Production performance and egg quality of four strains of laying hens kept in conventional cages and floor pens[1]

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ABSTRACT Production performance and egg quality were compared between 4 strains of beak-trimmed layers: 3 commercial strains—Lohmann White (LW), H&N White (HN), Lohmann Brown (LB)—and a noncommercial cross between Rhode Island Red (male) and Barred Plymouth Rock (female) in conventional cages and in floor pens. All chicks were reared and 857 pullets were housed at 18 wk of age in their respective environments. Body weight, hen-day egg production, feed consumption and efficiency, and egg quality were measured at wk 20, 30, 40, and 50. In floor pens, the location of eggs was recorded for 4 consecutive days at 4-wk intervals between 20 and 50 wk of age. Eggs from cages, nest-boxes, and the floor were tested for *Escherichia coli* and coliform contamination at 38 and 42 wk of age. Mortality was recorded during the rearing and laying periods. Housing systems significantly influenced BW and mortality but not feed consumption or feed efficiency. The interaction between environment and strain was significant for hen-day egg production at wk 20 to 30 and for BW at wk 30, 40, and 50. Hens in floor pens had greater BW, egg and yolk weights, and yolk color than those in cages. Commercial hens produced more eggs than the cross hens. Overall, HN hens had the best production performance, whereas cross hens had better egg quality. In floor pens, LW and HN hens laid most of their eggs in nest boxes, whereas LB and cross hens laid half of their eggs on the floor. Eggs from cages had lower *E. coli* and coliform contamination than those from nest-boxes and the floor, and *E. coli* contamination was greater for LB eggs than for LW eggs. Significant strain differences were found for the use of nest-boxes, with a high percentage of floor eggs for brown egg strains. This study suggests that genotype × environment interactions should be considered when alternative housing systems are proposed.

Key words: conventional cage, floor pen, laying hen, egg quality, production

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INTRODUCTION

Rapid intensification of the poultry industry during the 1930s and 1940s has resulted in mechanization and large-scale egg production in laying cages. Keeping hens in cages has permitted a dramatic reduction in labor requirements and improved both barn hygiene and the health of the laying hens. However, this housing regimen has been criticized (Brambell, 1965) for providing a barren environment to the birds. This criticism and a growing demand by consumers for eggs from birds not kept in cages (Savory, 2004) has led to the development of alternative and "animal-friendly" production systems (real or perceived) including free-run housing. However, negative aspects of some of these alternative systems in comparison with the conventional cage system such as greater ammonia emissions (Groot Koerkamp, 1998), greater labor costs, and unhealthy working conditions (van den Top et al., 1994; van Horne, 1994) are now coming under scrutiny.

Alternative housing systems for laying hens must be designed to balance the health and the welfare of the birds with consumer preferences, the needs of the industry, and the impact on environment. Different housing systems for laying hens have considerable effects on performance and production traits such as egg weight, feed efficiency, daily feed consumption, and mortality (Taylor and Hurnik, 1996; van Horne, 1996; Süto et al., 1997). Egg quality is important for consumer appeal, and the economic success of a producer depends on the total number of eggs sold. Egg quality encompasses several aspects (Stadelman, 1977) related to the shell (external quality) and to the albumen and yolk (internal quality). Egg quality has a genetic basis and the parameters of egg quality vary between strains of hens (Pandey et al., 1986; Silversides et al., 2006). However, egg quality is also influenced by the housing regimen

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under which the hens are kept (Mench et al., 1986; Fraser and Bain, 1994; Vits et al., 2005) as well as the age of the laying hens (Silversides et al., 2006).

The absence of nest sites in conventional cages is considered to be the most serious welfare problem (Duncan, 1992), and several experiments have shown that hens are strongly motivated to use a nest (Smith et al., 1990; Ekstrand and Keeling, 1994). Nests are important because of both the birds' preference for them and the birds' frustration when they are absent (review by Ekstrand and Keeling, 1994). Notwithstanding the hens' preference for laying eggs in a nest-box (Reed, 1994), in free-run systems some hens will still lay their eggs on the floor, and these floor eggs are considered to be one of the major disadvantages of noncage systems. Regardless of the housing regimen, bacterial contamination of eggs also has to be taken into consideration (Mayes and Takeballi, 1983; Wall et al., 2008).

This study was undertaken to evaluate the differences in egg laying performance and internal and external egg quality for 4 strains of laying hens kept in conventional cages and floor pens.

