British Poultry Science Volume 46, Number 5 (October 2005), pp. 536–544

Keeping laying hens in furnished cages and an aviary housing system enhances their bone stability

M. LEYENDECKER, H. HAMANN, J. HARTUNG[1], J. KAMPHUES[2], U. NEUMANN[3], C. SÜRIE[4] AND O. DISTL[1]

Institute of Animal Breeding and Genetics, [1]Institute of Animal Hygiene and Animal Welfare, [2]Institute of Animal Nutrition, [3]Clinic for Poultry and [4]Farm for Education and Research in Ruthe, University of Veterinary Medicine Hannover, Hannover, Germany

Abstract 1. Tibia and humerus breaking strength of Lohmann Silver hybrids kept in conventional cages, furnished cages and an aviary with outdoor run were examined in two production cycles. Each trial lasted a full laying period; feeding, management and healthcare were identical for all hens. In both trials bone strength was investigated at the end of laying months 6, 9 and 14.

2. The objective was to determine if bone strength increases when hens are kept in alternative housing systems, especially in furnished cages, and whether hen age affects bone stability.

3. The results indicated that housing system influenced bone breaking strength, which was consistently higher for hens in the aviary compared to hens in conventional and furnished cages. Furthermore, humerus breaking strength was higher for hens in furnished cages compared to conventional cages. No significant difference regarding tibia breaking strength was found between conventional and furnished cages.

4. Our results showed that lack of exercise contributed to the problem of weak bones more than did calcium depletion from eggshell formation.

5. Tibia breaking strength increased during the last third of the production cycle, whereas humerus breaking strength remained unaffected by hen age.

6. Genetic group affected only tibial bone breaking strength, which was lower overall in genetic group A than in group B, which in turn was lower than group C.

7. The increased bone strength in the aviary and in the furnished cages probably reduced the incidence of recently broken bones in these systems compared to the conventional cages. This increase in bone strength can be regarded as an improvement in welfare. Furnished cages, like the aviary system, might be considered an alternative housing system for laying hens, because both resulted in enhanced bone strength.

INTRODUCTON

In the last 15 years conventional cages for laying hens have been intensely criticised in the European Community, because they provide a barren environment which restricts the birds' movement and prevents them from performing natural behaviours such as nesting, perching and sand bathing (Duncan and Fraser, 1997). Another major issue in this dispute was the fact that the conventional cage, with its limited space, leads to brittle bones and bone breakage, which can result in death (McCoy *et al.*, 1996). This is assumed to be due to the development of osteoporosis (Wilson *et al.*, 1992). Whitehead (2000) defines osteoporosis in laying hens as a decrease in the proportion of fully mineralised structural bone, leading to increased fragility and susceptibility to fracture. High continuous egg production (Cransberg *et al.*, 1998), reduced mobility (Nightingale *et al.*, 1972) as well as nutritional deficiencies of calcium, phosphorus or cholecalciferol (Wilson and Duff, 1991) can induce osteoporosis.

Modern laying hybrids kept in conventional cages have a high prevalence of bone fractures (Fleming *et al.*, 1994). These fractures can occur during the laying period as well as during depopulation, transport and handling at slaughter. The weakness of the bones of hens

Correspondence to: Professor O. Distl, Institute of Animal Breeding and Genetics, University of Veterinary Medicine Hannover, Bünteweg 17p, 30559 Hannover, Germany. Tel: +49-511-953-8875. Fax: +49-511-953-8582. E-mail: ottmar.distl@tiho-hannover.de
Accepted for publication 11th May 2005.

ISSN 0007–1668(print)/ISSN 1466–1799(online) © 2005 British Poultry Science Ltd
DOI: 10.1080/00071660500273094

kept in conventional cages is estimated to be mainly due to the limited opportunity to exercise. Several studies over nearly 25 years have shown a consistently higher incidence of bone fragility in caged laying hens compared to that of hens kept in alternative housing systems, where the hens were allowed to exercise more (Fleming *et al.*, 1994; Van Niekerk and Reuvekamp, 1994; Leyendecker *et al.*, 2001). The extent of the problem is shown by the fact that recent studies of caged hens indicate that up to 35% of the losses during the laying period were attributable to bone weakness (McCoy *et al.*, 1996).

In response to welfare concerns a new EU directive (CEC, 1999) was issued in 1999 which bans conventional cage systems from the year 2012 onwards in all European Union countries. This new legal situation has inspired the development and testing of new egg production systems. Compared to conventional cages, these alternatives are intended to improve the welfare of laying hens. Various comparisons of laying hens kept in different alternative housing systems have been carried out with respect to welfare, in particular bone breaking strength. Aviaries are an acceptable alternative with regard to improved bone breaking strength, because they provide more space for locomotor activities such as running, wing flapping and flying, and allow the birds to perform natural behaviours such as nesting, perching and sand bathing. Another approach to alleviate the problems of conventional cages is to keep the birds in furnished cages. One of the aims of the furnished cage designs was to enhance hens' opportunity for exercise and so improve bone strength. In this system hens' bone breaking strength is reported to be higher than in conventional cages (Abrahamsson *et al.*, 1996; Abrahamsson and Tauson, 1997). Even modifications to conventional cages such as adding perches to the cage have been shown to improve bone strength (Tauson, 1984). On the basis of the increased bone strength of hens kept in cages with perches and its positive effects on health, one would expect furnished cages to bring some improvement in this respect.

