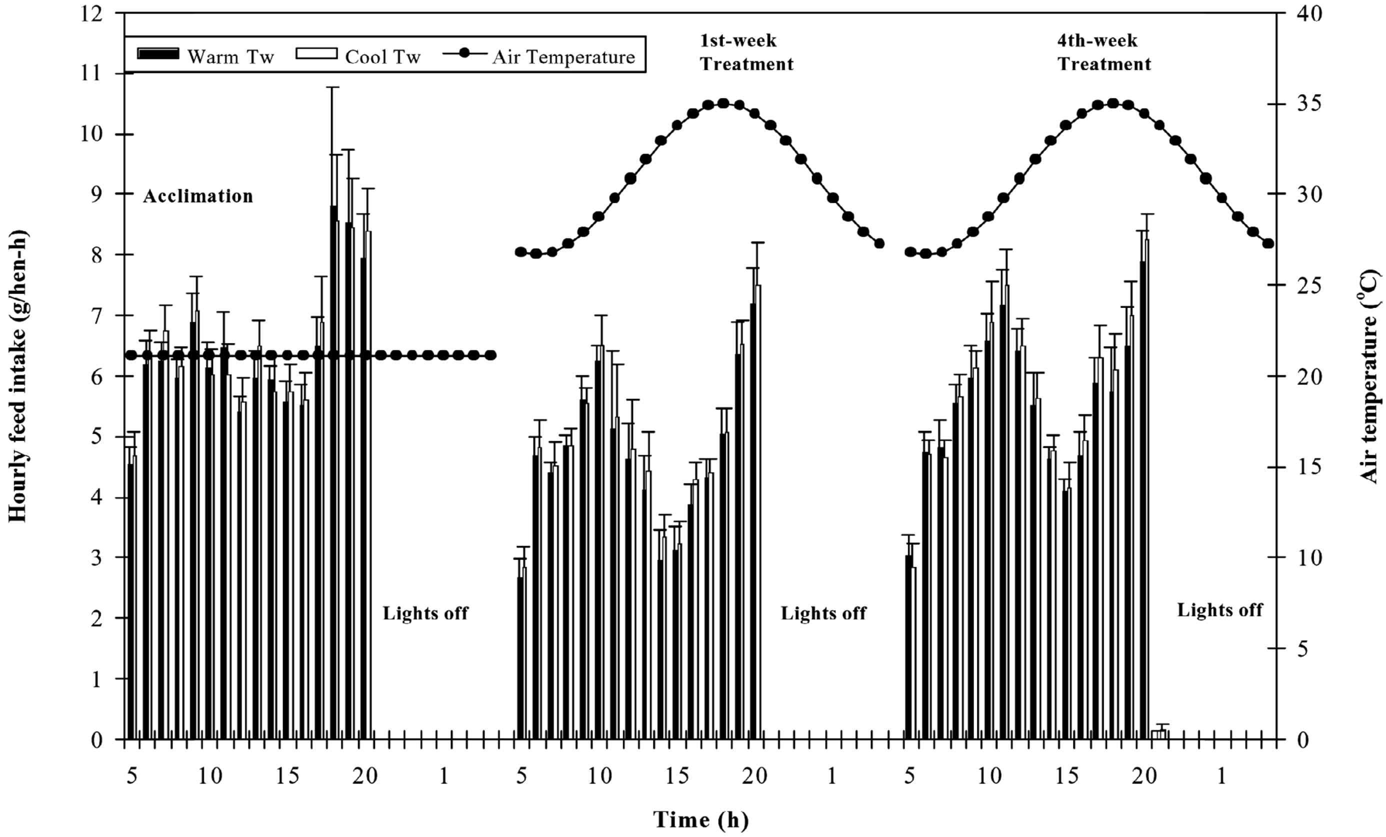


**FIGURE 3.** Hourly feed intake of laying hens in Experiment 1, at starting age of 29 wk, and during acclimation, and the first and fourth weeks of the treatment period. Drinking water temperature ($T_w$) and air temperature ($T_a$) were 21 C during the acclimation and recovery periods. During the treatment period, $T_w$ was 18 C (cool) or 27 C (warm) and $T_a$ varied diurnally from 27 to 35 C.

indicating the suppressing effect of warmer $T_a$ on feed intake. Also during the heat exposure, HFI for the cool $T_w$ hens was somewhat higher than HFI for the warm $T_w$ hens, although no significant difference was detected. The lack of measurable treatment effect could have resulted from the small number of hens involved.