MATERIALS AND METHODS

One-day-old Lohmann White (**LW**), Lohmann Brown (**LB**), and H&N White (**HN**) chicks were obtained from a commercial hatchery (Pacific Pride Chicks, Abbotsford, British Columbia, Canada), and chicks from a cross of Rhode Island Red males to Barred Plymouth Rock females (Silversides et al., 2007) were produced at Agassiz Research Centre. Approximately 120 chicks of each strain were reared in either conventional pullet rearing cages or in floor pens, although fewer cross chicks were available at hatching. Commercially obtained chicks were beak trimmed at the hatchery and the cross chicks were beak trimmed at the Agassiz Research Centre. All chicks were wing banded on d 1.

For the conventional cage treatment, chicks were reared with 60 birds per cage (200 cm^2/bird) until wk 5 and 30 birds per cage from wk 6 to 18 (400 cm^2/bird). At 18 wk of age, 457 birds were distributed randomly with 3 birds of the same strain per cage (688 cm^2/bird). In floor pens, each strain was reared separately in a single pen until 7 wk of age when 430 birds were randomly distributed between pens, with 21 to 24 birds of the same strain per pen (6,115 to 6,990 cm^2/bird). Each pen included a 2-tier (50 and 100 cm from the floor) perch assembly and a nest-box. Perches were 3 × 4 cm, were made of soft wood with rounded edges, and provided a space of 18 to 21 cm/bird. Four-nest, 2-tiered nest-boxes (Kuhl Corporation, Flemington, NJ) provided 1 nest for each 5 to 6 birds. Each nest-box was hung on the rear wall of the pen with the nest-box rails at 70 and 100 cm from the floor. The birds were exposed to both perches and nest-boxes from the second week of age. In both environments birds were fed manually and water was provided through nipple drinkers. Nutrient content of the feed (Table 1) followed recommendations of the NRC (1994) and management guides (ISA, 2000). All birds were reared with 9 h of light per day, which was increased to 14 h at 18 wk with an intensity of 5 lx throughout. Temperature and RH were between 21 and 23°C and 70%, respectively. All birds were vaccinated following a program typical of the region, and birds reared on the floor were also vaccinated against coccidiosis. All procedures were approved by the Animal Care Committee of the Agassiz Research Centre and followed guidelines described by the Canadian Council on Animal Care (1993).

Egg production per cage or pen was recorded for 5 d/wk and extrapolated to 7 d. All eggs were weighed on 1 d/wk, and egg mass was calculated from egg production and egg weight. Feed consumption was measured for 1 wk at 10-wk intervals from 20 to 50 wk of age. Feed efficiency was calculated by dividing the feed consumption by the egg mass produced during the time that feed consumption was measured. Individual BW were recorded every 10 wk starting at wk 20. Quality of all eggs produced on 1 d was measured at each of 20, 30, 40, and 50 wk of age. Eggs were stored at 4°C overnight and then broken onto a level surface. The height of the albumen was determined using a standard tripod micrometer after which the yolk was weighed. Shells were washed under running water, dried, and weighed. The albumen weight was calculated by difference. Yolk color was measured with a Roche yolk color fan scale (Roche scale). Mortality was recorded in both regimens over the rearing and laying periods. In floor pens, the

Table 1. Major ingredients and nutrients (%) of diets fed to 4 layer lines in 2 environments

Item	Wk 1 to 8	Wk 9 to 16	Wk 17 to 20	Wk 21 to 30	Wk 31 to 45	Wk 46 to 60
Ingredient						
Corn	35.60	44.32	45.20	51.82	52.52	54.15
Barley	23.00	21.08	9.98	0	0	0.50
Wheat	10.00	11.00	12.00	8.46	10.30	8.00
Canola meal	13.80	14.00	6.40	4.00	5.00	7.50
Meat meal	2.00	0	0	0	0	0
Soybean meal	10.27	5.06	16.25	21.26	17.79	15.08
Calculated nutrients						
ME, kcal/kg	2,800	2,800	2,800	2,800	2,800	2,800
CP	18.5	15.5	17.0	17.5	16.5	16.0
Calcium	1.00	0.92	2.50	4.10	4.20	4.30

Table 2. Egg production of 4 strains kept in cages and floor pens[1]

Item	Hen-day egg production (%)			
	Wk 20 to 30	Wk 31 to 45	Wk 46 to 50	Total
Environment				
Cage	90.8	89.2	72.1[b]	86.7
Floor pens	81.0	87.3	86.6[a]	85.0
SEM	0.01	0.01	0.02	0.01
Strain[2]				
LW	93.0	94.3[a]	71.6[ba]	89.8[a]
LB	92.3	88.4[b]	76.4[a]	87.5[a]
HN	89.3	91.9[ba]	78.4[a]	88.5[a]
Cross	82.9	79.2[c]	66.7[b]	78.3[b]
SEM	0.01	0.02	0.02	0.02
ANOVA	*P*-value			
Environment (Env)	<0.01	NS	<0.05	NS
Strain	<0.01	<0.05	<0.05	<0.05
Env × strain	<0.01	NS	NS	NS

[a–c]Means within main effects without a common letter differ ($P < 0.05$).