The aim of our study was to compare the bone breaking strength of Lohmann Silver hybrids (LS) housed throughout two full laying periods in conventional cages, furnished cages and an aviary with outdoor run kept under identical management conditions and feeding regimes. The hypotheses being tested were that keeping laying hens in alternative housing systems will result in increased bone strength and that the bone stability of hens in furnished cages will be similar to that of hens in the aviary. Because all three housing systems were located at our experimental and teaching farm at Ruthe in one unit and under the supervision of the same staff, we equalised different management practices and all other farm effects between housing systems, so that any differences would be attributable to housing system.

MATERIALS AND METHODS

Housing conditions

All three different housing systems were installed in parallel in the same experimental building. The conventional cages consisted of a block of double-decker cages (model 'Eurovent', Big Dutchman) three tiers high, with solid side partitions and horizontal metal bars in the rear; the droppings were automatically removed on conveyor belts. Each cage accommodated 4 hens, with 688 cm^2 of floor space (50·2 cm × 55·0 cm) per hen, and with 45 cm height at the front and 39 cm height at the back of the cage. Automatic chain feeders supplied feed from a trough at the front of the cage and water was provided from nipple drinkers.

The furnished cages consisted of a block of double-decker cages (model 'Aviplus', Big Dutchman), which were installed in three tiers. A furnished cage had solid side partitions and horizontal metal bars in the rear and the droppings were automatically removed on conveyor belts. Each furnished cage (120 cm wide, 63 cm deep, 45 cm height at the front and 51 cm height at the back of the cage) was equipped with perches, a family nest and a sand bath, with 10 hens sharing a cage. Thus, every hen had access to 609 cm^2 cage surface area, 150·8 cm^2 nest area and 120 cm^2 sand bath area. The nest box (1508 cm^2) was located in the bottom right corner of the cage, separated from the cage area by a plastic curtain and the floor was covered with artificial turf. The laid eggs rolled from the nest out of the back of the cage. Next to the nest box a sand bath (1200 cm^2) was situated and was filled up with sawdust once a week. During the laying period the sand bath was automatically opened 6 h after lights on and closed at the end of the daily photoperiod. Three perches were placed parallel to the feed trough. A perch length of 15 cm per hen was provided. Automatic chain feeders supplied the feed from a trough at the front of the cage and water was provided from nipple drinkers. Two claw shortening devices were placed parallel to the feed trough.

The aviary housing system (model 'Natura', Big Dutchman) was equipped with three central tiers. On the two lower tiers the hens were fed from a trough with automatic chain feeders and water was supplied from nipple drinkers. The top resting tier had perches and nipple drinkers.

The hens had no access to the floor under the lowest tier. Family nest boxes (model 'Colony-Nest', Big Dutchman) in one tier with an artificial turf floor and automatic egg collection belts were attached on the walls of the room opposite the aviary tiers. Droppings were automatically removed on conveyor belts which were installed under each wire tier floor. The floor was covered with sand and sawdust (15·3 hens per m^2 floor area in the first trial and 14·5 hens per m^2 floor area in the second). The removal of litter was not necessary and not carried out before the hens were removed from the aviary. The hens had access to a covered outdoor area (0·06 m^2 per hen in the first trial and 0·07 m^2 per hen in the second), where the floor was covered with straw. From here the hens had access to the free range, with 2·1 m^2 open area per hen in the first trial and 2·3 m^2 per hen in the second. The manure removal belts of each housing system were run once a week.

Breed, feeding and stocking

The first trial commenced in April 2000 and ended in June 2001, while the second was carried out between July 2001 and August 2002. The data of both trials were analysed starting when the laying rate per hen present reached 50%, till the 390th laying day.