HWI of the hens during acclimation and heat exposure shared similar patterns, with HWI during heat exposure being higher (Figure 4). Patterns of HWI generally coincided with those of HFI. As seen in HFI, HWI was highest during 3 h prior to lights off, indicating anticipation of darkness by the birds. HWI was similar for the two $T_w$ regimens during acclimation, but was numerically higher for the cooler $T_w$ regimen during heat exposure. However, differences in HWI between the two regimens during heat exposure were not significantly different. Again, the lack of significant treatment effect could have been due to the small number of hens used in the experiment.

## BM

For Experiment 1, average BM at the end of the acclimation period was 1.64 and 1.65 kg for the warm $T_w$ and cool $T_w$, respectively (Table 1). BM decreased by 6 to 7% (1.54 and 1.56 kg for warm and cool $T_w$, respectively) during the heat exposure period. It returned to nearly the acclimation period level during the recovery period (1.62 and 1.63 kg for the warm and cool $T_w$, respectively).

For Experiment 2, BM decreased from a mean value of 1.67 to 1.56 kg, a 6.6% reduction, during the heat exposure (Table 2). After 2-wk recovery, BM remained 42 g lower than that prior to the heat exposure. This result suggests that more than 2 wk would be necessary for full BM recovery from extended heat exposure episodes. The seemingly longer BM recovery period for Experiment 2 compared with Experiment 1 might have arisen from the higher $T_a$ (32.5 vs. 31.0 C daily mean) exposure.

## ES, EP, and FC

ES (g), EP (g/hen-day), and FC for Experiment 1 were not affected by $T_w$ during the heat exposure period (Table 3). Overall EP during the first 3 wk of the treatment period was lower than that during the acclimation period, but rebounded during the fourth week. There was a trend of increasing ES from the acclimation period until the recovery period. This progressive increase in ES may have been due to hens becoming older and thereby producing larger eggs. For Experiment 2, there was also no treatment effect on EP (Table 3). Compared with Experiment 1, EP for Experiment 2 became more suppressed during the heat exposure period. This

**TABLE 3. Overall means of egg production (EP), feed conversion (FC), and egg size (ES) of W-36 laying hens for Experiment 1 (starting age = 29 wk), and EP of laying hens for Experiment 2 (starting age = 30 wk) during acclimation, treatment, and recovery periods[1,2]**

| | Trial week | | | | | | |
|---|---|---|---|---|---|---|---|
| | Acclimation | Treatment | | | | Recovery | |
| Response variable | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| Experiment 1 | | | | | | | |
| EP (SE), g/hen-day | 52.0 (1.1) | 51.9 (1.6) | 48.6 (1.8) | 49.4 (1.8) | 53.0 (1.8) | 52.0 (1.6) | 52.8 (2.2) |
| FC (SE) | 1.90 (0.05) | 1.45 (0.03) | 1.50 (0.02) | 1.64 (0.04) | 1.64 (0.04) | 1.90 (0.04) | 1.99 (0.62) |
| ES (SE), g | 54.6 (0.7) | 54.8 (0.8) | 55.1 (0.7) | 55.0 (0.7) | 55.2 (0.8) | 56.6 (0.6) | 57.3 (0.7) |
| Experiment 2 | | | | | | | |
| EP (SE), g/hen-day | 52.8 (1.6) | 37.4 (2.9) | 46.6 (2.7) | 49.9 (2.9) | 49.2 (2.9) | 50.9 (2.2) | 56.8 (2.0) |

[1]Drinking water temperature ($T_w$) and air temperature ($T_a$) were 21 C during the acclimation and recovery periods.
[2]Values in parentheses are standard errors of the means.

greater suppression might have resulted from the higher $T_a$ in Experiment 2. EP then rebounded during the recovery period.