[1]Total number of observations was 169 for each measurement.

[2]Strains: LW = Lohmann White; LB = Lohmann Brown; HN = H&N White; Cross = Rhode Island Red male × Barred Plymouth Rock (female).

location of eggs was recorded for 4 consecutive days at 4-wk intervals between 20 and 50 wk of age.

To measure bacterial shell contamination, 12 to 20 eggs were collected from the conventional cages, from the nest-boxes, and from the floor of the floor pens at 38 and 42 wk of age. The eggs were collected into sterile plastic zip-lock bags in sterile conditions. Eggs were washed for 1 min in the same bags using buffered peptone water (EMD Chemicals Inc., Darmstadt, Germany) with 0.5 mL for each egg. The water was transferred and used for serial dilutions. One milliliter of each sample was spread on Petrifilms (3M, St. Paul, MN) specific for the recovery of *Escherichia coli* and coliform bacteria, incubated at 50°C for 48 h, and read at 24 h with verification at 48 h.

Statistical analyses were performed with ANOVA, using PROC GLM of SAS (version 9.1, SAS Institute Inc., Cary, NC). The model used for most data included the effects of environment, strain, age, and the interactions between them. Data on bacterial shell contamination were subjected to log-transformation and analyzed with an ANOVA including the main effects of source of the eggs, strain, age, and all interactions. Duncan's multiple range tests was used to separate group means. For mortality, a contingency chi-square test was performed to compare mortality among strains and between housing systems. A *P*-value <0.05 was considered significant for all analyses.

RESULTS

At wk 20 to 30, a 2-way interaction for environment and strain was significant for hen-day egg production (Tables 2 and 3). In cages, commercial strains (LW, LB, and HN) produced more eggs than the cross. In floor pens, LB and LW hens produced the most eggs and HN hens produced the fewest.

At 20 wk, BW of hens in floor pens was significantly greater than that of hens in cages (Table 4). The BW of the hens increased with age to 40 wk, but by 50 wk, hens in cages lost weight and those in floor pens did not. In a full ANOVA, a 2-way interaction between environment and strain was significant for BW at wk 30, 40, and 50 and is described in Table 3. In both environments, brown egg layers (LB and cross) were heavier than white egg layers (LW and HN), with cross

Table 3. Body weights and hen-day egg production of 4 strains in cages and floor pens[1]

Strain[2]	BW (g)						Wk 20 to 30 hen-day egg production (%)	
	Wk 30		Wk 40		Wk 50			
	Cages	Floor pens	Cages	Floor pens	Cages	Floor pens	Cages	Floor pens
LW	1,547[c]	1,749[b]	1,642[c]	1,850[b]	1,554[c]	1,851[b]	93.4[a]	90.4[ba]
LB	1,794[b]	1,854[a]	1,924[b]	1,945[a]	1,863[b]	1,950[a]	91.8[a]	93.2[a]
HN	1,542[c]	1,632[c]	1,638[c]	1,708[c]	1,570[c]	1,741[c]	93.5[a]	54.9[c]
Cross	1,952[a]	1,879[a]	2,116[a]	1,987[a]	2,101[a]	2,012[a]	82.4[b]	86.9[b]
SEM	2.9	2.6	3.4	2.9	3.9	3.1	0.03	0.02

[a–c]Means within main effects without a common letter differ ($P < 0.05$).

[1]Total number of observations for each measurement varied: 394 to 433 for BW and was 19 (free run) and 150 (cages) for hen-day egg production.

[2]Strains: LW = Lohmann White; LB = Lohmann Brown; HN = H&N White; Cross = Rhode Island Red male × Barred Plymouth Rock (female).

hens being heaviest and HN hens weighing the least. In cages, BW of white egg layers was not different, but in floor pens, LW hens were heavier than HN hens.

