Effect of housing system on the calcium requirement of laying hens and on eggshell quality

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ABSTRACT: The effects of housing systems on the calcium requirement for eggshell production, eggshell quality and on the breaking strength of the hen's tibia were evaluated. Unenriched cages (UN) (24 laying hens), enriched cages (EN) (16 laying hens) and floor system (FS) (24 laying hens) were used in this experiment. The eggshell production of laying hens from 19 to 66 weeks of age was higher ($P < 0.01$) in the cage systems (UN 39.6 g/hen/week and EN 39.2 g/hen/week) than it was in FS (35.0 g/hen/week). Consequently, the amount of calcium deposited in the eggshells (g/hen/week) was higher ($P < 0.01$) in the cage systems (14.2 and 14.0 g/hen/week) than in FS (12.6 g/hen/week). Despite of the same calcium intake of the hens housed in EN and FS the eggshell thickness (0.39 and 0.38 mm, respectively) and eggshell strength (38.04 and 36.43 N respect.) were higher ($P < 0.01$ and $P < 0.001$ respectively) in EN. The tibia breaking strength was higher ($P < 0.05$) in FS (156.6 N) in comparison with UN (92.7 N). The rate of calcium intake deposited in the eggshells was higher in the cage systems than in FS, namely by 1.7 to 8.9% depending on the age of laying hens. When determining the correct calcium requirements in the diets of laying hens, the housing system should be taken into account.

Keywords: enriched cage; unenriched cage; floor system; eggshell production; Ca requirement

Calcium plays a very important role in the nutrition of commercial laying hens not only because of eggshell quality but also because of bone quality. Bone breakages are an important welfare problem in laying hens and there is strong evidence that genetic variation exists for osteoporosis (Bishop et al., 2000). The results of Hocking et al. (2003) suggest that by selection for higher rates of lay and greater persistency whilst maintaining egg quality, breeders have inadvertently predisposed the commercial laying stock to bone-related damage. They found that commercial lines had very weak bones compared with traditional lines. And conversely, they found relatively low genetic variation for the eggshell strength. Vits et al. (2005b) also found a significantly higher strength of the humerus in brown hens (laying brown eggs) than in white hens (laying white eggs). Although selection for the enhanced bone strength can be used as a long-term strategy for alleviating the problems of osteoporosis in laying hens (Bishop et al., 2000), the housing system also has a significant effect on the bone strength (Vits et al., 2005b). In conventional cages the movement of laying hens is very restricted. Newman and Leeson (1998) and Knowles and Broom (1990) reported that the bone breaking strength was found to be lower in the laying hens housed in conventional cages than in the laying hens housed in alternative systems such as aviary or floor systems. A larger area in cages as well as different equipment in cages can improve the strength of the bones (perches, sand baths, nests) (Abrahamsson et al., 1996; Barnett et al., 1997).

The quality of the bones of laying hens is probably affected by laying intensity and by eggshell production. Abrahamsson et al. (1995) and Abrahamsson and Tauson (1997) reported that the egg production of hens in furnished cages is comparable with that in conventional cages. Conversely, the egg production of hens housed in conventional cages was higher than that of hens housed in alternative systems (Tauson et al., 1999). Because the housing systems affect the egg production, the requirements for nutrients should also be different in different housing systems. The opinions concerning calcium requirements are different (NRC, 1994), Zelenka et al. (1999) or Leeson and Summers (2005). According to Leeson and Summers (2005) the content of Ca should increase with age, which is known, but there are not any studies evaluating the requirement for Ca in different housing technologies.

The aim of the study was to determine the calcium requirements for eggshell production in different housing systems with regard to the age of laying hens. The aim was also to evaluate the effect of housing systems on the tibia strength with regard to the eggshell production.

MATERIAL AND METHODS

Unenriched cages (24 laying hens), enriched cages (16 laying hens) and floor system (24 laying hens) were used in this experiment. In unenriched cages laying hens were housed two hens per cage (550 cm^2/hen), in enriched cages they were housed 2 × 8 hens and in the floor system there was one group of 24 laying hens. The birds were selected in the 15th week of age according to live weight (1 300 ± 10 g). All housing systems met the demands of EU Directive 1999/74/ EC. However, in enriched cages the dust bath was not used. ISA Brown laying hens (Hendrix Genetics) were housed in these systems from 19 to 66 weeks of age. The laying hens were all housed in the same air-conditioned facility. Light was provided for 16 h per day from 04:00 h to 20:00 h. The hens were fed *ad libitum*. In unenriched cages the diet was based on wheat, thermally treated soya and soybean meal. In enriched cages and in the floor system the diet was based on wheat, soybean meal, fish meal and maize. Both diets were isonitrogenous and isoenergetic. The content of calcium was almost the same in both diets (36.8 g/kg and 34.4 g/kg, respectively). The composition and nutrient contents of the diets are shown in Table 1.

