Performance and welfare of laying hens in conventional and enriched cages

G. B. Tactacan, W. Guenter, N. J. Lewis, J. C. Rodriguez-Lecompte, and J. D. House¹

Department of Animal Science, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2

ABSTRACT Concerns regarding the welfare of laying hens raised in battery cages have led to the development of enriched cages that allow hens to perform natural behaviors including nesting, roosting, and scratching. This study was conducted to compare indices of production and welfare in birds housed in 2 different caging systems. Shaver White hens were housed from 21 to 61 wk in either conventional battery cages (n = 500; 10 cages; 5 hens/cage; floor space = 561.9 cm²/hen) or enriched cages (n = 480; 2 cages; 24 hens/cage; floor space = 642.6 cm²/hen) and were replicated 10 times. Enriched cages provided hens with a curtained nesting area, scratch pad, and perches. Production parameters and egg quality measures were recorded throughout the experiment. Plumage condition was evaluated at 37 and 61 wk. Bone quality traits and immunological response parameters were measured at 61 wk, and 59 and 61 wk, respectively. Hen-day egg production, feed consumption, egg weight, and percentage of cumulative mortality of laying hens were not affected by the cage designs. Specific gravity and the percentage of cracked and soft-shelled eggs were also similar between the 2 housing systems. The incidence of dirty eggs was, however, significantly higher (P < 0.0001) in enriched cages than in conventional cages. Feather scores were similar between birds except for the wing region, which was higher (P < 0.05) for hens housed in conventional cages. Bone quality measures tended to be higher for hens housed in enriched cages compared with hens in conventional cages. However, the increase was significant only for bone mineral density. Immunological response parameters did not reveal statistically significant differences. Overall, laying performance, exterior egg quality measures, plumage condition, and immunological response parameters appear to be similar for hens housed in the 2 cage systems tested. Enrichment of laying hen cages resulted in better bone quality, which could have resulted from increased activity.

INTRODUCTION
The welfare of laying hens raised in standard commercial cages has been placed under intense scrutiny. The traditional housing of egg-type chickens in conventional cages, long perceived as the most efficient method of housing laying hens, is now widely considered to have a negative effect on the welfare of hens (Appleby, 1993; Appleby et al., 1993; Craig and Swanson, 1994). The limited environmental complexity and confinement in conventional cages physically restrict hens and eliminate many of their natural behaviors such as nesting, roosting, and scratching (Nicol, 1987; Baxter, 1994). Concerns about the welfare of laying birds prompted an industry-wide search for a better system of housing.

Throughout Europe, concern for the welfare of laying hens in conventional cages has prompted changes in housing (Savory, 2004). Cage-based systems are being phased out and those that are retained must meet high welfare standards (Keeling and Svedberg, 1999). A laying hens directive approved in 1999 by the European Union, prohibits new investment in conventional cages beyond 2003 and bans their use from of January 1, 2012 (European Commission, 1999). This directive stated that all existing cages must meet the 750 cm²/bird space requirements and that each cage must be enriched with facilities that will allow birds to express normal behaviors.

In North America, the majority of laying hens are still raised in conventional cages. The United States and Canada generally consider conventional cages as an acceptable system of housing for laying hens (Canadian Agri-Food Research Council, 2003). Of the approximately 300 million egg-laying chickens in the United States, 95% are confined in conventional wire cages (USDA, 2005). Canada houses 98% of its 26 million egg laying hens in conventional cages (Canadian Coalition for Farm Animals, 2005). At present, legislation in North America has no comprehensive animal welfare law that regulates cage enrichment in laying hens and because conventional cages are considered standard in-
dustry practice, there are no regulations in place to prohibit the use of these types of cages.

With the impending ban of battery cages in Europe in 2012, substantial effort has been expended to find an alternative housing system for laying hens. Even though conventional cages in the United States and Canada are still legal, efforts have been made to find a better system for housing hens. In the present study, a Canadian conventional battery cage and a European enriched cage (Hellmann Poultry GmbH & Co., Vechta, Germany) equipped with a curtained nesting area, roost, and scratch-pad facilities were used to compare production and welfare measures of hens throughout a production cycle. The objective of the study was to investigate the potential benefit of the enriched cages to the production and welfare status of laying hens.

MATERIALS AND METHODS

Birds and Management

Beak-trimmed Shaver White hens procured from a commercial supplier were housed for 40 wk in conventional or enriched cages, starting at 21 wk of age. A laying hen diet based on wheat-soybean meal (2,800 kcal, 16.3% CP, 3.6% calcium, 0.3% available phosphorus) and water was available ad libitum. Light was provided daily from 0700 to 2300h. Feeders were filled manually on Monday and Thursday every week. Egg collection was conducted daily during the morning hours. Three times each week, manure was removed through an automatic belt system. The experimental protocol was approved by the University of Manitoba Animal Care Protocol Management and Review Committee, and hens were cared for according to the guidelines of Canadian Council on Animal Care (CCAC, 1993) and the Recommended Code of Practice for the Care and Handling of Pullets, Layers and Spent Fowl (Canadian Agri-Food Research Council, 2003).