There was no significant interaction between environment and strain for feed consumption or feed efficiency (Table 4), and this interaction was dropped from the ANOVA. Strain but not environment influenced the daily feed consumption and feed efficiency. The HN hens ate less than LW, LB, and cross hens, but significantly less than all other strains only at 40 wk. Feed consumption increased from wk 20 to wk 40, and feed efficiency was greatest at wk 30 and 40. At 30 and 40 wk of age the cross hens produced eggs significantly less efficiently than LB or either of the white egg layers.

The strain influenced egg shell weights markedly (Table 5). Eggs from LW and LB hens had similar shell weights, which were heavier than those from eggs from HN and cross hens. A 2-way interaction between environment and age for shell weight was significant. In both environments, shell weight increased with age from wk 20 to 40, but in cages, it decreased at wk 50; in floor pens, no significant difference was found at wk 40 and wk 50 (data not shown). A significant 3-way interaction was found between environment, strain, and age for egg, yolk, and albumen weight, albumen height, and yolk color; another ANOVA was performed (Table 6). In both environments, eggs of LB hens were heavier at wk 20 to 40 than white egg layers and cross hens, except at wk 40, when the egg weight of HN hens was similar to that of LB hens. At wk 40, in floor pens, egg weight for cross hens was not significantly different from that of white egg layers and LB hens. At wk 50, egg weight was not significantly different between any strains in either housing system. Yolk weight from wk 20 to 50 was not significantly different among strains in either environment. At wk 20 in cages, albumen weight was greater for HN hens; in floor pens, it was greater for HN hens and brown egg layers. At wk 40, HN and cross hens in cages had greater albumen weight than LW and LB hens; in floor pens, LW hens had lower albumen weight than other strains. In both cages and floor pens, egg weight and shell and yolk weight increased with age.

As shown in Table 6, albumen height of brown egg layers in cages was not different between wk 30 and 40, and that for white egg layers was not different between wk 40 and 50. In floor pens, only HN eggs differed significantly between wk 20 and 30 and had the lowest albumen height at wk 20 (based on only 9 eggs). Albumen height for all strains decreased as the age increased in both environments. Yolk color for all strains in cages was lowest at wk 30. For white egg layers there was no difference in yolk color between wk 40 and 50, whereas for brown egg strains the difference between these ages was significant. In contrast, in floor pens, eggs from brown egg layers and HN hens had greater yolk color at wk 40 and 50 than at wk 20 and 30. However, LW hens had significantly lower yolk color at wk 50 than at wk 40 and the lowest color at wk 20 and 30.

Table 4. Body weight, feed intake, and feed conversion of 4 strains of layers at 20, 30, 40, and 50 wk of age in cages and floor pens[1]

	BW (g)				Daily feed intake (g)				Feed efficiency (g of feed:g of egg)			
Item	20 wk	30 wk	40 wk	50 wk	20 wk	30 wk	40 wk	50 wk	20 wk	30 wk	40 wk	50 wk
Environment												
Cages	1,541[b]	1,693	1,813	1,754	88.7	105.0	111.3	110.3	2.48	2.32	2.09	1.42
Floor pens	1,576[a]	1,766	1,859	1,875	83.4	104.1	111.2	112.2	2.32	1.85	2.01	2.13
SEM	2.3	3.9	4.5	5.0	0.46	0.62	0.69	0.98	0.024	0.046	0.016	0.060
Strain[2]												
LW	1,390[c]	1,645	1,744	1,706	84.9[b]	102.7[bc]	112.6[a]	111.4	2.39	2.04[b]	2.03[b]	1.52
LB	1,750[b]	1,820	1,934	1,904	95.6[a]	109.2[ba]	114.5[a]	109.0	2.47	2.17[b]	2.08[b]	1.38
HN	1,351[d]	1,588	1,674	1,661	83.6[b]	97.8[c]	104.7[b]	108.1	2.36	1.93[b]	1.84[c]	1.66
Cross	1,824[a]	1,917	2,054	2,057	88.3[b]	111.6[a]	114.0[a]	114.4	2.71	3.12[a]	2.51[a]	1.48
SEM	1.1	1.98	2.3	2.5	0.23	0.31	0.34	0.34	0.011	0.023	0.008	0.030
ANOVA	*P*-value											
Environment (Env)	<0.01	<0.01	<0.05	<0.01	NS	NS	NS	NS	NS	NS	NS	NS
Strain	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	<0.05	NS	NS	<0.01	<0.01	NS
Env × Strain	NS	<0.01	<0.01	<0.01	—	—	—	—	—	—	—	—

[a–d]Means within main effects without a common letter differ ($P < 0.05$).

[1]Total number of observations is 862 for BW, 169 for feed consumption, and 167 for feed efficiency.

