ANIMAL WELL-BEING AND BEHAVIOR

Effect of space allowance and cage size on laying hens housed in furnished cages, Part I: Performance and well-being

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ABSTRACT There are few published data on the effects of housing laying hens at different densities in large furnished cages (FC; a.k.a. enriched colony cages). The objective of this study was to determine the effects of housing laying hens at 2 space allowances (SA) in 2 sizes of FC on measures of production and well-being. At 18 wk of age, 1,218 LSL-Lite hens were housed in cages furnished with a curtained nesting area, perches, and scratch mat, and stocked at either 520 cm^2 (Low) or 748 cm^2 (High) total floor space. This resulted in 4 group sizes: 40 vs. 28 birds in smaller FC (SFC) and 80 vs. 55 in larger FC (LFC). Data were collected from 20 to 72 wks of age. There was no effect of cage size ($P = 0.21$) or SA ($P = 0.37$) on hen day egg production, egg weight ($P_{\text{Size}} = 0.90$; $P_{\text{SA}} = 0.73$), or eggshell deformation ($P_{\text{Size}} = 0.14$; $P_{\text{SA}} = 0.053$), but feed disappearance was higher in SFC than LFC ($P = 0.005$). Mortality to 72 wk was not affected by cage size ($P = 0.78$) or SA ($P = 0.55$). BW ($P = 0.006$) and BW CV ($P = 0.008$) increased with age but were not affected by treatment. Feather cleanliness was poorer in FC with low SA vs. high ($P < 0.0001$) and small vs. large FC ($P < 0.0001$). Feather condition was poorer in low SA ($P = 0.048$) and the best in small cages with high SA ($P = 0.006$), but deteriorated in all treatments over time ($P < 0.0001$). Treatments did not affect the breaking strengths of femur, tibia, or humerus, proportions of birds suffering keel deformations, or foot health scores. Overall, the SA studied in the 2 cage sizes in this trial had few effects on production parameters. However, stocking birds at the lower space allowance resulted in some measures of poorer external condition in both sizes of FC, which indicates that the welfare of hens housed at the lower space allowance may be compromised according to some welfare assessment criteria.

Key words: laying hen, furnished cage, space allowance, cage size, well-being

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INTRODUCTION

Furnished cages are intended to improve the welfare of laying hens by providing opportunities for them to perform a larger behavioral repertoire while at the same time maintaining the health and hygiene benefits of conventional cages (Elson and Tauson, 2012). Furnished cages include an enclosed area for nesting, an area for scratching and dust bathing, and perches; there is evidence that the greater opportunity for perching and other load-bearing exercise afforded in these cages results in increased bone strength compared to conventional cages (Jendral et al., 2008). The earliest models of furnished cages, developed over 30 yr ago, generally held fewer than 15 hens, and often included a dust bath or box of litter (Tauson, 2002). However, because of problems with misplaced eggs and the hygiene and management challenges associated with providing dust bathing material within cages, more recent models of furnished cages instead provide a scratch mat onto which feed is distributed to facilitate foraging and dust bathing activities (Guinebretière et al., 2012). The sizes of furnished cages also have increased to accommodate much larger groups, with many enriched colony systems housing upwards of 60 hens.

Standards for space allowances for laying hens are generally derived from a variety of studies using measures of biological function and behavior (Widowski et al., 2016). In North America (**NA**), standards for space allowances for laying hens in conventional cages

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are mainly based on studies examining the effects of space on biological function, namely, measures of egg production, stress response, and mortality (Bell et al., 2004). The body of literature on space allowance generally indicates that for hens housed in conventional cages, space allowances below 465 cm^2 (~72 in^2) per hen result in reduced egg production, higher levels of stress responses, such as corticosterone concentration or an increased heterophil: lymphocyte ratio, and increased mortality (Bell et al., 2004; Widowski et al., 2013). In contrast, the standards for space allowances for hens in furnished cages as legislated in the EU are higher and require that hens be provided with a minimum of 750 cm^2 (of which 600 cm^2 must be usable space, e.g., of sufficient height and not nest box) per hen (European Commission, 1999). This standard is generally based on behavioral parameters and freedom of movement (Appleby et al., 2002; European Food Safety Authority [EFSA], 2005). Basic body postures and most behaviors of hens require a much larger space envelope than that afforded by NA space allowances. For example, the average amount of space required for standing, turning, and wing flapping in hens was determined to be 475, 1,272, and 1876 cm^2, respectively, for medium hybrid birds (Dawkins and Hardie, 1989) and 563, 1,316, and 1,693 cm^2, respectively, for light hybrids (Mench and Blatchford, 2014).

At any given space allowance, increasing the size of cages to accommodate larger groups alters the dynamics of space use, resulting in changes in the amount of space afforded to individual hens (Appleby, 2004). First, the total amount of space available to each hen increases, thereby affording an increase in the overall area available for locomotion. Additionally, the amount of free space available to individual birds for other behavior patterns increases at different times; hens usually cluster together when performing some types of behavior, resulting in higher densities in some areas of the cage while leaving other areas of the cage largely unoccupied (Collins et al., 2011). However, housing larger group sizes in furnished cages also is considered to increase the risks of feather pecking, aggression, and cannibalism (Mench and Keeling, 2001; Wall, 2011), and those risks could increase further at lower space allowances (Widowski et al., 2016).

There are numerous published studies that indicate the production performance and mortality of hens in furnished cages is on par with or better than that of hens in conventional cages (Elson and Tauson, 2012; Karcher et al., 2015). However, the vast majority of these studies were conducted with smaller group sizes within the context of European standards where hens were stocked at 750 cm^2/hen (European Commission, 1999). As more North American egg producers are adopting large furnished cages (a.k.a. enriched colony systems), there are questions as to the effects of housing hens in these systems at higher densities. This may be particularly important during interim periods of industry transition from conventional to furnished caging systems, as it would enable farmers to maintain a more steady supply of eggs as new barns are built to accommodate housing hens with more space. To date, there have been few published studies that have measured the production performance, mortality, or welfare of hens in large furnished cages at different space allowances. Therefore, the objectives of this study were to compare the production performance and indicators of physical well-being of hens in 2 sizes of large furnished cages stocked at ca. 520 vs. 748 cm^2/hen. Space allowances were adjusted by varying the number of birds in the cage, which confounds group size with feeder space and nest space. However, this is the most common method that producers use to adjust space allowance and therefore is the most commercially applicable. Behavioral assessments of nesting (Hunniford et al., 2014) and behavior at the feeder (Part II of this series; Widowski et al., 2017, *submitted*) are reported elsewhere. Performance of a reference population of hens in conventional cages stocked at 465 cm^2/hen also was measured for non-statistical comparison in this report.