The brown layer line LS was used, with two different strain crosses in trial 1 and only one strain cross in trial 2. Beaks of the LS hens were carefully trimmed by hot blade by a contractor at one day old, whereby only the corneal tip of the beak was trimmed. LS pullets from trial 1 were reared on a litter floor system with perches from one day old, while bird density was 23 per m^2 floor area. Feed and water were supplied *ad libitum* on slatted plastic flooring, which was lifted during the rearing period from ground level up to 1·70 cm height. LS pullets from trial 2 were reared in an aviary system (model 'Natura', Big Dutchman) while bird density was 31 per m^2 floor area. Both pullets were fed a standard grower diet. During the rearing phase the birds were vaccinated against Marek's disease, Newcastle disease, avian infectious bronchitis, infectious bursitis, encephalomylelitis, infectious laryngotracheitis, salmonella, *Escherichia coli*, coccidiosis and egg-drop syndrome. The LS hens were moved to their laying accommodation at the age of 17 weeks in trial 1 and 18 weeks in trial 2. In trial 1 a total of 2110 LS hens were placed in the aviary, 1541 LS hens were kept in the conventional cages and 1560 LS hens in the furnished cages. In trial 2 a total of 2004 LS hens were kept in the aviary, 1345 LS hens were placed in the conventional cages and 1533 LS hens in the furnished cages. Hens were fed standard layer diet (containing 167·2 g/kg CP, 11·6 MJ ME, 37·2 g/kg Ca and 5·4 g/kg P). From the beginning of laying month 7 the hens received feed with 5% oyster shell content. Feed and water were supplied for *ad libitum* consumption. When hens were initially accommodated in the experimental building the photoperiod was 10·5 h in all three housing systems. The light was increased by 30 min/week up to 14·5 h at 25 weeks in the conventional and furnished cages and in the aviary 16 h at 28 weeks. This was held constant until the systems were depopulated at the end of the laying period. During the laying period the hens were revaccinated every 3 months against Newcastle disease and infectious bursitis. An infestation with red mites (*Dermanyssus gallinae*) occurred in both trials; to reduce it each housing system was treated twice during trial 1 and once during trial 2 with an agent containing carbamate.

Production traits

Eggs from each housing system were transported daily on conveyor belts to an automatic egg weighing and grading machine, where they were automatically counted and graded according to weight class as well as dirty, cracked and broken. In the aviary, floor eggs and in the furnished cages sand bath eggs, were collected once a day and are included in all egg yield totals. The amount of feed consumed in each system was assessed daily. Table 1 gives the least square means and their standard errors for production traits and significant differences between the housing systems.

Egg quality traits

From point of lay, after automatic counting and sorting according to weight class, samples of 10% of a single day's egg production were collected from each housing system for 3 d every 4 weeks, and samples of 20% of one day's egg production were collected every 12 weeks for testing egg quality traits. The eggs were analysed over three consecutive days.

Eggshell breaking strength was determined by subjecting the egg to pressure (N) at the poles between two flat parallel steel plates until the shell fractured. Force was applied to all eggs at constant rate with test speed of 80 mm/min and automatic recording of the peak force. The machine used was a 'Zwicki-Z2,5/TNIS' (Zwick-Roell, Ulm, Germany). To determine eggshell thickness, a shell sample was taken at the equator and—after removal of the membrane—placed in a micrometer (QCT from TSS, York, UK) and measured in micrometers. To measure eggshell density the eggshells were dried in a

Table 1. *Least square means (LSM) and their standard errors (SE) and significant differences between the housing systems for egg production traits in both trials*

Traits	Conventional cages (C)		Furnished cages (F)		Aviary (A)		C – F	C – A	F – A
	LSM	SE	LSM	SE	LSM	SE	*P*	*P*	*P*
Trial 1									
Daily egg production per hen present, %	84·3	0·8	85·3	0·8	84·3	0·8	**	NS	**
Daily egg mass per hen present, g	53·1	0·5	53·3	0·5	52·4	0·5	NS	**	***
Average egg weight, g	63·0	0·1	62·5	0·1	62·2	0·1	***	***	***
Daily feed consumption per hen, g	117·7	1·1	118·4	1·1	120·5	1·1	NS	***	***
Trial 2									
Daily egg production per hen present, %	84·3	0·8	83·7	0·8	82·9	0·8	NS	***	**
Daily egg mass per hen present, g	53·2	0·5	52·2	0·5	51·8	0·5	***	***	*
Average egg weight, g	63·1	0·1	62·4	0·1	62·4	0·1	***	***	NS
Daily feed consumption per hen, g	116·5	1·1	116·7	1·1	117·8	1·1	NS	***	*

*$P \leq 0{\cdot}05$; **$P \leq 0{\cdot}01$; ***$P \leq 0{\cdot}001$.

Table 2. *Least square means (LSM) and their standard errors (SE) for egg quality traits and significant differences between the housing systems in both trials*

Trait	Conventional cages (C)		Furnished cages (F)		Aviary (A)		C – F	C – A	F – A
	LSM	SE	LSM	SE	LSM	SE	*P*	*P*	*P*
Trial 1									
Eggshell breaking strength, N	37·7	0·2	36·6	0·2	38·1	0·2	***	NS	***
Eggshell thickness, μm	319·2	0·7	316·0	0·7	324·7	0·6	***	***	***
Eggshell density, mg/cm^3	84·6	0·2	83·8	0·2	85·6	0·2	***	***	***
Trial 2									
Eggshell breaking strength, N	37·2	0·2	36·0	0·2	37·3	0·2	***	NS	***
Eggshell thickness, μm	319·9	0·7	316·6	0·7	324·0	0·7	***	***	***
Eggshell density, mg/cm^3	82·6	0·2	81·7	0·2	82·7	0·2	***	NS	***

***$P \leq 0{\cdot}001$.

microwave oven for 2 min at 800 W. Having weighed the complete shell in grams, a formula ($S = 4{\cdot}67 \times G^{2/3}$ [S = surface area; G = egg weight]) from a dedicated microprocessor (QCM from TSS) derived surface area from the weight of the egg. Then shell weight was divided by surface area. Shell density (shell weight per unit area) was expressed in mg/cm^3. To improve data quality, all quality assessments were carried out by the same person. In Table 2 the least square means and their standard errors for egg quality traits and significant differences between the housing systems are presented.