[2]Strains: LW = Lohmann White; LB = Lohmann Brown; HN = H&N White; Cross = Rhode Island Red male × Barred Plymouth Rock (female).

Table 5. Egg quality traits of eggs produced by 4 different strains at wk 20, 30, 40, and 50 of age in cages and floor pens[1]

Item	Egg weight (g)	Yolk weight (g)	Shell weight (g)	Albumen weight (g)	Albumen height (mm)	Yolk color
Environment						
Cages	54.3[b]	14.4[b]	5.21[b]	34.8[b]	8.58[a]	5.05[b]
Floor pens	58.6[a]	15.7[a]	5.49[a]	37.4[a]	8.45[b]	6.11[a]
SEM	0.14	0.04	0.02	0.14	0.03	0.02
Strain[2]						
LW	55.8[c]	15.0[b]	5.44[a]	35.5[c]	8.66[a]	5.41[c]
LB	56.6[b]	14.9[cb]	5.45[a]	36.3[b]	8.36[c]	5.70[b]
HN	55.0[d]	14.7[c]	5.27[b]	35.1[c]	8.57[a]	5.26[d]
Cross	59.3[a]	15.8[a]	5.16[b]	38.3[a]	8.46[b]	6.15[a]
SEM	0.19	0.06	0.04	0.09	0.04	0.03
Age						
Wk 20	45.0[d]	9.6[d]	4.38[d]	31.1[c]	9.28[a]	4.89[c]
Wk 30	57.0[c]	14.6[c]	5.36[c]	37.1[a]	8.80[b]	4.79[c]
Wk 40	58.5[b]	16.6[b]	5.70[a]	36.2[b]	8.37[c]	6.31[a]
Wk 50	60.3[a]	17.1[a]	5.51[b]	37.7[a]	7.82[d]	6.10[b]
SEM	0.19	0.06	0.04	0.09	0.04	0.03
ANOVA	*P*-value					
Environment (Env)	<0.05	NS	NS	<0.05	<0.05	<0.01
Strain	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Age	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Env × strain	NS	<0.05	NS	NS	<0.05	NS
Env × age	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Strain × age	<0.01	<0.01	NS	<0.01	<0.01	<0.01
Env × strain × age	<0.05	<0.05	NS	<0.05	<0.05	<0.05

[a–d]Means within main effects without a common letter differ ($P < 0.05$).

[1]Total number of observations for each measurement varied from is 2,506 to 2,515.

[2]Strains: LW = Lohmann White; LB = Lohmann Brown; HN = H&N White; Cross = Rhode Island Red male × Barred Plymouth Rock (female).

Table 6. Egg quality traits produced by 4 different strains[1] at wk 20, 30, 40, and 50 of age in cages and floor pens[2]