Table 1. The composition and the characteristics of the diets

	Unenriched cage	Enriched cage floor system
Composition (g/kg)		
Wheat	684	295
Full-fat thermally treated soya	100	0
Soybean meal	108	170
Maize	0	400
Fish meal	0	31
Premix[1]	108	104
Content of nutrients (g/kg)		
Dry matter	863.50	875.00
AME_N (MJ/kg)	11.06	11.11
Crude protein	172.20	170.70
Calcium	36.80	34.40
Phosphorus	6.38	6.35
Sodium	1.51	1.23
Ash	109.30	102.00

[1]premix contained 82% of fine limestone

the premix supplemented per 1 kg of diets the following amounts of nutrients: Cu = 4.94 mg; Fe = 142.8 mg; Zn = 60.4 mg; Mn = 59.9 mg; Co = 0.24 mg; I = 3.57 mg; Se = 0.44 mg; retinol = 3.3 mg; cholecalcipherol = 0.05 mg; tocopherol = 25.2 mg; menadione = 2.2 mg; thiamine = 2.24 mg; riboflavin = 7.85 mg; niacin = 25.1 mg; folic acid = 1.05 mg; calcium pantothenate = 9.8 mg; choline = 508.8 mg; L-lysine = 44 mg; DL-methionine = 773.6 mg; L-threonine = 39.6 mg

The content of nutrients was analyzed according to **Ordinance No. 124/2001 (2001)**. The eggs were collected and weighed each day during the experimental period. Feed consumption was measured at weekly intervals. The quality of eggshells was analyzed every 28 days by determining the strength, thickness (the average of both ends and in the middle), dry eggshell weight and eggshell weight ratio. The strength of the eggshells (N) was measured manually by a destructive method with an egg crusher (Veit Electronics, CZ). Eggs were compressed between two parallel plates by a steadily increasing load until they cracked. The force was measured vertically to the axis. The thickness was evaluated as the average of both ends and in the middle including shell membranes with a micrometer (TSS, England). The feed and the eggshells were analyzed for calcium content by atomic absorption spectrometry according to Ordinance No. 124/2001 (2001). The amount of calcium deposited in the eggshells during the whole experimental period for each housing system was calculated on the basis of egg weight and egg production, eggshell weight ratios and calcium content in the eggshells. Mathematical Yang's model (Yang and McMillan, 1989) was used for the calculation of the amount of calcium deposited in the eggshell in each housing system. The amount of calcium deposited in the eggshells was expressed by the equation

$$y = a \times e^{(-b \times t)}/(1 + e^{-c \times (t - d)})$$

where:
a = scale parameter
b = rate of a decrease in laying intensity
c = indicator of the variation in sexual maturity
d = mean age of the sexual maturity of hens
t = week of production

The requirement of calcium for eggshell production depending on the age of laying hens was estimated. The proportion of calcium intake deposited in the eggshells was also calculated for each housing system depending on the laying hen age. In the 67th week of laying age, the laying hens were slaughtered, both tibias of each hen were prepared, they were put to a physiological solution (1.0% NaCl) and on the same day the strength of tibia was measured by a three-point bending test (Crusher,VEIT Electronics, Brno, Czech Republic).

Data were analysed by the one-way analysis of variance (ANOVA) using the software package Unistat 5.1 (Unistat Ltd., England). Tukey's HSD was used as the *post hoc* test for all possible pairwise comparisons within groups.

RESULTS AND DISCUSSION

The laying intensity was significantly lower ($P < 0.05$) in the floor system (78.6%) in comparison with unenriched (86.9%) and enriched (87.2%) cages.