Cage Design

Two caging systems, conventional and enriched, were installed in the same building. Each system consisted of 2 rows of double-decker cages. Supporting elements and the partitions of the 2 cage systems were manufactured from galvanized wire and sheet steel. Conventional cages were designed to house 5 hens with dimensions measuring 50.8 cm wide, 55.9 cm deep, and 38.1 cm high. The average area per hen was 561.9 cm². According to the Recommended Code of Practice for the Care and Handling of Pullets, Layers and Spent Fowl, hens in Canada are allocated between 432 and 483 cm², depending on the breed (Canadian Agri-Food Research Council, 2003). An egg saver composed of wire and extending parallel to and underneath the feed trough allowed eggs to stop rolling before entering the egg cradle. This wire was lifted every 15 min after lights-on for 8 h and thereafter every hour until lights-out, allowing eggs to slowly roll into the egg cradle, reducing the incidence of cracked eggs. Nipple-type drinkers (3 nipples/cage) were positioned in the rear wall of each cage. The experimental unit was 10 cages with 5 hens/cage replicated 10 times.

The enriched cages used were the Hellmann furnished-cage model (Hellmann Poultry GmbH & Co.), designed to house 24 hens with an average area per hen of 642.6 cm². Cage dimensions were 241.3 cm wide, 55.9 cm deep, and 48.3 cm high. The Hellmann furnished cages were divided into 3 major areas; the scratch-pad area (48.3 cm wide × 20.3 cm deep), roost area (121.9 cm wide × 45.7 cm deep), and the nest area (58.4 cm wide × 25.4 cm deep). The nest area was separated from the other areas by a red curtain composed of plastic strips, through which the birds entered the nest. Nests were lined with a thin plastic mesh. Two plastic perches (length = 51 cm each) ran parallel to the feed trough in the perch area. Scratch-pad areas, where birds could scratch and forage, were lined with rough green artificial turf (AstroTurf, AstroTurf LLC, Dalton, GA). Scratch pads in the enriched cages were sprinkled with approximately 56 g of feed daily, allowing the hens to forage on the scratch pad. The amount of feed added as a foraging material in the scratch pad was added to the feed consumption of birds in enriched cages. An egg saver similar to that described for conventional cages was installed underneath the feed trough of enriched cages. This wire was also lifted every 15 min after lights-on for 8 h and thereafter every hour until lights-out. Nipple drinkers (8 nipples/cage) were located in the rear wall of the cages. The experimental unit was 2 cages with 24 hens/cage replicated 10 times.

Production Parameters and Exterior Egg Quality

Egg production and mortality for each cage type were collected daily from 21 to 61 wk of age. Laying hens that died within the first week of the study were replaced with hens of similar weight from a pool of extra birds that were separately maintained on each of the 2 housing systems. Hens that died afterwards were weighed and were not replaced. Hen-day egg production was calculated after daily egg counts. The egg savers for both treatments were manually locked before egg collection and counting to ensure that no eggs were released into the egg cradle during counting. Eggs laid from each cage were visually examined to record the number of cracked, soft-shelled, and dirty eggs. All the data were analyzed after pooling daily data into ten 28-d periods.

Body weight was recorded individually when the hens were 21 and 61 wk of age. Feed consumption was measured over 4-wk periods. Feed was weighed in and unconsumed feed was weighed back at the end of each period. Feed intake was calculated for each 4-wk period.
by dividing total feed consumed by number of hens per cage. Egg weight and specific gravity were measured on one-half of the eggs collected from each cage during the last 3 d of each 28-d period. Specific gravity measurements were conducted on eggs using the flotation measurement method (Holder and Bradford, 1979). Feed efficiency was calculated as gram of feed consumed per gram of egg produced.

**Plumage Scoring**

Birds from 50 conventional (250 birds) and 10 enriched (240 birds) cages were weighed individually and scored for plumage condition at 37 and 61 wk of age. Plumage condition was scored using a 4-point scoring system (Tauson et al., 1984) for 6 different areas of the body (neck, breast, back, wings, tail, and vent). A score of 4 indicated very good feathering with few worn or otherwise deformed feathers. Score 3 was used when feathers showed deterioration but when complete feather coverage was observed. Score 2 indicated areas of the body that showed marked deterioration with some part being denuded. Score 1 indicated areas with little or no feather coverage and when feathers were present they were severely damaged. The average plumage condition for each bird was calculated by adding over all 6 areas, to yield a total score ranging from 6 to 24 points.