MATERIALS AND METHODS

Animals, Housing, and Management

Twelve-hundred-eighteen Lohmann Selected Leghorn-Lite laying hen chicks were obtained from a commercial hatchery at one day old. Beak treatment was performed at the hatchery using infra-red treatment, and chicks were reared in conventional rearing cages. At 18 wk, the hens were individually weighed, wing banded for identification, and moved to the layer housing. Two layer rooms in the adult barn at the Arkell Poultry Research Station (Arkell, ON, Canada) with environmental control were outfitted with Farmer Automatic "Enrichable" System Enriched Cages (Clark Ag Systems; Caledonia, ON, Canada) that provided birds with a nest, perches, claw shorteners, and scratch pad. The nest consisted of an area of yellow plastic mesh overlaid on the wire cage floor surrounded by red plastic curtains. The scratch mat consisted of an area of smooth red plastic overlaid on the wire cage floor. An auger was positioned through the center of the cage and over the scratch mat from which small amounts of feed were delivered on the scratch mat. Perches were square-shaped smooth plastic and suspended approximately 10 cm above the cage floor. Two cage sizes were used and are referred to as Large (358 × 122 cm), which is the standard commercial model, and Small (178 × 122 cm), which was custom-built for our research station. Furnished cage layouts are illustrated in Figure 1.

The number of birds stocked in the furnished cages (**FC**) was adjusted to approximate floor space allowances (**SA**) of either 520 or 748 cm^2, such that group sizes were 40 vs. 28 birds (low vs. high SA) in the Small FC (**SFC**) and 80 vs. 55 birds (low vs. high SA) in the

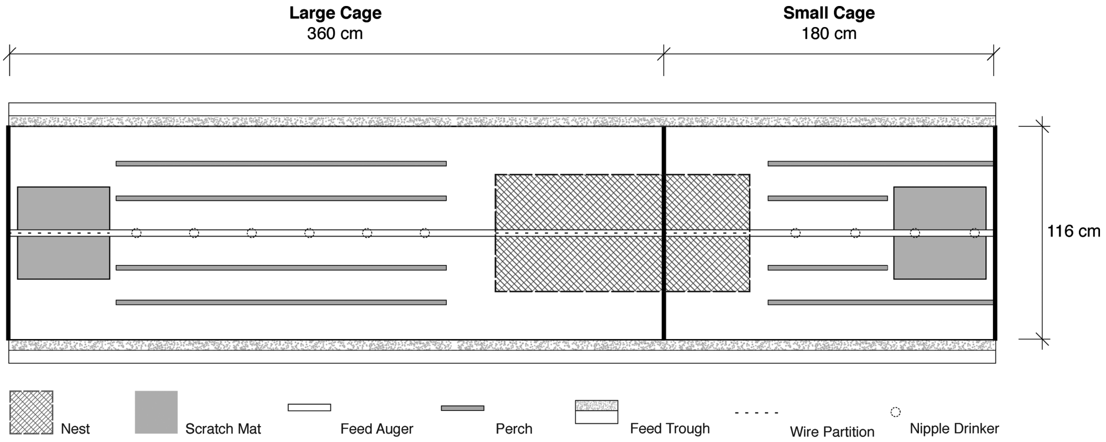

Figure 1. Top view of one tier of cages: one large FC (left) and one small FC (right). Except for the scratch area, all other resources are proportional between small and large cages. The legend depicts each of the resources in the scale diagram. Adapted from Figure 1 in Hunniford et al. (2014).

Table 1. Space allowances in the 4 treatment groups in cm^2 per hen (unless otherwise indicated).

Space allowance	Cage size (group size)	Floor space[1]	Cage space[2]	Feeder space (cm)[3]	Water nipples[4]	Nest	Scratch	Perch (cm)[5]
Low	Large (80)	516	559	8.9	13.3	70	31	12
	Small (40)	522	560	8.9	10.0	70	63	11
High	Large (55)	750	814	12.9	9.2	102	46	17
	Small (28)	746	800	12.7	7.0	102	89	16

[1]Floor area measured as area in the horizontal plane as depth from bottom of the manure deflector to the back wall × width between the sidewalls of the cage. Space includes nest and scratch mat areas.
[2]Cage area measured as area in the horizontal plane as depth from the front to the back cage walls × width between sidewalls of the cage. Space includes nest and scratch mat areas.
[3]Linear feeder space per hen.
[4]Six nipples in large cages and 4 nipples in small cages; unit is hens/nipple.
[5]Linear perch space per hen.

Large FC (**LFC**). Perch allowance and nest area were approximately proportional for LFC and SFC, whereas the scratch mat was the same size in both. Refer to Table 1 for exact space allowances in each of the 4 treatments.

Each treatment group comprised 6 replicates; there were 24 cages in total distributed between the 2 rooms with 3 tiers and 2 rows of cages in each room. There were 12 LFC and 12 SFC per room, and SA treatments were balanced across room and tier. A reference group of 100 hens was housed in 20 conventional cages (**CC**), 5 hens/cage, in an environmentally controlled room in the same building. Birds were given 464 cm^2 per bird, and the cages measured 50 cm in width, 45 cm in length, front height 45 cm, back height 40 cm, and a gate opening of 45 cm wide × 22.5 cm in height.

Birds were fed a corn/soy layer/breeder diet typical to southern Ontario formulated to provide 18.0% CP, 2,886 kcal/kg of ME, and 4.2% Ca, 0.44% available phosphorus, 0.38% methionine, and 0.89% lysine. Feed was distributed in the feeding troughs by chain feeders 5 times per d, and ca. 20 g of feed were distributed from the auger onto the scratch mats 10 times per day. The birds received 14 h of incandescent light (ranging from 5 to 15 lux at the feeders of bottom and top tiers, respectively) and 10 h of dark per day with a 15-minute dawn at 0500H and 15-minute dusk at 1900H. Room temperatures were maintained at approximately 21 °C.

Birds were cared for according to the required guidelines of the Canadian Council on Animal Care and with the approval of the University of Guelph Animal Care Committee, under Animal Utilization Protocol #11R062.

Data Collection

Egg Production, Quality, and Feed Disappearance Eggs were collected manually each d in both FC and CC, and hen-day egg production was calculated weekly from 20 wk of age to trial end at 70 wk of age. Egg quality was measured every 28 d when 30 eggs were randomly selected from each large cage, and 15 eggs were selected from each small cage for individual egg weight and measurement of eggshell deformation as a measure of shell strength (Schoorl and Boersma, 1962; Carter, 1968). In principle, deformation non-destructively compresses the shell using an apparatus that records the load applied at opposite points on the egg's equator (500 g) and the distance between the 2 points measured in μm where the egg was placed, hence providing a measure of shell strength (greater deformation indicates a weaker shell). At 50 and 69 wks, all eggs laid were visually assessed for dirtiness and the presence of cracks to quantify shell quality (adapted from Wu et al., 2008). Eggs were scored out of a maximum score of 2 for dirtiness (0 = clean, 1 = dirt on < 25% of shell area, and 2 = dirt on > 25% of shell area) and out of a maximum score of 2 for cracks (0 = free of cracks, 1 = cracks < 25% of the shell area, and 2 = crack webbing > 25% of the shell area or gross break with visible yolk). The numbers of eggs scored for dirt and cracks in each category were expressed as the percentage of eggs laid in each cage.