Bone breaking strength

At the end of laying months 6 and 9 of the first trial, 50 hens were removed from each of the three husbandry systems and slaughtered. The same procedure was conducted on 100 hens at laying month 14 of the first trial (end of the laying period). In the second trial 75 birds were taken from each of the three housing systems and slaughtered at the end of laying months 6, 9 and 14. After the muscles and tendons were completely removed from the bones, the length in millimetres and the weight in grams were measured. Then the bones were placed on two fulcrum points (9 cm apart for the tibia and 4 cm apart for the humerus) and force was applied midshaft using a machine of the type 'Zwicki-Z2,5/TNIS' (Zwick-Roell) until the bones fractured. Force was applied to all bones at constant rate with automatic recording of the peak force.

Statistical analysis

All analyses were performed using the GLM procedure of SAS package Version 9.1.3 (SAS Institute, Cary, NC, USA, 2004). The bone breakage of randomly collected hens from the three different housing systems was analysed for the effects of housing system, laying month, genetic group within trial, and interaction between these effects using the following univariate linear model:

$$\begin{aligned} Y_{ijkl} = \mu + \mathrm{SYS}_i + \mathrm{MON}_j + \mathrm{TYP}_k \\ + (\mathrm{SYS} \times \mathrm{MON})_{ij} + (\mathrm{SYS} \times \mathrm{TYP})_{ik} \\ + (\mathrm{MON} \times \mathrm{TYP})_{jk} \\ + (\mathrm{SYS} \times \mathrm{MON} \times \mathrm{TYP})_{ijk} + e_{ijkl} \end{aligned}$$

where:

Y_{ijkl} observation for the respective trait bone breaking strength in housing system i, laying month j and genetic group within trial k
μ model constant
SYS_i effect of the housing system i ($i = 1, 2, 3$)
MON_j effect of the laying month j (1 to 3)
TYP_k effect of the genetic group in trial k ($k = 1, 2, 3$)
$(SYS \times MON)_{ij}$ interaction between housing system and laying month
$(SYS \times TYP)_{ik}$ interaction between housing system and genetic group in the trial
$(MON \times TYP)_{jk}$ interaction between laying month and genetic group in the trial
$(SYS \times MON \times TYP)_{ijk}$ interaction between housing system, laying month and genetic group in the trial
e_{ijkl} random error variation.

The model for egg production traits included the effects of housing system, trial, three vaccinations against Newcastle disease and infectious bursitis, two treatments against red mite, the interaction between housing system and trial and the age of laying hens within the housing system and trial as linear and non-linear (quadratic, logarithmic) covariate. The vaccination and treatment effects had each two levels differentiating the 4 subsequent weeks after vaccination or treatment and all the other weeks in production. The model employed for egg quality traits contained effects for housing system, trial, laying month, genetic group and the interactions between housing system and trial, housing system and laying month, trial and laying month, housing system, trial and laying month. We used the LSMEANS function of GLM (SAS, 2004) to compute least square means and their standard errors.

The results of the statistical tests were regarded as significant when the probability of error was less than $P \leq 0{\cdot}05$. Residuals of the traits analysed were computed using the models for the respective traits and then these residuals were averaged by housing system, trial, laying month and genetic group. These means were used to compute the Pearson correlations to among egg production, egg quality and bone breaking strength traits.

RESULTS

Table 3 contains mean squares, their standard errors and the results of the *F*-tests for the effects of housing system, laying month, genetic group in the trial and the interaction between these effects for bone breaking strength in both trials. The housing system had a significant effect on the humerus and tibia bone breaking strength, while a significant effect of the laying month was found only on the tibia bone breaking strength. Furthermore, the different genetic groups used in the two trials and the interaction between the laying month and the genetic group used in the two trials had a significant effect only on the bone breaking strength of the tibia bones, whereas the humerus bone breaking strength seemed to be unaffected. But there was a significant effect of the interaction between housing system, laying month and genetic group used in the two trials on the humerus breaking strength.

Means and their standard errors for the bone breaking strength of the humerus and tibia bones and significance of differences between the housing systems are given in Table 4. Table 5 shows the means and their standard errors for bone breaking strength and significant differences between the laying months. The means and their standard errors for the bone breaking strength and significance of differences between the genetic groups used in both trials are given in Table 6.