**Bone Quality Traits**

Twenty laying birds from each cage design treatment were randomly selected and killed by cervical dislocation at 61 wk of age. The bone mineral density and bone mineral content of the left tibia and humerus of each intact bird were measured using a dual energy x-ray absorptiometry x-ray densitometer (GE Healthcare, Lunar Prodigy Advance PA+130472, Small Animal Software, Diegem, Belgium). Individual BW was recorded before each scan. Scanning began at the proximal end of the bone and lasted for approximately 10 min. The orientation of the bone was the same for each scan. After the scans were completed, the left tibia and humerus of each bird were excised, cleaned of all tissue, and subjected to bone ash analysis. To prepare for bone ash analysis, the tibia and humerus were dried at 100°C for 24 h. The dried bones were separately extracted (Soxhlet) for 48 h in 90% ethanol, and another 48 h in anhydrous diethyl ether. The fat-free bones were dried overnight. The bone ash digest was diluted with 100 mL of deionized water and filtered through a Q5 filter paper (Whatman brand, Fisher Scientific, Ontario, Canada) for inductively coupled plasma emission spectrophotometry analysis (Luh Huang and Schulte, 1985).

**Plasma Corticosterone**

At 59 and 61 wk of age, blood samples from 10 birds for each cage type were taken from the ulnar vein using a 23-gauge needle and heparinized syringe. To minimize the effects of sampling on plasma corticosterone, a standardized capture and bleeding method (Silverin, 1998) was used and all samples were taken within 3 min of the bird being removed from the cage. All blood samples were centrifuged within 20 min of collection. The plasma was frozen immediately at −20°C and later stored at −80°C. Plasma corticosterone was measured by enzyme immunoassay (Enzyme Immunoassay, Oxford Biomedical Research, Rochester Hills, MI).

**Humoral Immunity**

Killed Newcastle disease virus (NDV; Fort Dodge Animal Health, Fort Dodge, IA) was used as a test antigen to quantitatively analyze specific antibody responses, as a measure of humoral immunocompetence. At 59 wk of age, before vaccination with NDV, blood samples were collected from the ulnar vein of 10 birds from each cage type. After the blood collection, each bird was immunized through intraocular administration with NDV. The NDV vaccine was reconstituted using the supplied diluents. Fourteen days postimmunization, blood samples were again collected to determine the bird’s primary antibody responses. All blood samples were allowed to clot for 2 h and serum was decanted into microcentrifuge tubes and frozen at −20°C for later analysis. Antibody titers were determined using V-bottom microtitration 96-well plates after the microhemagglutination procedure (Witlin, 1967). Antibody titer values were expressed as base-2 logarithm of the highest serum dilution giving total agglutination.

**Heterophil/Lymphocyte Ratios**

At 61 wk of age, a drop of blood was taken from a small puncture in the comb of each hen for determination of the heterophil/lymphocyte (H/L) ratio. Blood samples were taken from 10 hens from each cage type and 2 blood smears per hen were made immediately after drawing blood using the 2-slide wedge method (Houwen, 2000). After air drying, the slides were fixed in methanol and stained with Diff Quik stain (Dade Behring Inc., Deerfield, IL). One hundred leucocytes, including granular (heterophils, eosinophils, basophils) and nongranular (lymphocytes, monocytes), were counted once on each slide using oil immersion microscopy 100× magnification following the method of Davis et al. (2004). The H/L ratios were determined by dividing the number of heterophils by that of lymphocytes.
Table 1. Performance summary and egg quality measurements throughout the production cycle of laying hens housed in conventional and enriched cages: main effects of period.