Significant effects of the heat exposure on FC and ES were noted for hens of Experiment 2 (Table 4). During the first 2-wk heat exposure, there were significant differences in the percentage change of FC for hens in the cooler $T_w$ (15 and 19 C) and those with the warmer $T_w$ (23 and 27 C). During the first 3-wk heat exposure, ES remained larger ($P < 0.1$) for hens in 23 and 27 C $T_w$ than that for hens in 15 and 19 C $T_w$. Significant differences in ES between the $T_w$ regimens during acclimation were observed. It should be noted also that during the treatment and recovery periods, hens in the cooler $T_w$ (15 and 19 C) laid fewer eggs than those in the warmer $T_w$ (23 and 27 C).

## Internal Egg Quality Parameters

For Experiment 1, yolk-to-white ratio and HU were unaffected by $T_w$ (Table 5). For Experiment 2, there were significant differences in percentage change in yolk-to-white ratio during the second and fourth weeks of the heat exposure period and the second week of the recov-

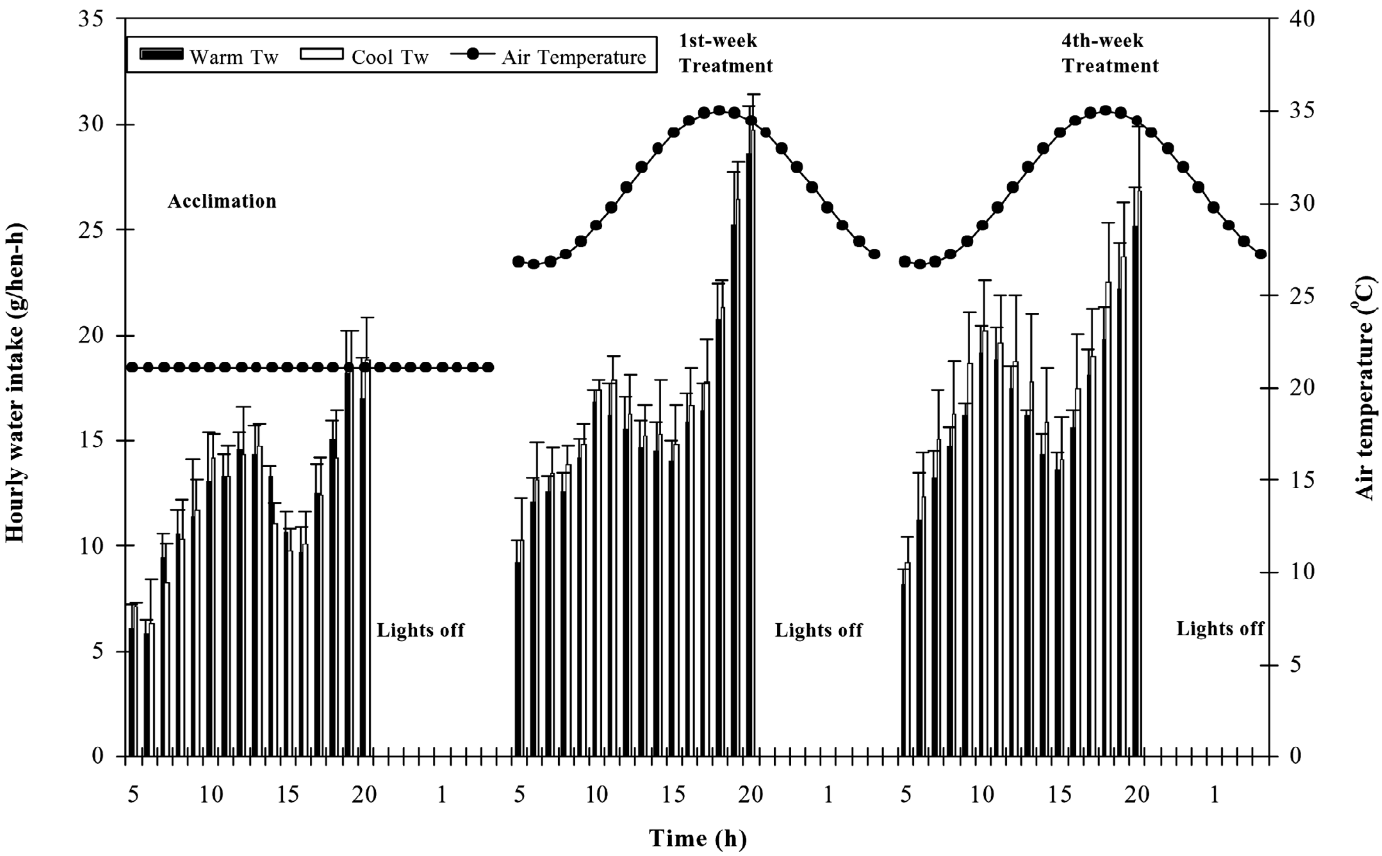


**FIGURE 4.** Hourly water intake of laying hens in Experiment 1, at starting age of 29 wk, and during acclimation, and the first and fourth weeks of the treatment period. Drinking water temperature ($T_w$) and air temperature ($T_a$) were 21 C during the acclimation and recovery periods. During the treatment period, $T_w$ was 18 C (cool) or 27 C (warm) and $T_a$ varied diurnally from 27 to 35 C.