The composition of the diets was a little different, but the diets were nearly isoenergetic and isoni-

Table 2. The effect of housing systems on calcium intake and output and on eggshell quality from 19 to 66 weeks of age

	n*	Unenriched cage	Enriched cage	Floor system	P-values
			average ± SE		
Feed intake (g/d)	48	124.1^{b} ± 1.49	117.7^{a} ± 1.34	121.6^{ab} ± 2.44	<0.050
Calcium intake (g/d)	48	4.6^{b} ± 0.05	4.0^{a} ± 0.05	4.2^{a} ± 0.08	<0.001
Eggshell production (g/hen/week)	48	39.6^{b} ± 0.98	39.2^{b} ± 1.05	35.0^{a} ± 1.03	<0.010
Output of calcium in eggshells (g/hen/week)	48	14.2^{b} ± 0.37	14.0^{b} ± 0.39	12.6^{a} ± 0.38	<0.010
Egg weight (g)	336	64.6^{ab} ± 0.49	62.8^{a} ± 0.54	64.9^{b} ± 0.63	<0.050
Eggshell weight (g)	120	6.80^{b} ± 0.047	6.41^{a} ± 0.038	6.48^{a} ± 0.037	<0.001
Eggshell weight ratio (%)	120	9.76^{a} ± 0.035	10.19^{b} ± 0.051	10.10^{b} ± 0.054	<0.001
Eggshell thickness (mm)	120	0.39^{b} ± 0.004	0.39^{b} ± 0.002	0.38^{a} ± 0.003	<0.010
Eggshell strength (N)	120	40.05^{c} ± 0.371	38.04^{b} ± 0.25	36.43^{a} ± 0.331	<0.001
Tibia strength (N)	20	92.7^{a} ± 7.75	131.4^{ab} ± 13.12	156.6^{b} ± 24.1	<0.050

*number of observations

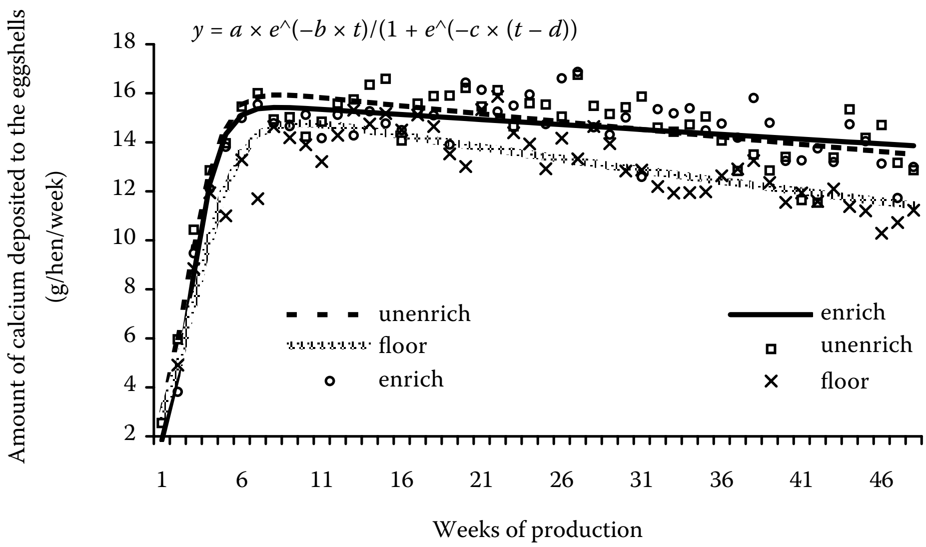

Figure 1. The effect of housing system on the amount of calcium deposited in the eggshells (g/hen/week) from 19 to 66 weeks of age

trogenous. Although the analyzed Ca content was a little higher in the diet for hens in unenriched cages (36.8 g/kg) than in the diet for hens in enriched cages and floor system (34.4 g/kg), the main source of calcium was the same in both diets (fine limestone). Neither Chandramoni et al. (1998), who used Ca levels 32.5 and 36.0 g/kg, found a significant effect of the Ca level on the eggshell quality (shell weight and shell weight per unit surface area) nor Leeson et al. (1993), who used 3.4 and 3.8% of calcium, observed any significant differences in the eggshell deformation between the diets nor Rao et al. (2003), who used 32.5, 35.0, 37.5, 40.0, 42.5 and 45.0 g/kg, observed any improvement in the eggshell quality (shell weight, eggshell thickness). Rao et al. (2003) also reported that Ca levels higher than 32.5 g/kg diet had no effect on the tibia breaking strength.