<table>
<thead>
<tr>
<th>Period</th>
<th>Hen-day production (%)</th>
<th>Feed consumption (g/hen per d)</th>
<th>Feed efficiency (g of feed/g of eggs)</th>
<th>Egg weight (g)</th>
<th>Specific gravity</th>
<th>Cracked eggs (%)</th>
<th>Soft-shelled eggs (%)</th>
<th>Dirty eggs (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>84.54a</td>
<td>95.10f</td>
<td>2.23b</td>
<td>50.43c</td>
<td>1.0882b</td>
<td>0.30b</td>
<td>0.12b</td>
<td>5.59d</td>
</tr>
<tr>
<td>2</td>
<td>92.46d</td>
<td>105.64e</td>
<td>2.01e</td>
<td>56.77c</td>
<td>1.0892c</td>
<td>0.29c</td>
<td>0.07c</td>
<td>5.99d</td>
</tr>
<tr>
<td>3</td>
<td>94.75bc</td>
<td>106.68f</td>
<td>1.92f</td>
<td>58.64c</td>
<td>1.0885c</td>
<td>0.42c</td>
<td>0.08c</td>
<td>6.81d</td>
</tr>
<tr>
<td>4</td>
<td>95.86d</td>
<td>113.51g</td>
<td>1.98g</td>
<td>59.93d</td>
<td>1.0879d</td>
<td>0.38g</td>
<td>0.06g</td>
<td>9.54e</td>
</tr>
<tr>
<td>5</td>
<td>95.33d</td>
<td>116.42h</td>
<td>2.03d</td>
<td>60.30d</td>
<td>1.0878d</td>
<td>0.45d</td>
<td>0.10d</td>
<td>8.95e</td>
</tr>
<tr>
<td>6</td>
<td>93.65bc</td>
<td>115.76ab</td>
<td>2.05b</td>
<td>60.33</td>
<td>1.0864d</td>
<td>0.55d</td>
<td>0.10d</td>
<td>7.10f</td>
</tr>
<tr>
<td>7</td>
<td>92.23cd</td>
<td>115.23bc</td>
<td>2.02e</td>
<td>61.94</td>
<td>1.0854d</td>
<td>0.80d</td>
<td>0.13d</td>
<td>8.75f</td>
</tr>
<tr>
<td>8</td>
<td>91.50d</td>
<td>114.55w</td>
<td>2.00de</td>
<td>62.51</td>
<td>1.0832d</td>
<td>0.99c</td>
<td>0.15d</td>
<td>10.42e</td>
</tr>
<tr>
<td>9</td>
<td>89.88e</td>
<td>111.64d</td>
<td>1.99de</td>
<td>62.40</td>
<td>1.0872d</td>
<td>1.08d</td>
<td>0.16d</td>
<td>9.66e</td>
</tr>
<tr>
<td>10</td>
<td>87.83e</td>
<td>111.44d</td>
<td>2.04e</td>
<td>62.26</td>
<td>1.0829d</td>
<td>1.30d</td>
<td>0.21f</td>
<td>9.30e</td>
</tr>
</tbody>
</table>

SEM 0.44 0.43 0.01 0.17 0.0002 0.70 0.03 0.28

**P-value** <0.0001 <0.0001 <0.0001 <0.0001 <0.0001 <0.01 <0.0001 <0.0001

Table 1. Performance summary and egg quality measurements throughout the production cycle of laying hens housed in conventional and enriched cages: main effects of period.

### Statistical Analysis

Statistical analysis was performed using the mixed model and t-test procedure of SAS (SAS, 1998). A completely randomized, repeated measure design was used to analyze the production and exterior egg quality data for the 10 experimental periods of the whole production trial. Compound symmetry with heterogeneous variance across periods, which allows for unequal variance across periods, proved to be the most accurate method available for the data. Differences between means were determined using the least squares differences test. Plumage condition and physiological response parameter were analyzed using the t-tests procedure. Mortality data were analyzed using PROC FREQ (SAS, 1998). Unless otherwise stated, the level of significance was assessed at *P* < 0.05.

### RESULTS

The overall hen-day egg production was not significantly different between the 2 cage designs. The only significant difference between treatments was observed in period 10, in which birds in conventional cages (CON; 88.6%) had higher (*P* < 0.05) hen-day egg production than birds in the enriched cages (ENR; 87.0%). The rate of lay in both treatments, over the period of 21 to 61 wk, ranged from 84.5 to 95.9% and was within the commercial production standards for Shaver White hens (Table 1). Shaver White hens on average reached production rates of 84.7% at 60 wk and 96.0% at peak (Institut de Selection Animale B. V., 2007).

Peak production occurred in period 4, between wk 34 and 37, and egg production then gradually declined. Caging type did not affect the overall feed consumption of laying hens. However, birds in conventional cages consumed significantly more feed than birds in enriched cages in periods 1 and 4 but significantly less in period 8 and 9 (Table 2). There was a significant (*P* < 0.0001) period effect for feed consumption. Feed consumption was highest in period 5, remained relatively constant throughout periods 6 to 8, and gradually declined from period 9 to 10. Significant cage × period interactions can be explained by a higher rise in feed intake in period 4 and more rapid decline in period 8 in conventional cages. A significant effect of cage type on feed efficiency was observed only in period 9 (CON = 1.97; ENR = 2.01). However, there was a significant (*P* < 0.0001) period effect on feed efficiency. Feed efficiency significantly improved in period 3 and 4, increased from period 5 to 7, remained relatively constant from period 8 to 9, and increased again in period 10 (Table 1). Although the cumulative percentage mortality (for the full 40 wk) was numerically lower in conventional cages (4.0%) than in enriched cages (5.6%), cumulative percentage mortality between cages was not statistically significant. Mortality for both cages remained relatively constant from period 1 to 3 (CON = 0.2 to 0.4%; ENR = 0 to 0.2%) but steadily increased from period 4 to 10 (CON = 0.6 to 4.0%; ENR = 0.8 to 5.6%).