	Cages				Floor pens			
Attribute and age	LW	LB	HN	Cross	LW	LB	HN	Cross
Egg weight (g)								
Wk 20	45.2[c]	46.7[b]	44.3[c]	47.5[c]	41.3[c]	43.0[b]	38.7[c]	43.9[c]
Wk 30	55.0[b]	57.4[a]	53.1[b]	59.0[b]	57.9[b]	59.4[a]	55.9[b]	60.9[b]
Wk 40	56.3[b]	57.4[a]	56.3[a]	59.1[b]	58.2[b]	61.0[a]	59.2[a]	62.7[ba]
Wk 50	58.7[a]	58.9[a]	56.0[a]	64.0[a]	61.2[a]	60.8[a]	60.3[a]	63.5[a]
SEM	0.26	0.29	0.26	0.35	0.27	0.25	0.29	0.36
Yolk weight (g)								
Wk 20	9.60[d]	9.99[d]	9.48[d]	9.73[d]	8.75[c]	9.35[c]	9.22[c]	9.21[c]
Wk 30	14.5[c]	14.7[c]	13.9[c]	14.8[c]	14.7[b]	15.1[b]	14.2[b]	15.2[b]
Wk 40	16.1[b]	16.5[b]	15.6[b]	17.8[b]	16.9[a]	16.5[a]	16.6[a]	17.5[a]
Wk 50	16.8[a]	17.2[a]	16.8[a]	18.4[a]	17.3[a]	16.5[a]	17.0[a]	17.9[a]
SEM	0.16	0.17	0.14	0.19	0.13	0.18	0.16	0.19
Albumen weight (g)								
Wk 20	31.1[c]	32.2[c]	30.3[b]	33.5[c]	28.5[c]	29.5[b]	25.6[b]	30.9[b]
Wk 30	35.3[ba]	37.3[a]	34.1[a]	39.0[a]	37.2[a]	38.6[a]	36.3[a]	40.6[a]
Wk 40	34.2[b]	35.1[b]	35.2[a]	35.6[a]	35.5[b]	38.7[a]	37.7[a]	40.1[a]
Wk 50	36.7[a]	36.6[ba]	34.1[a]	40.1[a]	38.3[a]	38.4[a]	37.7[a]	40.1[a]
SEM	0.58	0.57	0.52	0.65	0.52	0.48	0.44	0.69
Albumen height (mm)								
Wk 20	9.6[a]	9.3[a]	9.4[a]	9.7[a]	8.9[a]	8.7[a]	7.2[c]	8.7[ba]
Wk 30	8.9[b]	8.3[b]	8.9[b]	8.5[b]	9.1[a]	8.6[a]	8.9[a]	8.9[a]
Wk 40	8.2[c]	8.3[b]	8.3[c]	8.3[b]	8.5[b]	8.3[b]	8.6[a]	8.4[b]
Wk 50	7.9[c]	7.5[c]	7.9[c]	7.7[c]	7.9[c]	7.7[c]	7.9[b]	7.5[c]
SEM	0.04	0.05	0.05	0.06	0.04	0.05	0.07	0.06
Yolk color								
Wk 20	4.6[b]	4.9[c]	4.7[b]	5.2[c]	5.3[c]	5.3[b]	5.6[b]	5.1[b]
Wk 30	4.1[c]	4.4[d]	4.1[c]	4.4[d]	5.3[c]	5.3[b]	5.2[b]	5.6[b]
Wk 40	5.3[a]	6.2[a]	5.3[a]	6.7[a]	6.7[a]	7.0[a]	6.1[a]	7.8[a]
Wk 50	5.4[a]	5.6[b]	5.2[a]	5.9[b]	6.3[b]	6.9[a]	6.1[a]	7.4[a]
SEM	0.03	0.04	0.03	0.06	0.05	0.05	0.06	0.08

[a–d]Means within main effects without a common letter differ ($P < 0.05$).

[1]Strains: LW = Lohmann White; LB = Lohmann Brown; HN = H&N White; Cross = Rhode Island Red male × Barred Plymouth Rock (female).

[2]Total number of observations for each measurement varied from is 202 to 359.

Table 7. Percentage mortality of 4 strains during rearing and laying period in conventional cages and floor pens

	Rearing period		Laying period	
Strain[1]	Cages	Floor pens	Cages	Floor pens
LW	4.32[a]	2.82[a]	10.8[x]	3.33[y]
LB	2.16[ab]	30.5[b,y]	15.8[x]	1.67[y]
HN	0.00[b]	2.16[a]	13.3[x]	5.71[y]
Cross	4.26[ab]	6.06[a]	7.78	3.45

[a,b]Means within main effects without a common letter differ ($P < 0.05$).

[x,y]Means between main effects of two housing systems without a common letter differ ($P < 0.05$).

[1]Strains: LW = Lohmann White; LB = Lohmann Brown; HN = H&N White; Cross = Rhode Island Red male × Barred Plymouth Rock (female).

Mortality during the rearing period in cages was greater for LW hens than for HN hens (Table 7). In floor pens, mortality of LB hens was significantly greater than that of LW, HN, and cross hens. Only LB hens differed in mortality between housing systems. During the laying period, there was no difference among the strains, but mortality was greater in the cages than in floor pens for all strains except cross hens.

The LW and HN hens laid 88 and 75% of their eggs in nest-boxes, respectively, whereas LB and cross hens, respectively, laid 48 and 50% of their eggs on the floor, most under the nest-box and in the corners near the nest-box (Figure 1).

No interactions between main effects for bacterial shell contamination were found and they were dropped from the ANOVA (Table 8). Eggs from cages had lower *E. coli* and coliform contamination than those from nests and the floor. Contamination with *E. coli* was greater for LB eggs than for LW eggs. No strain difference was found for coliform contamination. Contamination with both bacteria was greater at 42 wk than at 38 wk.

Table 8. Log_{10} count of *Escherichia coli* and coliform microorganisms in caged eggs, nest-box, and floor eggs among 4 strains during 38 and 42 wk of age

Item	*E. coli*	Coliform
Origin of eggs		
Cage	1.89[b]	1.66[b]
Nest	4.76[a]	4.56[a]
Floor	4.99[a]	4.39[a]
SEM	0.26	0.35
Strain[1]		
LW	3.38[b]	3.04
LB	4.42[a]	4.19
HN	3.89[ba]	3.46
Cross	3.82[ba]	3.45
SEM	0.29	0.41
Age		
Wk 38	3.38[b]	3.04[b]
Wk 42	4.46[a]	4.12[a]
SEM	0.21	0.29

[a–d]Means within main effects without a common letter differ ($P < 0.05$).