Bone breaking strength was consistently higher for hens kept in the aviary compared to those kept in conventional and furnished cages (Table 4). Furthermore, humerus breaking strength was higher for hens kept in the furnished cages compared to hens housed in the conventional cages. This difference was significant. But no significant difference for tibia breaking strength was found between conventional and furnished cages. An increase in tibia breaking strength was found over the laying period, though the differences were

Table 3. *Mean squares (MSR) and the results of the F-tests for the effects of housing system, genetic group used in the two trials, laying month and the interaction between the effects*

Trait	Humerus strength		Tibia strength	
	MSR	*P*	MSR	*P*
Housing (H)	1 570 799·5	***	295 432·8	***
Month (M)	1093·2	NS	10 014·3	***
Genetic group/Trial (T)	4299·5	NS	12 864·7	***
H × M	2910·1	NS	1520·2	NS
H × T	2465·5	NS	2182·7	NS
M × T	1920·8	NS	4201·1	**
H × T × M	5049·4	*	1641·3	NS

$^*P \leq 0{\cdot}05$; $^{**}P \leq 0{\cdot}01$; $^{***}P \leq 0{\cdot}001$.

Table 4. *Least square means (LSM) and their standard errors (SE) for bone strength of humerus and tibia and significant differences between the housing systems*

Trait	Conventional cages (C)		Furnished cages (F)		Aviary (A)		C – F	C – A	F – A
	LSM	SE	LSM	SE	LSM	SE	*P*	*P*	*P*
Breaking strength humerus, N	104·5	2·9	129·6	2·9	247·0	2·9	***	***	***
Breaking strength tibia, N	116·7	2·0	121·6	2·1	175·4	2·1	NS	***	***

***$P \leq 0{\cdot}001$.

Table 5. *Least square means (LSM) and their standard errors (SE) for bone strength of humerus and tibia and significant differences between the laying months*

Trait	Laying month 6		Laying month 9		Laying month 14		6 – 9	6 – 14	9 – 14
	LSM	SE	LSM	SE	LSM	SE	*P*	*P*	*P*
Breaking strength humerus, N	160·1	3·0	158·6	3·1	162·4	2·5	NS	NS	NS
Breaking strength tibia, N	133·5	2·2	136·0	2·2	144·2	1·8	NS	***	**

**$P \leq 0{\cdot}01$; ***$P \leq 0{\cdot}001$.

Table 6. *Least square means (LSM) and their standard errors (SE) for bone strength of humerus and tibia and significant differences between the genetic groups used in the two trials*

Trait	Genetic group A in trial 1 (I)		Genetic group B in trial 1 (II)		Genetic group C in trial 2 (III)		I – II	I – III	II – III
	LSM	SE	LSM	SE	LSM	SE	*P*	*P*	*P*
Breaking strength humerus, N	155·8	3·1	164·7	3·2	160·6	2·5	NS	NS	NS
Breaking strength tibia, N	131·4	2·3	138·4	2·3	143·9	1·5	*	***	*

*$P \leq 0{\cdot}05$; ***$P \leq 0{\cdot}001$.

significant only between laying months 6 and 14, and 9 and 14.

Tibia bone breaking strength was significantly lower in genetic group A than in group B, which in turn was lower than in group C (Table 6). The difference was significant only in laying month 6 between genetic groups A and B (124·9 *vs* 137·4 N, $P \leq 0{\cdot}05$) and months 6 and 9 between genetic groups A and C (124·9 *vs* 138·2 N, $P \leq 0{\cdot}01$; 127·4 *vs* 148·8 N, $P \leq 0{\cdot}001$). Tibial breaking strength was greater in group C than in group B, but significantly so only in laying month 9 (131·8 *vs* 148·8 N, $P \leq 0{\cdot}001$). The significant interaction between housing system, laying month and genetic group humerus bone breaking strength was attributable to changes in humerus strength within housing system, laying month and genetic group in the trial.

The residual correlations (r_e) between bone breaking strength of tibia and humerus on the one hand and daily egg production, egg mass per hen present and egg weight on the other hand varied between −0·15 and 0·11 and were not statistically different from zero. Eggshell thickness and density were positively correlated with bone breaking strength of tibia and humerus ($r_e = 0{\cdot}33$ to 0·64) but not significantly different from zero, while the correlations of eggshell breaking strength with bone breaking strength were close to zero.

DISCUSSION

The housing system in which the hens were kept had a significant influence on bone breaking strength: it was consistently higher for hens housed in the aviary compared to those kept in the cage systems. The hens in conventional and furnished cages had relatively less space to move around in, while the hens in the aviary system with outdoor run had much more freedom for locomotor activity and to perform behaviours such as flying, wing flapping and running than the birds in the cage systems. So the higher bone breaking strength is presumably due to the increased opportunity to exercise (Whitehead, 2000): the results suggest that the exercise taken by the caged hens was insufficient to prevent bone degeneration.