Average egg weight did not differ between the 2 cage types. The weights of eggs of birds in conventional cages were higher in period 2, 4, and 6 but these did not affect the average. As expected, egg weight increased with hen maturity. A significant (*P* < 0.0001) increase in egg weight throughout the duration of the production cycle was observed. Egg weight increased substantially from period 1 to 3, followed by a gradual but steady increase from period 4 to 10 (Table 1). A cage × period interaction (*P* < 0.01) was evident as a result of heavier eggs being produced by hens in conventional cages than in enriched cages, with progressive maturity (periods 2, 4, and 6). Consistent throughout the production period, the specific gravity of the eggs was similar between cage types (Table 2). Specific gravity of eggs from both cages gradually declined (*P* < 0.0001) from period 1 (1.0887) to period 10 (1.0829). Cage type did not affect the overall percentage of cracked eggs (Table 2).
there was no significant effect of cage type. However, the number of cracked eggs significantly increased with increasing days in lay (Table 1). Percentage cracked egg was higher in the second half of the production cycle, periods 6 to 10, than the first half of the production cycle, periods 1 to 5. The percentage of soft-shelled eggs was not affected by cage design. The influence of the housing system on percentage of soft-shelled eggs was only observed in periods 4 (CON = 0.10; ENR = 0.02) and 9 (CON = 0.11; ENR = 0.22), in which the number of soft-shelled eggs was higher and lower, respectively, in conventional cages than in the enriched cages. Consequently, these observed differences were unable to elicit a cage × period interaction effect. As with the percentage of cracked eggs, incidence of soft-shelled eggs gradually increased with age (Table 1). The overall percentage of dirty eggs, unlike the other egg quality measurements, differed markedly between cage designs (P < 0.0001; Table 2). The percentage of dirty eggs in the conventional cages was consistently lower throughout the laying cycle. There was a significant (P < 0.0001) period effect for percentage of dirty eggs (Table 1). Percentage of dirty eggs in enriched cages remained relatively constant from period 1 to 2 but increased steadily from period 3 to 10. A cage × period interaction was brought about by the higher increase in percentage of dirty eggs in period 3 and a more rapid decline in period 6 in enriched cages.

At 37 and 61 wk, overall plumage condition was not affected by cage type (Table 3). However, in the wing region, feather score was higher in birds in conventional cages than enriched cages. The mean score for each of the other 5 individual body parts did not differ between cages. The tail region consistently scored the lowest (worst), wings, neck, and vent regions having intermediate scores and the back and breast regions the highest (best) score among all body regions (Table 3). Bone mineral density of tibia and humerus of birds housed in enriched cages was significantly higher (P < 0.05) than birds in conventional cages (Table 4). A similar but nonsignificant pattern was observed for bone mineral content, ash weight, and percentage of calcium and phosphorus of tibia and humerus. Mean values of plasma corticosterone and antibody production (log2 antibody titer against NDV vaccine) before and after vaccination for NDV (Table 5) and H/L ratio for laying hens housed in conventional and enriched cages were not affected by cage design (Table 6). Plasma corticosterone level remained the same after NDV vaccination. However, as expected, a significant increase in antibody titer was observed in both housing systems postvaccination (Table 5). Differential leukocyte counts were similar in conventional and enriched cages except for the number of lymphocytes, which was higher (P < 0.05) in conventional than in enriched cages (Table 6).

**DISCUSSION**

In the current study, there were no marked differences in production variables or egg quality measures observed between the 2 types of cages except for the differences in the percentage of dirty eggs. This agrees with other studies comparing egg production (Smith et al., 1993) and other variables (Abrahamsson et al., 1995; Abrahamsson and Tauson, 1997) in conventional and enriched type of cages. Some studies, however, have reported that egg production of laying hens was higher in conventional cages than those housed in alternative systems such as aviaries, floor pens, or free range (Abrahamsson et al., 1996; Tauson et al., 1999). This study supports the hypothesis that production is not reduced when hens are provided with environmental enrichment.

The previous finding that lower stocking density in enriched cages resulted in increased feed consumption (Preisinger, 2000) was not supported by our results. Preisinger (2000) reported that birds in enriched cages tended to eat more feed to provide energy for heat production to compensate for the lower heat generated by cage mates. Higher stocking rates in conventional cages
have been associated with ease of maintaining temperature within the optimal range of 21 to 24°C, resulting in lower feed consumption (Emmans and Charles, 1977). Built in ventilation fans and convection heaters designed to control temperature inside the poultry facility building where our study was conducted might have contributed to our finding that feed consumption did not vary between housing types. This similarity in feed consumption coupled with the lack of differences observed in egg production resulted in similar egg weight between cages. A similar conclusion, showing the lack of influence of housing conditions on the weight of eggs produced by laying hen, was reached by Tauson (2003) and Guesdon and Faure (2004).