**TABLE 4. Weekly means of feed conversion (FC) and egg size (ES, g) and percentage change from acclimation level of W-36 laying hens for Experiment 2 (starting age = 30 wk) during acclimation, treatment, and recovery periods[1]**

| | $T_w$ (C) and change (%) from acclimation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Trial week | 15 | Change | 19 | Change | 23 | Change | 27 | Change | SE |
| | | | | | FC | | | | |
| Acclimation | | | | | | | | | |
| 0 | 2.06 | | 1.98 | | 1.83 | | 1.87 | | 0.09 |
| Treatment | | | | | | | | | |
| 1 | 1.45 | –29.6[ab] | 1.22 | –38.4[a] | 1.67 | –8.7[b] | 1.31 | –29.9[ab] | 0.20 |
| 2 | 1.64 | –22.4[a] | 1.54 | –22.2[a] | 1.67 | –8.7[ab] | 1.83 | –2.1[b] | 0.08 |
| 3 | 1.66 | –19.4 | 1.59 | –19.7 | 1.69 | –7.6 | 1.51 | –19.2 | 0.09 |
| 4 | 1.74 | –15.5 | 1.79 | –9.6 | 1.72 | –6.0 | 1.68 | –10.2 | 0.08 |
| Recovery | | | | | | | | | |
| 5 | 2.27 | 10.2 | 2.14 | 8.1 | 2.19 | 19.7 | 2.05 | 9.6 | 0.12 |
| 6 | 2.13 | 3.4 | 1.94 | 2.0 | 1.90 | 3.8 | 1.93 | 3.2 | 0.09 |
| | | | | | ES | | | | |
| Acclimation | | | | | | | | | |
| 0 | 57.1[a] | | 56.7[a] | | 58.1[ab] | | 60.0[b] | | 1.1 |
| Treatment | | | | | | | | | |
| 1 | 55.6 | –2.63[a] | 55.0 | –3.0[a] | 58.4 | 0.5[b] | 60.0 | 0.0[b] | 1.2 |
| 2 | 54.9 | –3.8[a] | 54.5 | –3.9[a] | 57.7 | –0.7[b] | 59.7 | –0.5[b] | 1.1 |
| 3 | 54.9 | –3.8[a] | 54.4 | –4.1[a] | 57.5 | –3.0[b] | 59.2 | –1.3[ab] | 1.2 |
| 4 | 55.0 | –3.5 | 55.0 | –3.0 | 57.1 | –1.7 | 58.5 | –0.3 | 1.3 |
| Recovery | | | | | | | | | |
| 5 | 55.6 | –2.6[a] | 56.5 | –0.3[ab] | 59.2 | 1.9[b] | 59.8 | –0.3[ab] | 1.4 |
| 6 | 56.9 | –0.4[a] | 58.3 | 2.8[ab] | 60.3 | 3.8[b] | 61.1 | 1.8[a] | 1.2 |