Average daily feed disappearance (**ADFD**; g/bird/d) was measured over a 2-day period at 30, 43, 49, 56, and 70 wk in FC and CC. Feed troughs shared by different cages in a row were separated by a partition, chain feeders in the FC were turned off, and feed troughs were replenished manually twice each d during the period of measurement.

Indicators of Health and Well-being All bird mortalities were recorded daily, and dead birds were submitted to the University of Guelph Animal Health Laboratory for postmortem examination by a board certified poultry pathologist to determine cause of death.

At 30, 50, 60, and 70 wk of age, 20% of the birds in each cage were randomly selected. The birds were weighed and evaluated for measures of well-being that included cleanliness, feather condition, keel breaks and deformities, toe injuries, and foot health. Methodologies for welfare assessments were adapted from some of the procedures given in the Welfare Quality® Assessment Protocol for Poultry (2009), but scoring systems were used at the individual bird rather than flock level. Overall cleanliness was scored subjectively according to the degree of manure soiling on back, rump, breast, belly, and wings with scores of 0 (little soiling on any area), 1 (one body area lightly soiled), 2 (2 body areas soiled), or 3 (> 3 body areas soiled). Feather condition was scored out of a maximum of 10 points, which was a sum of the scores for the head, neck, back, rump, and belly; each area was scored as either 0 (no wear), 1 (worn or damaged feathers but no skin visible), or 2 (featherless areas, some bare skin visible). Keel damage was determined by palpation, to detect abnormal curvatures of the keel or bony callouses indicative of healed fractures, and scored as either positive or negative for deviations and/or fractures. Toes were scored as positive or negative for damage (e.g., broken or missing claws, twisted or broken toes). Foot health was evaluated by examining 2 possible conditions: pododermatitis, which included footpad dermatitis (lesions on the central footpad) and bumble foot; and hyperkeratosis (thickening of the epilthelium on the footpad or toes). Bumblefoot was scored from 0 to 3 with increasing severity: 0 (no lesion), 1 (slight lesion on footpad), 2 (easily detectible lesion covering footpad), or 3 (bumblefoot dorsally visible). Hyperkeratosis also was scored from 0 to 3 with increasing severity, as adapted from the methods of Weitzenbürger et al. (2006): 0 (no thickened epithelium), 1 (detectible thickened epithelium), 2 (moderately thickened epithelium on toes but not footpad), or 3 (thickened epithelium on both footpad and toes). Each assessment began with 2 experimenters, blinded to treatment, simultaneously scoring a sample of birds and arriving at a consensus. Then, the 2 different experimenters assessed birds from different cages simultaneously, with treatments balanced across experimenters.

At the end of the trial (70 wks), half of the birds scored as above (10% from FC and CC) were randomly sampled for measures of bone breaking strength according to the methods of Newman and Leeson (1999). The birds were euthanized by cervical dislocation, and the femur, tibia, and humerus were dissected out, cleaned, and air-dried. Breaking strength was measured using a 3-point bending test performed on a Universal Testing Machine (Model 4202 Instron Corp., Canton, MA) located in the university's engineering department. Breaking strength was measured in Newtons.

Statistical Analyses

All data were analyzed as a 2 × 2 factorial with cage as the experimental unit. Data were tested for homogeneity of variance and normality and transformed when necessary. Mixed model analyses of variance, using Proc Mixed (SAS 9.4), were used to test continuous response variables for effects of cage size, SA, age, and their interactions. Room and tier were included but subsequently removed from the models when not significant. Where appropriate, repeated measures statements were incorporated into the mixed model. The variables analyzed using Proc Mixed included the response variables egg production, egg weight, eggshell deformation, shell quality, feed disappearance, and body weight (mean and coefficient of variation). Keel damage and toe condition, each scored as positive or negative, were calculated as a proportion of birds sampled in the cage having the condition; the proportions were transformed using arcsine square root prior to analysis. Feather condition score, feather cleanliness score, and foot health (hyperkeratosis and pododermatitis) scores were not transformed prior to being analyzed using Generalized Linear Mixed Models (Proc Glimmix, SAS 9.4), with the appropriate response distributions: negative binomial for cleanliness and feather condition and gamma distribution for pododermatitis and hyperkeratosis (Stroup, 2015). Cumulative mortality and bone breaking strength were analyzed using a General Linear Models procedure (Proc GLM, SAS 9.4). Means were separated using the method of least squares. Because CC were all located in a separate room, the values could not be statistically compared to FC, but the data are presented as a reference for visual comparison.

RESULTS

Hen-day egg production was not affected by either SA or cage size. Overall mean hen-day egg production was 93.0 ± 0.1% in the low SA and 94.4 ± 0.2% in the high SA ($P = 0.21$) and 93.2 ± 0.1% in LFC and 94.2 ± 0.2% in SFC ($P = 0.36$). Hen-day egg production