The cumulative percentage of mortality was slightly higher but not statistically significant in enriched cages (5.6%) than in conventional cages (4.0%). This was in line with the findings of Abrahamsson and Tauson (1997), who reported that enriched cages in comparison with conventional cages did not affect mortality rates of laying hens. Several studies have shown that mortality can be low in alternative housing systems such as aviary, free-range, or floor husbandry systems as well as in furnished cages (Tanaka and Hurnik, 1992; Abrahamsson and Tauson, 1995). However, it is difficult to classify different housing systems for laying hens on the basis of mortality because mortality is influenced by several factors including condition during the early rearing period, management during the laying period, and the type of laying hen strains used for production. The observed mortality values in this study were also comparable to the values reported by Weitzenbürger et al. (2005) when they compared 2 types of hen in 3 designs of enriched cages and found mortality rates between 4.0 and 5.2%. However, Weber et al. (2003) recorded mortality levels of 8.7% in enriched cages and 11.7% in a floor pen system. Because cannibalism is one of the most common causes of mortality in caged-based housing for laying hens (Weitzenbürger et al., 2005), the relatively low percentage of mortality observed in the present study can be attributed to the use of beak-trimmed birds, which reduced the incidence of death due to cannibalism. Occasional incidences of cannibalism observed in this study were mostly triggered by prolapse, in which birds tended to pick at the protruding uterus resulting in the necessity for euthanasia of the birds. Guesdon et al. (2006) compared beak-trimmed and non beak-trimmed birds in conventional and 2 designs of enriched cages and found low mortality (<5%) in beak-trimmed hens but unacceptably high mortality (>40%) in non beak-trimmed hens as a result of cannibalism.

Exterior egg quality measures, except the percentage of dirty eggs, were similar between conventional and enriched cages. The overall proportion of cracked eggs observed in this study (CON = 0.71%; ENR = 0.60%) was relatively low compared with commercial standards. Wall et al. (2002) noted that percentage of cracked eggs in enriched cages is usually higher than in conventional cages because the area where the eggs are laid is small and collisions can easily occur between eggs, thus damaging the egg shell. However, the egg-saver wire installed in conventional and enriched cages for this study likely reduced the percentage of cracked eggs. The proportion of dirty eggs in enriched cages was 3 times higher than those laid in conventional cages. This can be largely attributed to eggs laid in the scratch-pad region of the cage. Appleby et al. (2002) found that eggs laid in the dust bath were dirtier compared with eggs laid in any other part of the cage. The AstroTurf carpet where birds dustbathed was similar to the scratch pad in our study, accumulating excreta and resulting in dirty eggs. Due to the high percentage of the eggs laid in the scratch-pad area of the enriched cages, a higher overall incidence of dirty eggs was observed in this type of cage design. We believe that this was an anomaly resulting from the age at which the birds were placed in the cages. Due to unforeseen delays installing the cages, birds were housed at 21 wk instead of the normal 18 wk. Consequently, birds had already started to lay in the pullet barn. This might have accounted for the observed lower percentage of eggs laid in the nesting area. This was not a problem with the next flock housed at 18 wk (our personal observation).

Cage design in this study did not affect the overall feather condition of laying hens. Significant differences between cages were observed only in the wings where birds from conventional cages had better coverage.

<table>
<thead>
<tr>
<th>Item</th>
<th>CON</th>
<th>ENR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck</td>
<td>3.74 ± 0.05</td>
<td>3.77 ± 0.05</td>
</tr>
<tr>
<td>Breast</td>
<td>3.97 ± 0.01</td>
<td>3.93 ± 0.02</td>
</tr>
<tr>
<td>Vent</td>
<td>3.85 ± 0.02</td>
<td>3.88 ± 0.03</td>
</tr>
<tr>
<td>Back</td>
<td>3.95 ± 0.02</td>
<td>3.99 ± 0.01</td>
</tr>
<tr>
<td>Wings</td>
<td>3.44a ± 0.06</td>
<td>3.10b ± 0.06</td>
</tr>
<tr>
<td>Tail</td>
<td>2.75 ± 0.04</td>
<td>2.74 ± 0.07</td>
</tr>
<tr>
<td>Total</td>
<td>21.69 ± 0.13</td>
<td>21.42 ± 0.17</td>
</tr>
</tbody>
</table>

Table 3. Feather score for 6 body regions of laying hens in conventional (CON) and enriched (ENR) cages at 37 and 61 wk of age
Poorly feathered birds not only present a problem for welfare but also affect overall production economics. Birds with highly deteriorated feather cover can show increased feed consumption due to the increased heat loss resulting in higher maintenance energy requirement (Tauson and Svensson, 1980; Peguri and Coon, 1993). The nonsignificant effect of cage design on feed consumption observed in the current study was probably, at least partially, a reflection of its lack of effect on the overall condition of the plumage. Other studies have, however, shown that hens in furnished cages have better feather quality than hens in conventional cages (Appleby et al., 1993; Tauson and Abrahamsson, 1995). However, in these studies, the effect of housing design on feather condition was assessed on a considerably smaller group of laying hens (4 or 5 hens/cage). Feather pecking, which is one of the main causes of feather damage and loss, is influenced by group size (Hughes and Duncan, 1972) and stocking density (Tauson, 1984). The greater space available for hens housed in the enriched cages increased the opportunity for birds to flap their wings, which may have increased the possibility of wing abrasion on the bars of the cage. Aside from this, the higher number of birds housed in enriched cages in this study may have increased the possibility of feather pecking and could have contributed to the observed greater wing feather deterioration.