[a–d]Row means with different superscripts are significantly different ($P < 0.10$).

[1]Drinking water temperature ($T_w$) and air temperature ($T_a$) were 21 C during acclimation and recovery periods. During the treatment period, $T_w$ was 15, 19, 23, or 27 C, and $T_a$ varied diurnally from 27 to 38 C.

ery period (Table 6). Generally, yolk-to-white ratio for hens in the cooler $T_w$ (15 and 19 C) was significantly higher than that for hens in the warmer $T_w$ (23 and 27 C). For Experiment 2, HU for eggs from hens in 23 C $T_w$ was significantly different from that for hens in 15 and 27 C $T_w$ but not from hens in 19 C $T_w$. There were significant differences in percentage change of shell dry weight during the second week of the heat exposure and during the recovery period (Table 6). During the second week of the heat exposure period, percentage reduction in eggshell weight for hens in 23 C $T_w$ was significantly lower than that for hens in 19 C $T_w$ but not for hens in 15 and 27 C $T_w$. During the first week of recovery, percentage increase in eggshell weight of hens in 23 C $T_w$ was significantly higher than that for hens in other $T_w$. Eggshell weight for hens in 15 and 27 C $T_w$ was still lower than the acclimation level during that period. Rebound of eggshell weight for hens in 23 C $T_w$ continued until the second week of the recovery period, although percentage change was not significantly different from that of hens in 19 and 27 C $T_w$.

Results from the two experiments suggest that certain cooler $T_w$ tended to enhance feed and water intake of laying hens during early stage of heat exposure. An optimal range of $T_w$ (near 23 C), especially in terms of DFI and DWI, seems to exist for hens challenged by heat exposure. However, large variations among the individual hens were noted. Further tests involving a larger number of birds are warranted to verify the potential merits of supplying heat-challenged hens with certain

**TABLE 5. Overall means of internal egg quality parameters of W-36 laying hens in Experiment 1 (starting age = 29 wk) during acclimation, treatment, and recovery periods[1,2]**

| | Trial week | | | | | | |
|---|---|---|---|---|---|---|---|
| | Acclimation | Treatment | | | | Recovery | |
| Response variable | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
| Yolk/white, % | 39.7 (0.4) | 40.8 (0.5) | 41.0 (0.6) | 39.7 (0.8) | 40.3 (0.4) | 41.0 (0.3) | 42.3 (0.2) |
| Haugh unit | 82.0 (1.0) | 89.0 (1.5) | 82.4 (1.6) | 81.6 (1.2) | 84.0 (1.4) | 82.2 (0.9) | 81.0 (0.7) |

[1]Drinking water temperature ($T_w$) and air temperature ($T_a$) were 21 C during the acclimation and recovery periods. During the treatment period, $T_w$ was 18 or 27 C, and $T_a$ varied diurnally from 27 to 35 C.

[2]Values in parentheses are standard errors of the means.