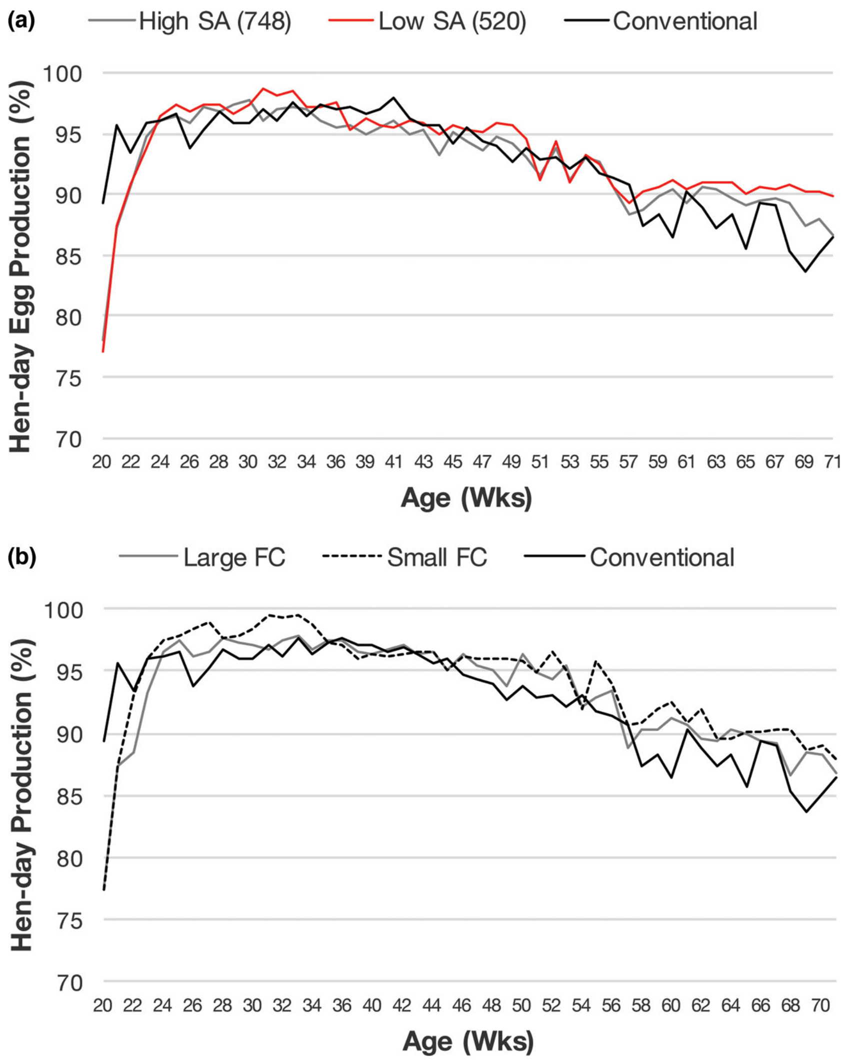

Figure 2. a. Hen-day production from 20 wks of age in furnished cages with HIGH or LOW space allowance. *P*-values (given in text) indicate there was no difference between treatments and no interaction. Values for conventional cages were not statistically compared but are presented for reference. **2b.** Hen-day production from 20 wks of age of hens in SMALL or LARGE furnished cages. *P*-values (given in text) indicate there was no difference between treatments but a significant interaction with age. Values for conventional cages were not statistically compared but are presented for reference.

in cages with different space allowances did not change over time ($P = 0.77$; Figure 2a). However, there was a significant interaction between cage size and the age of the birds ($P = 0.010$; Figure 2b); egg production was higher in Small FC compared to Large during some wk early in the production period (wk 26 to 27 and 31 to 34). The hen-day egg production of hens in CC averaged 92.7 ± 0.6%.

The data from the other production measures (egg weight, eggshell deformation, feed disappearance, eggshell quality, and egg mass) are given in Table 2. Egg weights were unaffected by cage size ($P = 0.90$) and SA ($P = 0.74$). There was a significant increase in egg weight with age ($P < 0.0001$). Birds in furnished cages had overall average egg weight of 60.0 ± 0.4 g, and those in CC had overall average egg weights of 59.4 ± 0.3 g. Eggshell deformation increased (indicating shell strength decreased) in all treatments over time ($P < 0.0001$). There was no effect of cage size on eggshell deformation ($P = 0.14$), but eggs from hens housed at low SA tended to have weaker shells ($P = 0.053$). There was a significant interaction between age and SA on eggshell deformation ($P = 0.005$), with greater deformation at 57 wk of age in low SA compared to high. There were no main effects of cage size or SA, and no interaction, on the percentages of dirty or cracked eggs. However, the percentage of dirty eggs was higher at wk 69 (59.8 ± 4.0%) compared to 50 (34.2 ± 3.7%; $P < 0.0001$). There were also more cracked eggs at wk 69 (17.9 ± 1.5%) compared to wk 50 (12.0 ± 2.0%; $P = 0.031$).

Hens housed in small cages had a greater ADFD (110.7 ± 1.3 g/bird/d) than hens in large cages (105.3 ± 1.1 g/bird/d; $P = 0.005$; Table 2). SA had no effect on ADFD ($P = 0.79$), even though feeder space allowances were lower in the more crowded cages. Feed disappearance over the experimental period was variable but generally increased over time as the hens matured ($P < 0.0001$; Table 2). Hens in CC had an ADFD of 112 ± 1.61 g/bird/d.

Table 2. Average egg weight, eggshell deformation, and feed disappearance presented for both cage sizes (S; large and small) and space allowances (SA; low and high), in addition to mean values at each of 4 ages (A).

Variable	SA		S		*P*-value						
Age (wk)	Low (520)	High (748)	Large	Small	SA	S	A	S × SA	A × SA	A × S	Conv.
Egg weight (g)											
25	53.9	54.1	54.0	53.8							54.9
33	59.2	59.6	57.1	59.2							59.3
45	61.2	61.3	61.4	61.4	0.74	0.90	**<0.0001**	0.55	0.96	0.56	59.6
57	62.1	61.8	62.3	61.7							60.4
69	63.9	63.7	63.6	63.6							62.8
Overall	60.0 ± 0.38	60.1 ± 0.37	60.1 ± 0.38	60.0 ± 0.38							59.4 ± 0.34
Eggshell deformation (μm)											
25	19.2	19.2	19.1	19.3							19.2
33	20.2	20.0	20.1	20.1							20.9
45	21.5	21.4	21.4	21.5	0.053	0.14	**<0.0001**	0.87	**0.005**	0.80	21.4
57	23.1	22.2	22.6	22.8							23.3
69	22.4	22.4	22.6	22.2							20.9
Overall	21.2 ± 0.20	20.9 ± 0.16	21.2 ± 0.15	21.2 ± 0.21							20.8 ± 0.49
Feed disappearance (g/bird/d)											
30	117.6	118.8	115.8	120.6							99.3
43	111.0	110.3	107.9	113.3							97.2
49	99.5	101.5	99.7	101.3	0.79	**0.005**	**<0.0001**	0.51	**0.045**	0.08	118.8
56	100.9	99.3	97.5	102.7							119.6
70	109.7	111.3	105.6	115.4							114.8
Overall	108.2 ± 1.3	107.7 ± 1.2	105.3 ± 1.1	110.7 ± 1.3							112.13 ± 1.61
Eggshell quality											
Dirty shells (%)											
50	34.8	33.6	33.1	35.2							
69	59.4	60.1	56.3	63.2	0.97	0.50	**< 0.0001**	0.42	0.84	0.62	
Overall	47.1 ± 4.1	46.8 ± 5.2	44.7 ± 4.7	49.2 ± 4.7							
Cracked shells (%)											
50	10.9	13.1	12.9	11.1							
69	17.8	17.9	19.7	16.1	0.66	0.31	**0.0305**	0.75	0.70	0.73	
Overall	14.4 ± 1.7	15.5 ± 2.0	16.3 ± 1.8	13.6 ± 1.9							
Total egg mass per bird (kg/bird)											
	18.2	18.5	18.3	18.5	0.20	0.38		1.00			17.9 ± 0.55
Total feed intake per bird (kg/bird)											
	1.40	1.41	1.37	1.44	0.74	**0.004**		0.38			1.41 ± 0.03
Egg mass/Feed intake											
	13.0	13.1	13.3	12.8	0.47	**0.039**		0.41			12.7 ± 0.51

Total egg mass per bird, feed intake per bird, and egg mass to feed intake ration also are presented. Reference values from hens housed in conventional cages are given for visual comparison.