One of the main welfare concerns in conventional cages is the hen’s inability to exercise. Lack of exercise leads to development of bone weakness and at peak production can easily result in skeletal damage (Webster, 2004). In the current study, the bone mineral density of the tibia and humerus was higher ($P < 0.05$) in birds housed in enriched cages. Although not significant, bone mineral content, bone ash weight, and percentage of calcium and phosphorus of the tibia and humerus were also higher in enriched cages. Results from other studies support this finding. Knowles and Broom (1990) and Newman and Leeson (1998) found that bone strength in conventional cages was lower compared with alternatives such as aviary systems or floor pens. Hughes and Appleby (1989) found that bone strength can be increased by providing perches. The reduced space and the absence of perches in the conventional cages restricted locomotor activity, roosting, and wing-flapping and likely led to the lower values of skeletal integrity measures. These lower values indicate a greater susceptibility of laying hens housed in conventional cages to skeletal problems, especially during the later stages of the laying cycle. Laying hens at the end of their economically viable laying cycle (spent hens) are usually transported to processing plant for conversion into meat products. However, during this period, they tend to have relatively weak bones. As a result, bone fracture is a common problem when these hens are handled before slaughter (Gregory and Wilkins, 1992). The potential of cage enrichment as a viable method in increasing bone strength could therefore result in a better welfare condition of spent hens at the end of

<table>
<thead>
<tr>
<th>Bone mineral density (g/cm²)</th>
<th>Bone mineral content (g)</th>
<th>Bone ash weight (g)</th>
<th>Percentage calcium (%)</th>
<th>Percentage phosphorus (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tibia</td>
<td>CON</td>
<td>ENR</td>
<td>Tibia</td>
<td>CON</td>
</tr>
<tr>
<td>0.23 ± 0.01</td>
<td>0.26 ± 0.01</td>
<td>2.94 ± 0.12</td>
<td>3.28 ± 0.16</td>
<td>30.97 ± 1.01</td>
</tr>
<tr>
<td>Humerus</td>
<td>CON</td>
<td>ENR</td>
<td>Humerus</td>
<td>CON</td>
</tr>
<tr>
<td>0.15 ± 0.01</td>
<td>0.17 ± 0.01</td>
<td>1.28 ± 0.06</td>
<td>1.40 ± 0.03</td>
<td>33.96 ± 1.11</td>
</tr>
</tbody>
</table>

*Means ± SE within a row with different superscript letters are significantly different ($P < 0.05$).
their production cycle. Finding ways of improving bone strength is one of the recommended means to improving animal welfare considerations involved in spent hen management (Newberry et al., 1999).

The plasma corticosterone levels of birds housed in conventional and enriched cages were the same. Similar plasma corticosterone levels could indicate that the stress level was similar between cageing systems. Previous studies on plasma corticosterone levels with laying hens housed in different housing systems yielded equivocal results. Plasma corticosterone concentrations in laying hens were similar in those housed in cages and birds reared on outside range (7,430 cm²/bird; Koelkebeck and Cain, 1984), whereas plasma corticosterone concentrations in floor pens can be higher (Edens et al., 1982; Barnett et al., 1997), lower (Gibson et al., 1986), or not different than in cages (Craig and Craig, 1985).