**TABLE 6. Weekly means of internal egg quality parameters and percentage change from acclimation level of W-36 laying hens in Experiment 2, at starting age of 30 wk, and during acclimation, treatment, and recovery periods[1]**

| Trial week | $T_w$ (C) and change (%) from acclimation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 15 | Change | 19 | Change | 23 | Change | 27 | Change | SE |
| | Yolk/white ratio (%) | | | | | | | | |
| Acclimation | | | | | | | | | |
| 0 | 39.4 | | 38.8 | | 37.6 | | 37.1 | | 0.9 |
| Treatment | | | | | | | | | |
| 1 | 41.8 | 6.1 | 42.7 | 10.0 | 40.0 | 6.4 | 40.0 | 7.8 | 1.1 |
| 2 | 39.2 | –0.5[a] | 40.8 | 5.2[b] | 39.0 | 3.7[ab] | 38.8 | 4.6[b] | 0.9 |
| 3 | 39.5 | 0.25 | 40.2 | 3.6 | 39.0 | 3.7 | 37.7 | 1.6 | 0.8 |
| 4 | 39.8 | 1.0[ac] | 40.0 | 3.1[ac] | 39.6 | 5.3[a] | 36.9 | –0.5[bc] | 0.9 |
| Recovery | | | | | | | | | |
| 5 | 37.9 | –3.8 | 37.2 | –4.1 | 35.8 | –4.8 | 36.3 | –2.2 | 1.0 |
| 6 | 37.9 | –3.8[ac] | 39.0 | 0.5[a] | 33.5 | –5.6[ac] | 35.6 | –4.0[bc] | 0.9 |
| | Haugh unit | | | | | | | | |
| Acclimation | | | | | | | | | |
| 0 | 87.7 | | 89.5 | | 87.7 | | 88.1 | | 2.1 |
| Treatment | | | | | | | | | |
| 1 | 88.2 | 0.4 | 90.3 | 0.9 | 86.0 | –1.9 | 88.5 | 0.4 | 1.5 |
| 2 | 88.2 | 0.4[a] | 88.4 | –1.2[ab] | 83.9 | –4.3[b] | 88.7 | 0.7[ac] | 1.6 |
| 3 | 87.9 | 0.2 | 91.3 | 2.0 | 87.7 | 0.0 | 91.6 | 4.0 | 2.0 |
| 4 | 88.1 | 0.4 | 87.7 | –2.0 | 87.0 | –0.8 | 87.3 | –0.9 | 1.8 |
| Recovery | | | | | | | | | |
| 5 | 89.9 | 2.5 | 90.0 | 0.6 | 90.4 | 3.1 | 89.3 | 1.4 | 1.6 |
| 6 | 88.7 | 1.1 | 90.9 | 1.6 | 89.9 | 2.5 | 86.7 | –1.6 | 1.6 |
| | Shell dry weight (g) | | | | | | | | |
| Acclimation | | | | | | | | | |
| 0 | 5.51 | | 5.39 | | 5.26 | | 5.80 | | 0.14 |
| Treatment | | | | | | | | | |
| 1 | 5.08 | –7.8 | 4.79 | –11.1 | 4.86 | –7.6 | 5.32 | –8.3 | 0.14 |
| 2 | 5.19 | –5.8[ab] | 5.00 | –7.2[a] | 5.05 | –4.0[b] | 5.46 | –5.9[ab] | 0.14 |
| 3 | 5.20 | –5.6 | 4.96 | –8.0 | 5.00 | –4.9 | 5.47 | –5.7 | 0.15 |
| 4 | 5.20 | –5.6 | 5.05 | –6.3 | 4.98 | –5.3 | 5.44 | –6.2 | 0.14 |
| Recovery | | | | | | | | | |
| 5 | 5.44 | –1.2[a] | 5.42 | 0.6[a] | 5.47 | 4.0[b] | 5.76 | –0.7[a] | 0.13 |
| 6 | 5.45 | –1.1[a] | 5.43 | 0.7[ab] | 5.42 | 3.0[b] | 5.80 | 0.0[ab] | 0.13 |

[a–d]Row means with different superscripts are significantly different ($P < 0.10$).

[1]Drinking water temperature ($T_w$) and air temperature ($T_a$) were 21 C during the acclimation and recovery periods. During the treatment period, $T_w$ was 15, 19, 23, or 27 C, and $T_a$ varied diurnally from 27 to 38 C.

cooled drinking water to enhance their production performance and well-being.

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