[1]Strains: LW = Lohmann White; LB = Lohmann Brown; HN = H&N White; Cross = Rhode Island Red male × Barred Plymouth Rock (female).

DISCUSSION

Growing consumer demand has led to cage-free methods of poultry production, including free-run systems (Savory, 2004), which allow expression of a greater be-

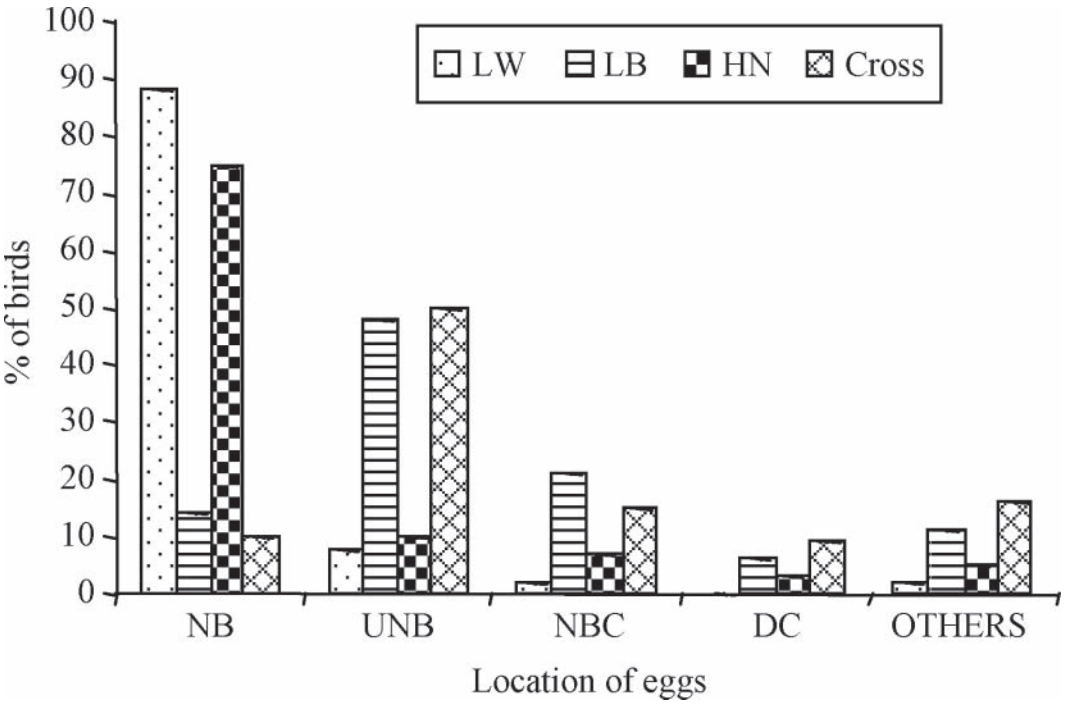

Figure 1. Location of eggs laid by 4 strains in floor pens. NB = nest-box; UNB = under nest-box; NBC = nest-box corner; DC = door corner; LW = Lohmann White; LB = Lohmann Brown; HN = H&N White; Cross = Rhode Island Red male × Barred Plymouth Rock (female).

havioral repertoire compared with conventional cages (McLean et al., 1986). However, the effect of changing from conventional cages to other systems on production traits requires investigation, especially in relation to the ability of different strains of chickens to adapt to these alternate systems.

In this study, egg production of white egg and brown egg commercial hens was similar, likely because intensive selection of commercial brown egg layers has brought their production to similar levels as those of white egg strains (Scott and Silversides, 2000). Although both parental lines of the cross hens have very good egg production (Silversides et al., 2007), they have not been selected intensively and a lower level of production than industrial layers could be expected. Early egg production of HN hens was low in floor pens, but not in cages, possibly because maturity was delayed for this strain in this environment.