The parameters of the hen's feed and calcium intake, calcium output and the quality of the eggshells, as well as the tibia breaking strength in each housing system are shown in Table 2. The feed intake was significantly higher ($P < 0.05$) in unenriched cages in comparison with the feed intake in enriched cages. Consequently, the intake of calcium was significantly higher ($P < 0.001$) in comparison with enriched cages and floor system. Due to significantly higher ($P < 0.01$) eggshell production (g/hen/week) in cage systems than in the floor system the output of calcium in the eggshells was also significantly higher ($P < 0.01$) there. The eggshell production was almost the same in both cage systems. Guesdon and Faure (2004) and Vits et al. (2005a) also reported that the type of cage did not affect the laying rate, which consequently means eggshell production. The weekly amount of calcium deposited in the eggshells (g/hen/week) is shown in Figure 1 for each housing system from 19 to 66 weeks of age. The amount of calcium

Table 3. The parameters of the equations expressing the amount of calcium deposited in the eggshells (Figure 3)

Parameter	Unenriched cage	Enriched cage	Floor system
	average ± SE		
a	16.59 ± 0.405	15.81 ± 0.373	15.97 ± 0.490
b	0.004 ± 0.0008	0.003 ± 0.0008	0.007 ± 0.0011
c	0.93 ± 0.139	1.11 ± 0.170	0.71 ± 0.107
d	2.59 ± 0.168	2.82 ± 0.151	3.13 ± 0.221
R^2	0.862	0.887	0.861

$y = a \times e^{(-b \times t)}/(1 + e^{-c \times (t - d)})$

t = week of production; a = scale parameter; b = the rate of a decrease in laying intensity; c = indicator of the variation in sexual maturity; d = the mean age of the sexual maturity of hens

Table 4. The requirements for calcium for eggshell production depending on hens' age and the real intake of calcium in cage and floor systems

Age (weeks)	Unenriched and enriched cages			Floor system		
	Ca requirement for shell production (g/hen/day)	Ca intake (g/hen/day)	Ca shell:Ca intake ratio (%)	Ca requirement for shell production (g/hen/day)	Ca intake (g/hen/day)	Ca shell:Ca intake ratio (%)
>22	1.80	3.78	47.6	1.75	4.52	38.7
23–33	2.24	4.42	50.7	2.12	4.61	46.0
34–44	2.19	5.02	43.6	2.03	4.85	41.9
45–55	2.11	4.83	43.7	1.88	4.62	40.7
56–66	2.03	4.59	44.2	1.74	4.47	38.9

deposited in the eggshell was determined using mathematical Yang's model (Yang and McMillan, 1989) and it is expressed by the equation

$$y = a \times e^{(-b \times t)}/(1 + e^{-c \times (t - d)})$$

The parameters for each equation for each housing system are shown in Table 3. The R^2 of all equations was in the range from 0.861 to 0.887. The amount of calcium deposited in the eggshells was very similar in both cage systems but was lower in the floor system during the experimental period. Based on the results, the requirement for calcium for eggshell production (depending on the age of laying hens) was estimated for the cage systems (unenriched and enriched together) and for the floor system. The requirements for calcium together with real calcium intake and the proportion of calcium deposited in the eggshells from calcium intake are shown in Table 4. The Ca shell:Ca intake ratio was the highest from 23 to 33 weeks of age and then the ratio decreased in both housing systems. Also the requirement for calcium at this age is the highest, and then it slowly decreases.

Although the eggshell weight ratio was significantly lower ($P < 0.001$) in the hens housed in unenriched cages, the eggshell strength was significantly the highest ($P < 0.001$) in this housing system. The eggshell thickness was the same in the cage systems and it was significantly higher ($P < 0.01$) than in the floor system. These findings do not agree with the hypothesis of Vits et al. (2005a), who stated that hens laying more eggs with only slightly higher feed consumption have less calcium available for the eggshell formation, which could have led to inferior eggshell quality. In the present investigation the calcium intake was almost the same in enriched cages and in the floor system but the eggshell production was significantly higher ($P < 0.01$) in cages and also eggshell thickness and strength were significantly higher in enriched cages than in the floor system.

The eggshell strength in unenriched cages was significantly higher ($P < 0.001$) than in enriched cages, but Guesdon et al. (2006) reported that the eggshell quality (index and breaking strength) was only slightly influenced by the cage type.

The breaking strength of the tibia was only slightly higher in the hens kept in enriched cages than it was in the hens living in unenriched cages. But Vits et al. (2005b) reported the significantly higher breaking bone strength of hens housed in enriched cages in comparison with the hens housed in unenriched cages. Guesdon et al. (2004) and Leyendecker et al. (2005) did not observe any significant improvement of humeral or tibia (respectively) quality in hens housed in furnished cages compared to unenriched cages. The breaking strength of the tibia was significantly lower ($P < 0.05$) in the hens housed in unenriched cages in comparison with those in the floor system. Vits et al. (2005b) also observed the higher breaking strength in hens housed in furnished cages in comparison with those in conventional cages. Probably the increased exercise in alternative housing systems leads to an improvement of bone strength as Fleming et al. (1994) reported. Webster (2004) noted that hens in housing systems that promote physical activity tend to have less osteoporosis and rarely manifest the cage layer fatigue.