Total egg mass over the experimental period was calculated on a per bird basis and was unaffected by cage size ($P = 0.38$) or SA ($P = 0.20$). Eggs from hens in furnished cages had a total egg mass averaging 18.2 to 18.5 ± 0.6 kg/bird, while those from CC had a total average egg mass of 17.9 ± 0.6 kg/bird. The ratio of total egg mass (kg) to total feed disappearance (kg) was greater in large cages (13.3 ± 0.5) compared to small cages (12.8 ± 0.5; $P = 0.039$) but was not affected by SA ($P = 0.47$). Eggs from CC had a mass: feed ratio of 12.7 ± 0.5.

Data for body weight, body weight uniformity, bird mortality, and bone strength are given in Table 3. Body weight and body weight uniformity were not affected by either cage size ($P = 0.38$) or SA ($P = 0.64$). As expected, as birds matured, body weight increased and hence age was a significant factor ($P = 0.006$). There was a significant interaction between age and SA for overall body weight CV ($P < 0.05$), but the pattern over time was not consistent and differed only at 50 wks when uniformity was lower for hens in low SA (BW CV = 10.8 ± 1.1) compared to hens in high (BW CV = 8.5 ± 0.6). Hens housed in CC were heavier overall than birds in FC.

Mortality over the experimental period was unaffected by cage size ($P = 0.78$) or SA ($P = 0.55$). Major causes of mortality were disorders of calcium metabolism (51.2%; osteoporosis, osteopenia, osteomalacia, and hypocalcemia), mechanical injury (22%; entrapment, fracture, laceration, and trauma) fatty liver (9.8%) or "other causes" (17%; septicemia, salpingitis, yolk peritonitis, and splenitis). There was no mortality related to cannibalism. Overall mortality in CC was 2.0% compared to 4.6% in the furnished cages.

The bone breaking strengths of the femur, tibia, and humerus measured at the end of the trial were not affected by cage size or SA (Table 3). Bone strength of hens in FC was similar to bone strength of hens in CC.

TABLE 3. Mean values for body weight and body weight CV for each of 4 ages (A), and overall means for both space allowances (SA; low and high) and cage sizes (S; large and small), ± standard error.

Variable	SA		S		*P*-value						
Age (wk)	Low (520)	High (748)	Large	Small	SA	S	Age	S × SA	A × SA	A × S	Conv.
					Body weight (g)						
30	1615	1615	1617	1612							1746
50	1715	1757	1732	1733	0.64	0.38	**0.006**	0.29	0.24	0.63	1870
60	1722	1726	1720	1732							1880
70	1736	1726	1719	1756							1764
Overall	1702 ± 8.0	1711 ± 9.1	1701 ± 7.4	1714 ± 10.4							1815 ± 17.9
					Body weight CV						
30	9.4	8.0	9.1	8.5							8.9
50	9.2	10.9	9.7	10.5	0.28	0.90	**0.008**	0.32	**0.047**	0.60	7.5
60	11.9	10.4	11.4	11.1							7.3
70	11.8	10.0	11.2	10.7							9.6
Overall	9.9 ± 0.36	9.3 ± 0.52	9.6 ± 0.42	9.5 ± 0.47							8.3 ± 0.5
					Mortality (%)						
Overall	4.79 ± 0.68	4.35 ± 0.87	4.47 ± 0.76	4.67 ± 0.80	0.55	0.78		0.60			2.00 ± 0.004
					Bone strength (Newtons[1])						
Femur	222.2 ± 6.1	214.0 ± 8.3	225.7 ± 4.6	210.6 ± 10.4	0.48	0.20		0.26			219.7 ± 24.0
Tibia	175.7 ± 6.8	172.5 ± 6.0	173.7 ± 4.2	174.5 ± 7.6	0.72	0.93		0.48			171.4 ± 12.4
Humerus	89.6 ± 3.1	91.6 ± 3.8	92.4 ± 2.5	88.7 ± 3.5	0.66	0.42		0.82			98.5 ± 12.2

[1]Newtons: 1 kg force = 9.8 N (m/s^2).

Cumulative mortality to 72 wk and bone strength at 70 wk are presented. Reference values from hens housed in conventional cages are given for visual comparison.

Data for feather cleanliness, feather condition, keel, and foot health are shown in Table 4. Hens housed in small cages had higher overall feather cleanliness scores (they were dirtier) than those housed in large cages ($P < 0.0001$); hens housed at low SA had dirtier plumage than those hens housed at higher SA ($P < 0.0001$). Hens housed in CC had overall better external cleanliness than those in FC.

Space allowance ($P = 0.048$), but not cage size ($P = 0.77$), affected feather condition score. Feather condition deteriorated over the experimental period as the hens aged ($P < 0.0001$). Hens housed in low SA cages had poorer feather condition, regardless of cage size. There was also an interaction between cage size and SA; hens housed in small cages with high SA had the lowest feather scores, i.e., the best feather condition overall ($P = 0.006$; Figure 3). Although no direct statistical comparison could be made, the overall feather condition score of hens housed in CC (2.74 ± 0.11; SA of 464 cm^2/bird) more closely resembled the feather condition of hens in low SA FC (2.80 ± 0.12; SA of 520 cm^2/bird) than in high (2.02 ± 0.11; SA of 750 cm^2/bird).

The proportion of hens with keel damage increased significantly over time ($P = 0.002$). Overall, SA and cage size had no effect on the proportion of birds with keel damage. Unexpectedly, birds in FC had a lower overall proportion of damaged keels than hens housed in CC.

The proportion of hens with toe damage increased over the experimental period ($P = 0.007$), but there was no difference due to cage size ($P = 0.14$) or SA ($P = 0.71$). More hens had toe damage in FC than in CC. Overall scores for pododermatitis increased over time as hens aged ($P < 0.0001$), with no effect of cage size or space allowance. Hens housed in FC had overall higher scores for pododermatitis than birds in CC. Hyperkeratosis increased in both treatments over time ($P = 0.0003$), and was not affected by cage size, space allowance, or any interactions.

DISCUSSION

This research is some of the first to assess the welfare of hens housed in LFC of different sizes and SA using measures of production, health, and body condition. Most previous investigations on the effects of SA on hens in FC have focused primarily on behavior, and most of these have used SFC housing 10 birds or less (e.g., Albentosa et al., 2007). Similar to previous studies, different SA were provided by altering the number of birds in the cage, which results in confounds with group size, feeder space, and SA, and in other amenities such as nesting area (Sarica et al., 2008; Karcher et al., 2014; Gast et al., 2016). In the majority of published studies focusing on the effect of group size in FC, cage design also has differed considerably with different group sizes, making it difficult to draw conclusions on cage size per se (e.g., Vits et al., 2005; Wall, 2011; Meng et al., 2015). The primary objective of our study was to identify whether there are significant risks to production and mortality when hens are stocked at a lower SA in LFC, since this may happen when an interim standard is set during an industry-wide transition from conventional to alternative housing systems (National Farm Animal Care Council [NFACC], 2017).

There were no effects of treatments on most measures of productivity. The lack of differences is not surprising considering that the current standard stocking rate for

TABLE 4. Mean scores for feather cleanliness, feather condition, and foot health; and the average proportion of hens with damaged keels or toes.