At 20 wk, birds kept on the floor were heavier than caged birds and they laid larger eggs at least partly because BW and egg weights are positively correlated (Siegel, 1962). Heavier birds in the floor pens could be attributed to better physical condition (our unpublished data). Vits et al. (2005) also found greater egg weights in floor pens than in conventional cages, in contrast to the findings of Yakabu et al. (2007) who found that eggs from conventional cages were larger than those from floor pens. Brown egg layers were heavier and laid larger eggs with greater egg, yolk, and albumen weights than white egg layers, which is in general agreement with Scott and Silversides (2000). In floor pens but not cages, HN hens weighed less than LW hens, possibly because this strain used the increased space more effectively for physical activity.

In this study, we found that shell weights of LW and LB eggs were different from those of HN and cross eggs, which is not surprising because different strains of laying hens vary significantly in egg shell quality (Curtis et al., 1985). Only minor increases were seen in the shell weight with age in both environments because the hens have difficulty producing an increased amount of egg shell at an older age (Joyner et al., 1987). However, late in production the shells were better in floor pens than in cages likely because increased activity may benefit calcium metabolism.

At the start of lay, earlier egg production in cages led to heavier eggs, especially for HN hens. Egg weight is genetically linked to the shell, albumen, and yolk weights although each has different heritabilities. In this study, the major factor contributing to egg weight was the yolk, although heritability for yolk weight is lower (Washburn, 1979) than those for shell and albumen weights. Basmacioglu and Ergul (2005) also found greater yolk, shell, and albumen weights in floor pens than in cages, although Pištěková et al. (2006) found no influence of housing systems on yolk weight.

The housing systems did not influence feed consumption or feed efficiency. The HN hens ate less than LW and the brown egg layers. Feed efficiency was best for HN hens, possibly because of genetic differences in physical activity, physical condition, basal metabolic rate, body temperature, and body composition (Luiting, 1990). As the hens aged, feed intake increased, with a corresponding increase in BW. Body weights of selected lines of chickens are associated with appetite (McCarthy and Siegel, 1983), and changes in feed intake and feed efficiency that correspond to changes in BW have been clearly demonstrated in other studies (Barbato et al., 1983; Marks, 1991).

Mortality is an important indicator of poor welfare (LayWel, 2006). Greater rearing period mortality in floor pens was because LB hens had very high mortality, although no major cause was diagnosed. Greater mortality in cages during the laying period was distributed between the strains. Tauson and Abrahamsson (1999) found overall greater mortality of LB hens in floor pens than in cages, largely related to feather pecking, with no difference between housing systems for Lohmann Selected Leghorn hens.

Lower albumen height in eggs from floor pens than that in cages may be due in part to their exposure to ammonia (from litter), which affects albumen quality (Roberts, 2004). A similar housing effect was found by Süto et al. (1997). Albumen height was greater in white eggs than in brown eggs and decreased with age in both environments, similar to the results of Silversides et al. (2006), who studied commercial strains housed in cages. In contrast, Curtis et al. (1985) found better albumen quality in brown eggs than white eggs (using different strains than described here).

Yolk color was greater for eggs from floor pens than for eggs from cages. The main contributing factor for yolk color is the diet (Leeson and Summers, 1991), and although the hens were all fed the same diet, there was a difference in yolk color between commercial and noncommercial layers. This could possibly be because of the dilution effect of greater egg production by commercial layers, and the difference between commercial lines could be attributed to genetic variation unrelated to productivity (Hocking et al., 2003). Differences in the yolk color among strains at different ages could be caused by access to litter in the floor pens. Süto et al. (1997) and Pištěková et al. (2006) both found greater yolk color in floor pens than in cages, but provided no potential reason for the difference.

Nest-boxes were provided in the floor pens, but LB and cross hens used them poorly compared with LW and HN hens, in contrast to studies on nest-box usage (Smith et al., 1990; Duncan, 1992; Ekstrand and Keeling, 1994) that found them to be very important. Reed (1994) and Walker and Hughes (1998) found that design and location of the nest-box is important, but our nest-boxes were commercially produced and provided 2 levels at the same level as the perches. Our results show that not all strains are highly motivated to use nest-boxes.

Lower bacterial contamination in caged eggs was because the eggs were separated from excreta by the

wire floor, whereas floor eggs and those from nest boxes were in contact with litter containing excreta. Quarles et al. (1970) also found that eggs from hens kept on litter floors had greater bacterial contamination than those laid in rollaway nest-boxes. Eggshell contamination increased with age, likely because litter quality deteriorated with time.

This study found interactions between environments, strains, and ages on hen-day egg production, BW, and egg quality over a period of time, suggesting that strain should be considered when using alternative housing systems. Our conclusions can only be applied to the 4 strains and 2 housing systems studied, but suggest the need for further studies on strain and environment interactions.

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