The relationship between total eggshell production and strength of tibia is shown in Figure 2. The highest total eggshell production was in unenriched

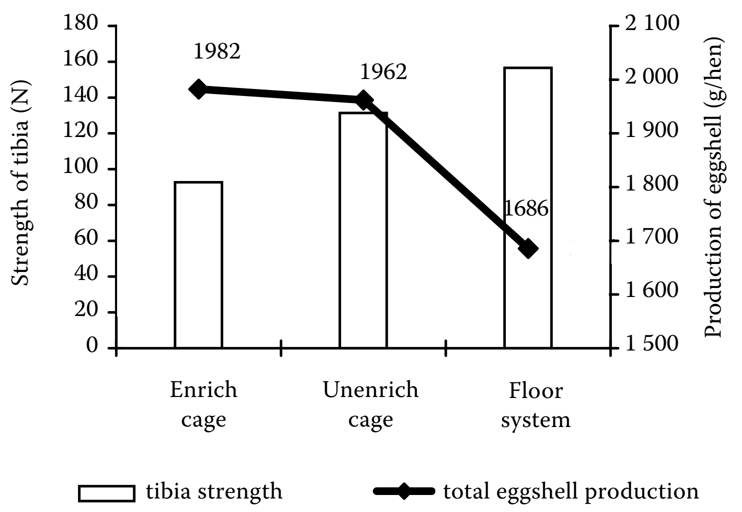

Figure 2. The effect of housing system on the strength of tibia (N) and on eggshell production during the experimental period (g/hen)

cages but the strength of tibia was the lowest there. By contrast, the lowest total eggshell production was found in the floor system but the strength of tibia was the highest there. In enriched cages the total eggshell production and also the breaking strength of the tibia reached the middle values. Figure 3 shows the relationship between tibia strength and eggshell strength. Although the eggshell production in hens kept in the floor system was significantly lower ($P < 0.01$) than in the cage systems, the strength of the eggshell was the lowest there ($P < 0.001$). In the cage systems, calcium was more effectively utilized by the hens for eggshell production and its quality compared to the floor system (shown also in Table 4 – Ca shell: Ca intake ratio).

The hens with the highest requirement for calcium were those in unenriched cages because of the highest eggshell production and also because the eggshell quality was the highest in this system. But the strength of the tibia was the lowest there. When determining the correct calcium requirements in the diets of laying hens, the housing system should be taken into account. Despite similar calcium intake in hens in enriched cages and in the floor system, a lower proportion of this calcium was deposited in the eggshells in the floor system. The hens were overfed calcium in this system. Enriched cages improved the strength of the tibia and the performance of these laying hens was comparable with hens housed in unenriched cages. Extra movement can improve the bone quality (enriched cages vs. unenriched cages), but the higher bone quality can be caused also by lower eggshell production (cages vs. floor system).

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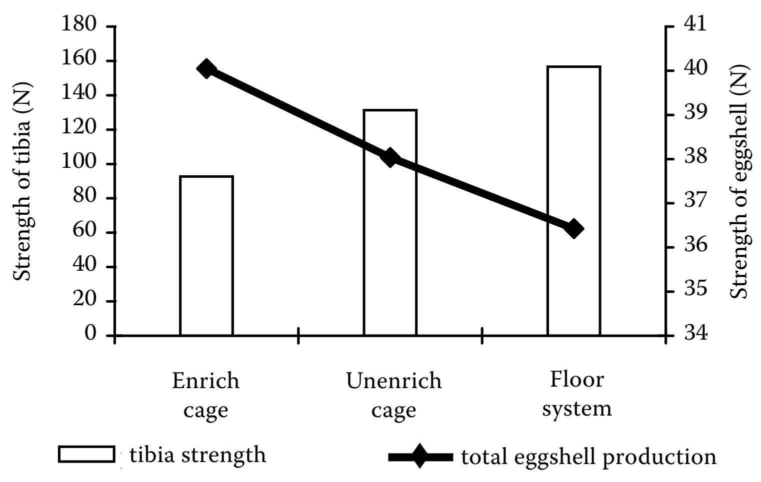

Figure 3. The effect of housing system on the strength of tibia and on the strength of eggshell from 19 to 66 weeks of age

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