Variable	SA		S		*P*-value						
Age (wk)	Low (520)	High (748)	Large	Small	SA	S	A	S × SA	A × SA	A × S	Conv.
					Feather cleanliness[1]						
30	0.20	0.08	0.09	0.26							0.10
50	0.88	0.66	0.71	0.94	**<0.0001**	**<0.0001**	**<0.0001**	0.41	0.13	0.13	0.60
60	1.19	0.99	0.98	1.35							1.15
70	1.34	1.19	1.08	1.65							0.90
Overall	0.90 ± 0.03	0.73 ± 0.03	0.71 ± 0.02	1.05 ± 0.04							0.69 ± 04
					Feather condition score[2]						
30	0.05	0.02	0.02	0.06							0.55
50	1.95	1.11	1.58	1.62	**0.048**	0.77	**<0.0001**	**0.006**	0.49	0.60	1.15
60	3.87	2.93	3.61	3.23							4.15
70	5.39	4.00	5.07	4.32							5.10
Overall	2.80 ± 0.12	2.02 ± 0.11	2.56 ± 0.10	2.31 ± 0.14							2.74 ± 0.11
					Keel score[3]						
30	0.13	0.13	0.12	0.14							0.30
50	0.45	0.49	0.45	0.50	0.54	0.66	**0.002**	0.087	0.46	0.35	0.60
60	0.56	0.50	0.56	0.49							0.60
70	0.64	0.63	0.67	0.60							0.80
Overall	0.45 ± 0.24	0.44 ± 0.25	0.45 ± 0.25	0.44 ± 0.25							0.65 ± 0.1
					Toe damage score[4]						
30	0.20	0.17	0.22	0.14							0.05
50	0.16	0.18	0.18	0.15	0.71	0.14	**0.007**	0.17	0.61	0.79	0.05
60	0.39	0.39	0.40	0.38							0.0
70	0.42	0.48	0.48	0.42							0.01
Overall	0.29 ± 0.2	0.30 ± 0.2	0.32 ± 0.2	0.27 ± 0.2							0.03 ± 0.02
					Foot health						
					Pododermatitis[5]						
30	0.19	0.38	0.26	0.31							0.1
50	0.33	0.30	0.11	0.53	0.78	0.29	**<0.0001**	0.59	0.85	0.96	0.05
60	0.31	0.14	0.23	0.21							0.0
70	0.86	0.82	0.71	0.98							0.25
Overall	0.42 ± 0.4	0.41 ± 0.4	0.33 ± 0.3	0.51 ± 0.4							0.1 ± 0.38
					Hyperkeratosis[6]						
30	0.03	0.10	0.05	0.08							0.0
50	0.35	0.22	0.36	0.22	0.84	0.45	**0.0003**	0.94	0.94	0.19	0.70
60	1.01	0.88	0.93	0.95							1.85
70	1.17	1.04	1.00	1.20							1.65
Overall	0.64 ± 0.5	0.56 ± 0.5	0.58 ± 0.5	0.63 ± 0.6							1.05 ± 0.97

Overall mean values for both cage sizes (S; large and small) and space allowances (SA; low and high) are reported (with standard errors), in addition to mean values at each of 4 ages (A). Reference values from hens housed in conventional cages are given for visual comparison.

[1]Overall cleanliness was scored as 0, 1, 2, or 3, increasingly dirty.

[2]Overall feather score is the sum of the scores for head, neck, back, rump, and belly. Each area scored as 0, 1, or 2 with possible overall score of 10.

[3]Proportion of birds scoring positive for keel damage.

[4]Proportion of birds scoring positive for toe damage.

[5]Overall pododermatitis score is the sum of the scores for footpad dermatitis (0 to 3) and bumble foot (0 to 3).

[6]Hyperkeratosis scored as 0, 1, 2, or 3, increasing severity.

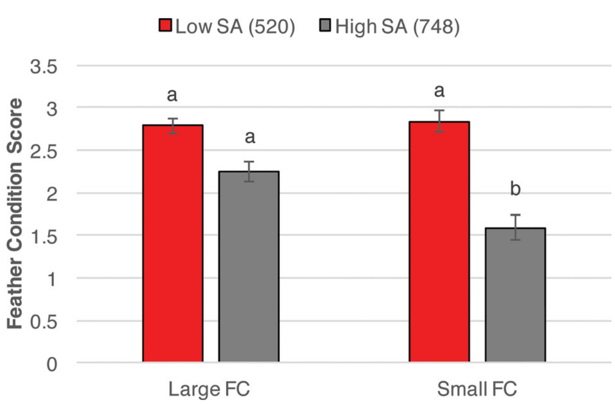

Figure 3. Feather condition score for the interaction between cage size and space allowance (S × SA interaction, $P = 0.006$). Different superscripts indicate statistical significance. Lower scores indicate better feather cover.

conventional cages in NA is 432 cm^2/bird for white hens (United Egg Producers, 2016; NFACC, 2017), and this results in acceptable levels of production for producers. Welfare measures were more affected than the production measures. Numerically, the productivity of hens in FC was comparable or better than that in CC, which is in general agreement with the literature and other scientific reports (EFSA, 2005; Lay et al., 2011; Elson and Tauson, 2012; Widowski et al., 2013; Karcher et al., 2015). Unexpectedly, there was a significantly higher amount of feed consumed in SFC compared with large, which disagrees with other studies comparing different sizes of FC where no differences were found (Tactacan et al., 2009; Guo et al., 2012) and with Vits et al. (2005) who found higher consumption in 10 vs. 20 bird cages but not 40 vs. 60. The feed disappearance data in our study may have been subject to measurement error. Hens in FC were usually fed 5 times per d with chain feeding, but when measuring feed intake, the birds were hand fed, and the feeders were filled only 2 times per d, which could have led to greater feed wastage. There was no evidence of cage size differences on feeder occupancy rates (%) or on displacement or aggression at the feeder that could also lead to increased wastage (Widowski et al., 2017, *submitted*). Additionally, data collected from 4 subsequent flocks of hens housed in these same cages did not show a cage size difference in feed disappearance (T. Widowski, unpublished data).

There was no effect of SA on mortality in either of the cage sizes, but cumulative mortality in the FC was numerically higher than in our reference group in CC. Our mortality rate of around 4.5% was similar to that found by Karcher et al. (2015), who used the same strain of bird as in our study but were kept in large 60-bird enriched colony cages under commercial conditions. These mortality rates were somewhat lower than the 5 to 7% range indicated in the Lohmann layer management guide (Lohmann Tierzucht, 2011). Most of the mortality in our study occurred early during the production cycle when farm and research staff was adjusting to the management challenges of the new system. One of the major causes (22%) of mortality in this study was injury or mechanical damage (e.g., trapped birds). Our mortality rates were lower than or similar to those reported for other styles of FC (4.8% in 60-bird FC and 5.6% in 40-bird FC, Weitzenbürger et al., 2005; 4.7% in 20-bird FC and 4.9% in 40-bird FC, Wall, 2011).