A follow-up study by Koelkebeck et al. (1987), who investigated the effect of floor space on the level of stress, reported an 11% increase in plasma corticosterone concentration in caged hens when space allowance was decreased from 460 to 350 cm²/bird. Similarly, Mashaly et al. (1984) showed that stocking density elevated plasma corticosterone in hens. However, Craig et al. (1986) reported that increased stocking density increased total plasma corticosteroids in some experiments but was without effect in others. Conversely, Davis et al. (2000) found that increasing stocking density did not affect corticosterone levels in hens. Although these studies, particularly results on production and mortality, would suggest that additional space is of benefit to birds, the precise area that will provide optimum comfort and better welfare for hens is still very difficult to define. In the current study, the furnishing of enriched cages with a nest, roost, and perch plus the provision of more floor space per bird, while geared toward lowering the level of stress and improving welfare of hens, appeared not to significantly influence stress levels. On a similar note, a nonsignificant effect of housing design was also observed for the H/L ratio. Although, lymphocyte count ratio was similar between the 2 cage types. Previous studies in chickens suggested that an increased H/L ratio was associated with increased environmental stress (McFarlane and Curtis, 1989). Onbasiliar and Aksoy (2005) reported a higher H/L ratio with birds reared in groups having 5 hens/cage than those groups having 1 or 3 hens/cage. A study by Hester et al. (1996) investigating the effect of different heat stress conditions with birds housed in various cage densities revealed that hens kept in single-bird cages (1,085 cm² per bird) had lower H/L ratios (34.4%) than those kept in multiple-bird cages (42.6%) at 362 cm² per bird. Both studies did not conform to the findings of the present study. However, because H/L ratios and plasma corticosterone concentrations in this investigation were not affected by cage design, it appears that the levels of stress were similar and low in conventional and enriched cages. The age of the birds when plasma corticosterone and H/L ratio were taken might have contributed to the nonsignificant effect of cage design on both physiological response parameters. Because birds had been caged in the conventional and enriched cages for the entire 11-mo production period, familiarity with cage mates and the environment might have ameliorated effects of cage design on plasma corticosterone and H/L ratio. As a consequence, similar antibody responses of laying hens in conventional and enriched cages before and after vaccination of NDV were obtained. Patterson and Siegel (1998) and Heckert et al. (2002) both observed that cage density treatments had no significant effect on hemagglutinin titers to SRBC. However, in a study conducted by Hester et al. (1996), they reported that birds housed in multiple cages (362 cm² of floor area/bird) had significantly lower titers against SRBC than those in single-bird cages (1,085 cm² of floor area/bird), when birds were subjected to high environmental temperature (38°C). However, because this study was conducted under heat stress condition, it is intuitively logical to assume that the high environmental temperature further contributed to the immunosuppression observed for birds housed in cages at higher density.

Table 5. Plasma corticosterone and antibody titers to Newcastle disease (B1) vaccine of laying hens in conventional (CON) and enriched (ENR) cages at 59 and 61 wk of age

<table>
<thead>
<tr>
<th>Period</th>
<th>Plasma corticosterone (ng/mL)</th>
<th>Antibody titer (log2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CON</td>
<td>ENR</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>59 wk</td>
<td>1.75 ± 0.08</td>
<td>1.82 ± 0.08</td>
</tr>
<tr>
<td>61 wk</td>
<td>1.70 ± 0.08</td>
<td>1.80 ± 0.05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>ENR</td>
</tr>
<tr>
<td></td>
<td>4.20 ± 0.36</td>
<td>3.50 ± 0.22</td>
</tr>
<tr>
<td></td>
<td>7.60 ± 0.27</td>
<td>7.10 ± 0.35</td>
</tr>
</tbody>
</table>

*Means ± SE within each column with different superscript letters are significantly different (P < 0.05).

Table 6. Differential leukocyte counts and heterophil/lymphocyte (H/L) ratios of laying hens in conventional (CON) and enriched (ENR) cages

<table>
<thead>
<tr>
<th>Treatment</th>
<th>H/L ratios</th>
<th>Heterophils</th>
<th>Lymphocytes</th>
<th>Monocytes</th>
<th>Eosinophils</th>
<th>Basophils</th>
</tr>
</thead>
<tbody>
<tr>
<td>CON</td>
<td>0.313 ± 0.012</td>
<td>21.55 ± 0.67</td>
<td>69.20 ± 0.69</td>
<td>5.25 ± 0.54</td>
<td>1.45 ± 0.24</td>
<td>2.55 ± 0.20</td>
</tr>
<tr>
<td>ENR</td>
<td>0.338 ± 0.013</td>
<td>22.45 ± 0.65</td>
<td>67.05 ± 0.79</td>
<td>6.30 ± 0.32</td>
<td>1.35 ± 0.21</td>
<td>2.85 ± 0.20</td>
</tr>
</tbody>
</table>

*Means ± SE within a column with different superscript letters are significantly different (P < 0.05).
In summary, the results of the study provide evidence that production performance, egg quality, and mortality of laying hens were similar between the 2 cage designs. Additional refinements to the enriched cages may be necessary to reduce the higher percentage of dirty eggs, which could lead to reduced returns through egg downgrading. The larger floor space and the incorporation of perches in enriched cages led to a marginal improvement in bird’s skeletal integrity. The higher bone mineral density of birds in enriched cages may lead to a reduction in the incidence of fractures and the eventual threat of osteoporosis at the latter stage of the hen’s life. This indicates an improvement in 1 marker of bird welfare, but further research is needed to determine the significance of this improvement. The similar response to immunological parameters intended to measure degree of stress in conventional and enriched cages indicates similar levels of existing stress condition between the 2 caging designs.

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