As stated by Cransberg *et al.* (1998), high egg production can also promote the development of osteoporosis. The hens in the aviary laid almost as many eggs per hen present as the hens in the cage systems, but their bone breaking strength was higher than that of the birds in the conventional and furnished cages: tibia, 150 and 144%; humerus, 136 and 90%. These findings demonstrated that only the caged hens suffered from osteoporosis, and that the lack of exercise probably contributed to the problem of weak bones to a greater extent than did the calcium depletion from eggshell formation. Nevertheless, the risk of losing mineralised bone volume is higher when the immobilisation of hens in conventional cages is combined with continuous egg production. Another factor that may have contributed to lower bone degeneration in the aviary system is that the hens in the aviary laid eggs of lower weight and consumed more feed. So they presumably had relatively more calcium available for eggshell formation and indeed in this study the aviary hens laid eggs with thicker shells than the hens in the two cage systems. The results of Bishop *et al.* (2000) and Leyendecker *et al.* (2001) suggest that eggshell stability and thickness seem to be negatively correlated with the bone strength. In contrast we found a positive correlation between eggshell thickness and bone strength in both trials, a positive correlation between eggshell density and bone strength in the first trial and no correlation between these two traits in the second trial. Furthermore, in both trials we found no correlation between eggshell stability and bone strength. Eggshell stability, thickness and density and bone strength too seem to be influenced by various factors, and the reasons for the different results for the correlations between these traits might be due to factors not accounted for in our experiments.

Humerus breaking strength was higher for hens kept in furnished cages as compared to those kept in conventional ones, a finding which corroborates those of Abrahamsson *et al.* (1996) and Abrahamsson and Tauson (1997). The higher humerus breaking strength in the present study could be due to the greater space available and the perches and sand baths provided in the furnished cages. The hens probably performed behaviours such as wing and leg stretching, wing flapping and sand bathing more often in the furnished cages than in the conventional cages, thus strengthening their humerus bones. The arrangement of the perches in the furnished cages could have had a positive effect on humerus breaking strength, because laying hens use their wings to get on to the perches (Abrahamsson and Tauson, 1993).

However, no significant difference in tibia breaking strength was observed between conventional and furnished cages. So here the larger space, supposedly combined with a greater opportunity to exercise, as well as the structural enrichment in the furnished cages did not lead to a higher tibia breaking strength of the birds. Neither Abrahamsson and Tauson (1993) nor Hughes *et al.* (1993) found any significant increase in the tibia bones of hens housed in furnished cages as compared to those kept in conventional cages, either. Our results differ from those of Hughes and Appleby (1989), who showed that installing perches in conventional cages resulted in a higher tibia breaking strength. Bone mass has been shown to rise with increased mechanical loading in many species (Smith and Gilligan, 1989). This suggests that minimal mechanical exercise depresses bone remodelling, a process which appears mainly in trabecular bone (Li and Jee, 1991). The tibia bones were not subject to great force when the hens stepped down from the perches. If the perches had been higher, so that the hens had to jump down from the perches on to the cage floor, then the tibia bones would have experienced higher dynamic forces. This arrangement might have led to an improvement in the tibia bone strength. The perches as arranged here prevented the hens from using the full floor space, because the hens could not get underneath the perches. So in this study the hens in the furnished cages actually did not have very much more floor space to move around in than did their counterparts in the conventional cages.

Severe osteoporosis can result in death (McCoy *et al.*, 1996). The pathological findings for all dead hens in this study showed that the incidence of recently broken bones occurred with highest frequency in the conventional cages (first trial, 31·9%; second trial, 12·8%). In contrast, only 4·6% (first trial) and 1·3% (second trial) of losses were due to recently broken bones in the aviary; in the furnished cages, 7·6% (first trial) and 7·3% (second trial). So, compared to the conventional cages, the improvement in bone breaking strength in the aviary and even the relatively minor enhancement of bone strength in the furnished cages probably reduced the risk of bone breakage in these systems throughout the laying period. However, Gregory *et al.* (1990) reported that fractures can also be common in alternative systems. These authors found more old breaks in the aviary and the free range system than in conventional cages, while the caged birds had a higher incidence of recently broken bones than the aviary and free range birds. So, also in alternative housing systems bones can fracture, even though these birds have stronger bones. According to Bessei and Damme (1998) bone breakage in alternative housing systems such as aviary or free range occurs because the hens experience more traumatic accidents in these systems.

Like McCoy *et al.* (1996), we found that the breaking strength of the tibia bones increased with age. However, previous research

(Whitehead and Wilson, 1992; Wilson *et al.*, 1992) has shown that structural bone content constantly declines throughout the laying period, resulting in reduced bone breaking strength. Laying hens have two types of bone, structural (cortical and trabecular) and medullary. Cortical and trabecular bone maintains the physical integrity of the skeleton, while medullary bone is used as a source of calcium for eggshell formation, but it can also contribute to overall bone strength, as shown by Fleming *et al.* (1996). At the onset of sexual maturity, the rise in circulating oestrogen results in a switch in bone formation from structural to medullary bone. Furthermore, after the medullary bone begins to be formed at the point of lay, the volume of this bone continues to rise throughout the laying period (Wilson *et al.*, 1992). The tibia is known to contain marked amounts of medullary bone. So, the significant increase of the tibia breaking strength over the last third of the laying period observed in the present study may be due to accumulation of medullary bone, contributing to overall tibia bone strength, while there had been little resorption of structural bone.

Nutrition cannot prevent osteoporosis, but it can minimise it (Whitehead, 2000). Guinotte and Nys (1991) have shown that feeding particulate calcium sources led to higher tibia strength. Oyster shells were added to the layers' diet as a source of extra calcium at the beginning of month 7 making more calcium available. This factor could have increased medullary bone, as described by Fleming *et al.* (1998), and reduced cancellous bone resorption, also contributing directly to tibia bone strength.