The main effects of SA in this study were significant reductions in cleanliness and feather condition when birds were provided with less space. This agrees with previous work where hens with lower SA had poorer feather coverage than hens with higher SA in conventional (Sarica et al., 2008) and FC (Engle, 2015). Hens in our small cages with the high SA had the best feather condition of all the treatment combinations. In FC, reduced feather condition may be caused by abrasion from the furnishings, which would be exacerbated by low SA (Karcher et al., 2014), or an increase in feather pecking, which may be indicated by the location of feather damage on the body (e.g., see Blatchford et al., 2016). Decreased feather cover can have welfare consequences in terms of reducing hens' ability to thermoregulate, increasing their energy expenditure and feed intake, and increasing their susceptibility to further injury (Sarica et al., 2008; Widowski et al., 2013).

Hens were significantly dirtier in small cages compared with large, and in low SA cages compared with high. This may be explained by the design of the cages. Small cages did not have a wire partition over the scratch mat area, which meant that hens could perch or roost on the auger and defecate on the scratch mat. In contrast, there was a wire partition in large cages that prevented perching over the scratch mat. Additionally, nipple drinkers were located above the mats, which could lead to dirtier feather condition if the manure mixed with water. Although not quantified, we did observe that the scratch mats were dirtier in small cages than large at depopulation.

Toe damage was not affected by either SA or cage size, but it also increased over time. Toe damage was numerically greater for hens in FC than CC, potentially because the furnishings in the cages may lead to more mechanical injuries and caught toes. However, hyperkeratosis was, numerically, the worst in the CC. This is not surprising, given that compression loads from standing on wire floors are thought to contribute to this condition (Weitzenbürger et al., 2006). Although the main effects of SA or cage size did not affect the prevalence of pododermatitis, there were greater levels observed in enriched cages compared to conventional cages. This also has been documented by other researchers (e.g., Weitzenbürger et al., 2006).

There were no significant effects of cage size or SA on the strength of the tibia, humerus, or femur and no numerical differences between FC and CC. This latter observation is surprising because bone strength (Vits et al., 2005; Jendral et al., 2008; Meng et al., 2017) and bone mineral density are usually higher for hens housed in furnished compared to CC (Tactacan et al., 2009; Casey-Trott et al., 2017b), which is usually explained by the increase in load-bearing exercise accommodated by larger cage sizes and the provision of perches. However, Casey-Trott et al. (2017b) found similar results for bone breaking as those reported here and attributed the lack of differences between housing systems on our measurement technique. There was no effect of treatment on the incidence of keel bone injuries, similar to that in Habig and Distl (2013), but prevalence did increase over time, as has been reported by other researchers (Weitzenbürger et al., 2006; Petrik et al., 2015; Casey-Trott et al., 2017a). Surprisingly, the reference population in CC had a higher percentage of fractured keels than hens in FC. However, we sampled only one bird per cage, which may have led to sampling error. In subsequent studies (e.g., Casey-Trott et al., 2017a), we sampled all birds housed in conventional cages to ensure our sample size was representative, and in those cases, there was no difference in the prevalence of keel bone fractures between conventional and furnished cages.

CONCLUSION

Stocking birds at the lower SA in this study did not affect measures of productivity or mortality, but did influence feather condition and cleanliness. Therefore, the welfare of hens housed at the lower SA may be compromised according to some welfare assessment criteria.

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REFERENCES

Albentosa, M. J., J. J. Cooper, T. Luddem, S. E. Redgate, H. A. Elson,, and A. W. Walker. 2007. Evaluation of the effects of cage height and stocking density on the behaviour of laying hens in furnished cages. Br. Poult. Sci. 48:1–11.

Appleby, M. C. 2004. What causes crowding? Effects of space, facilities and group size n behaviour, with particular reference to furnished cages for hens. Anim. Welfare 13:313–320.

Appleby, M. C., L. W. Walker, C. J. Nicol, A. C. Lindberg, R. Friere, B. O. Hughes,, and H. A. Elson. 2002. Development of furnished cages for laying hens. Br. Poult. Sci. 43:489–500.

Bell, D., B. Chase, A. Douglass, P. Hester, J. Mench, R. Newberry, M. Shea-Moore, L. Stanker, J. Swanson,, and J. Armstrong. 2004. UEP uses scientific approach in its establishment of welfare guidelines. Feedstuffs 76:1–10.

Blatchford, R. A., R. M. Fulton,, and J. A. Mench. 2016. The utilization of the Welfare Quality® assessment for determining laying hen condition across three housing systems. Poult. Sci. 95:154–163.

Carter, T. C. 1968. Egg Quality: A Study of the Hen's Egg. Oliver and Boyd. Tweddale Court, Edinburgh, UK.

Casey-Trott, T. M., M. Guerin, V. Sandilands, S. Torrey, and T. M. Widowski. 2017a. Rearing system affects prevalence of keel bone damage in laying hens: A longitudinal study of four consecutive flocks. Poult. Sci. doi: https://doi.org/10.3382/ps/pex026.

Casey-Trott, T. M., D. Korver, M. T. Guerin, V. Sandilands, S. Torrey, and T. M. Widowski. 2017b. Opportunities for exercise during pullet rearing Part II: Long-term effects on bone characteristics of adult laying hens at the end-of-lay. Poult. Sci. doi: http://dx.doi.org/10.3382/ps/pex060.

Collins, L. M., L. Asher, D. U. Pfeiffer, W. J. Browne, and C. J. Nicol. 2011. Clustering and synchrony in laying hens: The effect of environmental resources on social dynamics. Appl. Anim. Behav. Sci. 129:43–53.

Dawkins, M. S.,, and S. Hardie. 1989. Space needs of laying hens. Brit. Poult. Sci. 30:413–416.

Elson, H. A., and R. Tauson. 2012. Furnished cages for laying hens. Pages 190–209 in Alternative Systems for Poultry—Health, Welfare and Productivity. V. Sandilands, and P. M. Hocking, eds. CABI Publishing, Wallingford, Oxon, U.K.

Engle, J. M. 2015. The effects of floor space allowance and nest box access on the welfare of caged laying hens (*Gallus gallus domesticus*). PhD Dissertation, University of Melbourne, Pages 140.

European Commission. 1999. Council Directive 1999/74/EC of July 19, 1999. Laying down minimum standards for the protection of laying hens. Official Journal of the European Communities L203:53–57.

European Food Safety Authority. 2005. The welfare aspects of various systems of keeping laying hens. The EFSA Journal. 197: 1–23.

Gast, R. K., R. Guraya, D. R. Jones, K. E. Anderson, and D. M. Karcher. 2016. Colonization of internal organs by *Salmonella* Enteritidis in experimentally infected laying hens housed in enriched colony cages at different stocking densities. Poult. Sci. 95:1363–1369.

Guinebretière, M., A. Huneau-Salaün, D. Huonic,, and V. Michel. 2012. Cage hygiene, laying location, and egg quality: The effects of linings and litter provision in furnished cages for laying hens. Poult. Sci. 91:808–816.

Guo, Y. Y., Z. G. Song, H. C. Jiao, Q. Q. Song,, and H. Lin. 2012. The effect of group size and stocking density on the welfare and performance of hens housed in furnished cages during summer. Anim. Welfare 21:41–49.

Habig, C., and O. Distl. 2013. Evaluation of bone strength, keel bone status, plumage condition and egg quality of two layer lines kept in small group housing systems. Brit. Poult. Sci. 54:413–424.

Hunniford, M. E., S. Torrey, G. Bedecarrats, I. J. H. Duncan, and T. M. Widowski. 2014. Evidence of competition for nest boxes by laying hens in large furnished cages. Appl. Anim. Behav. Sci. 161:95–104.

Jendral, M. J., D. R. Korver, J. S. Church,, and J. J. R. Feddes. 2008. Bone mineral density and breaking strength of white leghorns housed in conventional, modified and commercially available colony battery cages. Poult. Sci. 87:828–837.

Karcher, D. M., M. M. Malagon, C. I. Robison, and R. J. Tempelman. 2014. Assessment of density in enriched colony cages: Production and welfare quality. Poult. Sci. 93(E-Suppl. 1):59. (Abstr.).

Karcher, D. M., D. R. Jones, Z. Abdo, Y. Zhao, T. A. Shepherd, and H. Xin. 2015. Impact of commercial housing systems and nutrient and energy intake on laying hen performance and egg quality parameters. Poult. Sci. 94:485–501.

Lay, D. C., Jr, R. M. Fulton, P. Y. Hester, D. M. Karcher, J. B. Kjaer, J. A. Mench, B. A. Mullens, R. C. Newberry, C. J. Nicol, N. P. O'Sullivan, and R. E. Porter. 2011. Hen welfare in different housing systems. Poult. Sci. 90:278–294.

Lohmann Tierzucht. 2011. Lohmann LSL Lite Management Guide for Layers. Cuxhaven, Germany.

Mench, J. A.,, and R. A. Blatchford. 2014. Determination of space use by laying hens using kinematic analysis. Poult. Sci. 93:794–798.

Mench, J. A.,, and L. J. Keeling. 2001. The social behaviour of domestic birds. Pages 177–209 in Social Behaviour in Farm Animals. L. J. Keeling, and H. W. Gonyou, eds. CABI Publishing, Wallingford, Oxon, U.K.

Meng, F., D. Chen, X. Li, J. Li, and J. Bao. 2015. Effects of large or small furnished cages on performance, welfare and egg quality of laying hens. Anim. Prod. Sci. 55:793–798.

Meng, F., D. Chen, X. Li, J. Li, and J. Bao. 2017. The effect of large or small furnished cages on behaviors and tibia bone of laying hens. J. Vet. Behav. 17:69–73.

National Farm Animal Care Council. 2017. Code of practice for the care and handling of pullets and laying hens. Egg Farmers of Canada. Ottawa, Ontario. http://www.nfacc.ca/pdfs/codes/pullets_and_laying_hens_code_of_practice.pdf.

Newman, S.,, and S. Leeson. 1999. Effect of dietary supplementation with 1,25-dihydroxycholecalciferol or vitamin C on the characteristics of the tibia of older laying hens. Poult. Sci. 78:85–90.

Petrik, M. T., M. T. Guerin, and T. M. Widowski. 2015. On-farm comparison of keel fracture prevalence and other welfare indicators in conventional cage and floor-housed laying hens in Ontario, Canada. Poult. Sci. 94:579–585.

Sarica, M., S. Boga, and U. S. Yamak. 2008. The effects of space allowance on egg yield, egg quality and plumage condition of laying hens in battery cages. Czech. J. Anim. Sci. 8: 346–353.

Schoorl, P., and H. Y. Boersma. 1962. Research on The Quality of the Egg Shell: A New Method of Determination. 12th World's Poultry Science Congress, Sydney, 432–435.

Stroup, W. W. 2015. Rethinking the analysis of non-normal data in plant and soil science. Agron. J. 107:811–827.

Tactacan, G. B., W. Guenter, N. J. Lewis, J. C. Rodriguez-Lecompte, and J. D. House. 2009. Performance and welfare of laying hens in conventional and furnished cages. Poult. Sci. 88:698–707.

Tauson, R. 2002. Furnished cages and aviaries: Production and health. World's Poult. Sci. J. 58:49–63.

United Egg Producers. 2016. Animal Husbandry Guidelines for U.S. Egg Laying Flocks. http://www.unitedegg.com/information/pdf/UEP-Animal-Welfare-Guidelines2016.pdf.

Vits, A., D. Weitzenbürger, H. Hamann, and O. Distl. 2005. Production, egg quality, bone strength, claw length, and keel bone deformities of laying hens housed in furnished cages with different group sizes. Poult. Sci. 84:1511–1519.

Wall, H., 2011. Production performance and proportion of nest eggs in layer hybrids housed in different designs of furnished cages. Poult. Sci. 90:2153–2161.

Weitzenbürger, D., A. Vits, H. Hamann, and O. Distl. 2005. Effect of furnished small group housing systems and furnished cage on mortality and causes of death in two layer starins. Brit. Poult. Sci. 46:553–559.

Weitzenbürger, D., A. Vits, H. Hamann, M. Hewicker-Trautwein, and O. Distl. 2006. Macroscopic and histopathological alterations of foot pads of laying hens kept in small group housing systems and furnished cages. Brit. Poult. Sci. 47: 533–543.

Welfare Quality® Assessment protocol for poultry. 2009. Welfare Quality® Consortium, Lelystad, Netherlands.

Widowski, T. M., H. Classen, R. C. Newberry, M. Petrik, K. Schwean-Lardner, S. Yue Cottee, and B. Cox. 2013. Scientists Committee Report on Priority Welfare Issues for Laying Hens. National Farm Animal Care Council, https://www.nfacc.ca/resources/codes-of-practice/poultry-layers/Layer_SCReport_2013.pdf.

Widowski, T. M., P. H. Hemsworth, J. J. Barnett, and J.-L. Rault. 2016. Laying hen welfare I. Social environment and space. World's Poult. Sci. J. 72:333–342.

Widowski, T. M., L. Caston, T. Casey-Trott, and M. Hunniford. 2017. The effect of space allowance and cage size on laying hens housed in furnished cages, Part II: Behavior at the feeder. Poult Sci. 96:3816–3823.

Wu, G., P. Gunawardana, M. M. Bryant, and D. A. Roland, Sr. 2008. Influence of dietary energy and antibiotic on performance, egg solids, and egg quality in bovans white and dekalb white hens. J. Appl. Poult. Res. 17:323–330.