According to Rennie *et al.* (1997), when egg production decreases, the laying hen is able to restore calcium and replenish trabecular and medullary bone. The fact that egg production declined sharply at the end of the laying period may explain why tibia bone stability increased at the end of month 14, because less calcium was required for eggshell formation at that time and the hens were able to restore calcium and replenish trabecular and medullary bone. Arafa and Harms (1987) reported that resting hens by moulting could increase their bone strength after their normal laying cycle of 52 weeks. Whitehead (2000) also observed that structural bone formation resumed after the loss of reproductive condition induced by forced moulting. Some of the hens in the present study had probably already stopped laying eggs at the end of the laying period, had rested by moulting and had thereby increased their tibia bone strength. The changes in the tibia breaking strength through the laying period thus seem to be dependent on egg output, age and the nutritional status of the hen, and are linked to the incidence of medullary bone. To underline this thesis it must be pointed out that the humerus breaking strength was not affected by hen age (Tables 3 and 5); this bone is known to be pneumatised and therefore generally contains no medullary bone.

In addition to exercise and nutrition, genetics can also influence bone stability and bone breaking strength can be dependent on the layer line used (Leyendecker *et al.*, 2001). Furthermore, Bishop *et al.* (2000) showed that bone stability could be enhanced through selection within a few generations. The results of the present study clearly demonstrate that the genetic groups differed significantly in their tibia breaking strength. Therefore, not only do layer lines differ in respect to their bone breaking strength, but genetic group crosses do as well, and selection between genetic group crosses for a high tibia bone breaking strength seems promising with the different genetic groups used in this study. This finding is of interest to poultry breeders, who have regarded osteoporosis as a serious congenetic group to further genetic development in commercial laying hens (Cransberg *et al.*, 1998). Moreover, the use in trial 2 of genetic group C, with its significantly higher tibia bone breaking strength, resulted in a lower incidence of bone fractures in trial 2 as compared to trial 1, in which the two other genetic groups were used. Even though there was no common control for the genetic groups in the two trials, the housing system, farm staff, feeding rations and management did not change between these consecutive trials. So the comparisons between the three genetic groups should not be greatly influenced by environmental influences. One may conclude that layer line or genetic group affects the incidence of bone fractures and thus the overall health status of the hens. Interactions between housing system, laying month and genetic group in the different trials were significant for humerus strength suggesting that genetic-group-specific effects on humerus breaking strength occurred in the three hen housing systems throughout the laying period.

The conclusions drawn from the present study must be regarded as of a preliminary nature until more multi-site trials or meta-analyses of trials at different sites are available. Meanwhile, our findings suggest that housing system and the extent of movement possible, the age of the hens and the genotype, all strongly influence the degree of bone weakness in laying hens. The keeping of hens in furnished cages enhances humerus bone strength, but may not improve tibia bone breaking strength. The increase in humerus strength can regarded as an improvement in the welfare of the laying hens.

ACKNOWLEDGEMENTS

The authors wish to recognise the contribution of the staff and management of the Farm for Education and Research in Ruthe. This project was financially supported by Lohmann Tierzucht GmbH, Deutsche Frühstücksei GmbH, Big Dutchman GmbH and the Lower Saxony Ministry of Nutrition, Agriculture and Forestry.

REFERENCES

ABRAHAMSSON, P. & TAUSON, R. (1993) Effects of perches at different positions in conventional cages for laying hens of two different genetic groups. *Acta agriculturae scandinavica*, **43**: 228–235.

ABRAHAMSSON, P. & TAUSON, R. (1997) Effects of group size on performance, health and birds' use of facilities in furnished cages for laying hens. *Acta agriculturae scandinavica*, **47**: 254–260.

ABRAHAMSSON, P., TAUSON, R. & APPLEBY, M.C. (1996) Behaviour, health and integument of four hybrids of laying hens in modified and conventional cages. *British Poultry Science*, **37**: 521–540.

ARAFA, A.S. & HARMS, R.H. (1987) Comparison of bone characteristics of hens of three different ages in cages and floor pens. *Applied Agricultural Research*, **2**: 175–176.

BESSEI, W. & DAMME, K. (1998) Neue Verfahren für die Legehennenhaltung. *KTBL Schrift* 378.

BISHOP, S.C., FLEMING, R.H., MCCORMACK, H.A., FLOCK, D.K. & WHITEHEAD, C.C. (2000) The inheritance of bone characteristics affecting osteoporosis in laying hens. *British Poultry Science*, **41**: 33–40.

CEC (COMMISSION OF THE EUROPEAN COMMUNITIES) (1999) Council Directive 99/74/EC: Laying down minimum standards for the protection of laying hens. *Official Journal of the European Communities* (L 203/53), 19 July.

CRANSBERG, P.H., JONGMAN, E.C., THORP, B.H., WILSON, S., GOLDSMITH, J., ALMOND, A. & PARKINSON, G.B. (1998) Sequential studies of skeletal calcium reserves and structural bone volume in a commercial layer flock. *Proceedings of the Australasian Poultry Science Symposium*, **10**: 98–102.

DUNCAN, I.J.H. & FRASER, D. (1997) Understanding animal welfare, in: APPLEBY, M.C. & HUGHES, B.O. (Eds) *Animal Welfare* (Cambridge, Cambridge University Press).

FLEMING, R.H., MCCORMACK, H.A., MCTEIR, H.A. & WHITEHEAD, C.C. (1996) The influence of medullary bone on humeral breaking strength. *British Poultry Science*, **37**: 30–32.

FLEMING, R.H., MCCORMACK, H.A. & WHITEHEAD, C.C. (1998) Bone structure and strength at different ages in laying hens and effects of dietary particulate limestone, vitamin K and ascorbic acid. *British Poultry Science*, **39**: 434–440.

FLEMING, R.J., WHITEHEAD, C.C., ALVEY, D., GREGORY, N.G. & WILKINS, L.J. (1994) Bone structure and breaking strength in laying hens housed in different husbandry systems. *British Poultry Science*, **35**: 651–662.

GREGORY, N.G., WILKINS, L.J., BALLANTYNE, E.S.D. & OVERFIELD, N.D. (1990) Broken bones in domestic fowls, effects of husbandry system and stunning method in end-of-lay hens. *British Poultry Science*, **31**: 59–69.

GUINOTTE, F. & NYS, Y. (1991) Effects of particle size and origin of calcium sources on eggshell quality and bone mineralisation in egg laying hens. *Poultry Science*, **70**: 583–592.

HUGHES, B.O. & APPLEBY, M.C. (1989) Increase in bone strength of spent laying hens housed in modified cages with perches. *Veterinary Record*, **124**: 483–484.

HUGHES, B.O., WILSON, S., APPLEBY, M.C. & SMITH, S.F. (1993) Comparison of bone volume and strength as measures of skeletal integrity in caged laying hens with access to perches. *Research in Veterinary Science*, **54**: 202–206.

LEYENDECKER, M., HAMANN, H., HARTUNG, J., KAMPHUES, J., RING, C., GLÜNDER, G., AHLERS, C., SANDER, I., NEUMANN, U. & DISTL, O. (2001) Analyse von Genotyp-Umwelt-Interaktionen zwischen Legehennenhybriden und Haltungssystemen in der Legeleistung, Eiqualität und Knochenfestigkeit. 3. Mitteilung: Knochenfestigkeit. *Züchtungskunde*, **73**: 387–398.

LI, X.J. & JEE, W.S.S. (1991) Adaptation of diaphyseal structure to ageing and decreased mechanical loading in the adult rat: a densitometric and histomorphometric study. *Anatomical Record*, **227**: 12–24.

MCCOY, M.A., REILLY, G.A.C. & KILPATRICK, D.J. (1996) Density and breaking strength of bones of mortalities among caged layers. *Research in Veterinary Science*, **60**: 185–186.

NIGHTINGALE, T.E., LITTLEFIELD, L.H. & MERKLEY, L.W. (1972) Osteoporosis induced by unilateral wing immobilisation. *Poultry Science*, **51**: 1844–1845.

RENNIE, J.S., FLEMING, R.H., MCCORMACK, H.A., MCCORQUODALE, C. & WHITEHEAD, C.C. (1997) Studies on effects of nutritional factors on bone structure and osteoporosis in laying hens. *British Poultry Science*, **38**: 417–424.

SMITH, E.L. & GILLIGAN, C. (1989) Mechanical forces in bone, in: PECK, W.A. (Ed) *Bone and Mineral Research*, pp. 139–174 (Elsevier, New York).

TAUSON, R. (1984) Effects of a perch in conventional cages for laying hens. *Acta agriculturae scandinavica*, **34**: 193–209.

VAN NIEKERK, T.G.M.C. & REUVEKAMP, B.F.J. (1994) Husbandry factors and bone strength in laying hens, in: *Proceedings of the 9th European Poultry Conference*, Glasgow, UK, pp. 133–136.

WHITEHEAD, C.C. (2000) Wechselwirkung zwischen Genotyp und Ernährung im Zusammenhang mit Knochenstärke bei Legehennen. *Lohmann Information*, **1**: 21–26.

WHITEHEAD, C.C. & WILSON, S. (1992) Characteristics of osteopenia in hens, in: WHITEHEAD, C.C. (Ed) *Bone Biology and Skeletal Disorders in Poultry*, pp. 265–280 (Abingdon, Carfax).

WILSON, S. & DUFF, S.R.I. (1991) Effects of vitamin or mineral deficiency on the morphology of medullary bone in laying hens. *Research in Veterinary Science*, **50**: 216–221.

WILSON, S., DUFF, S.R.I. & WHITEHEAD, C.C. (1992) Effects of age, sex and housing on the trabecular bone of laying genetic group domestic fowl. *Research in Veterinary Science*, **50**: 52–58.