CODE OF PRACTICE FOR THE CARE AND HANDLING OF PULLETS, LAYERS, AND SPENT FOWL: POULTRY (LAYERS)

REVIEW OF SCIENTIFIC RESEARCH ON PRIORITY ISSUES

December 2013

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CONSEIL NATIONAL POUR LES SOINS AUX ANIMAUX D'ÉLEVAGE

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Excerpt from Scientific Committee Terms of Reference

Background

It is widely accepted that animal welfare codes, guidelines, standards or legislation should take advantage of the best available knowledge. This knowledge is often generated from the scientific literature, hence the term "science-based".

In re-establishing a Code of Practice development process, NFACC recognized the need for a more formal means of integrating scientific input into the Code of Practice process. A Scientific Committee review of priority animal welfare issues for the species being addressed will provide valuable information to the Code Development Committee in developing or revising a Code of Practice. As the Scientific Committee report is publicly available, the transparency and credibility of the Code process and the recommendations within are enhanced.

For each Code of Practice being developed or revised, NFACC will identify a Scientific Committee. This committee will consist of 4-6 scientists familiar with research on the care and management of the animals under consideration. NFACC will request one or two nominations from each of 1) Canadian Veterinary Medical Association, 2) Canadian Society of Animal Science, and 3) Canadian Chapter of the International Society for Applied Ethology.

Purpose & Goals

The Scientific Committee will develop a report synthesizing the results of research relating to key animal welfare issues, as identified by the Scientific Committee and the Code Development Committee. The report will be used by the Code Development Committee in drafting a Code of Practice for the species in question.

The full Terms of Reference for the Scientific Committee can be found within the NFACC Development Process for Codes of Practice for the Care and Handling of Farm Animals, available at www.nfacc.ca/code-development-process#appendixc.

PREFACE

The following document, compiled by the Scientific Committee, was based on six Priority Welfare Issues that were identified by a multi-stakeholder group for the Code of Practice for the Care and Handling of Pullets, Layers, and Spent Fowl. This slate of issues was narrowed down from a much broader list and is not meant to be an exhaustive review of all of the issues that can affect the welfare of laying hens. At around the same time as the Layer Code Scientific Committee was struck, the Scientific Committee for the Code of Practice for the Care and Handling of Chickens, Turkeys and Breeders also began a review of Priority Welfare Issues for poultry in the meat sectors. Since some of the same scientists served on both committees and there is a degree of overlap among the welfare issues and related scientific studies across poultry sectors, it was decided that the same topics would not be reviewed twice but that information from each of these reviews would provide background for the other code, where appropriate. For this reason the topics "Methods of Euthanasia" and "Air and Litter Quality" are not included in this review but research relevant to laying hens is covered in the Scientific Committee Report for meat birds. Similarly, a much more detailed review of research on "Beak Treatment" and on "Feather Pecking and Cannibalism", which may also be relevant for broiler breeders, is included in the Scientific Committee report on layers but not the one for meat birds.

It should also be noted at the outset that there is a great deal of diversity across genetic stocks of laying hens and that change due to selection for different traits happens very rapidly in the poultry industry. Although there are considerable strain differences in behaviour, body size, and production traits that may affect how birds adapt to different housing systems and, consequently their welfare, scientific research often does not keep pace with the selection for new traits within a particular strain. For this reason we have not included the specific names of genetic strains in the text of the report but instead refer more generally to brown and white commercial birds. For purposes of this report, the "brown strain" refers to commercial medium- to heavy-weight birds that lay brown-shelled eggs. "White strain" refers to commercial light-weight birds that lay white-shelled eggs.

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APPROACHES TO DEFINING AND EVALUATING ANIMAL WELFARE

The scientific evaluation of animal welfare involves the use of empirical methods to obtain information about animals that can be used to inform ethical decision-making regarding their quality of life. One major challenge is that people have diverse views about what constitutes a good quality of life and therefore express a variety of ethical concerns and use different criteria for defining animal welfare. These have been grouped into three general categories: 1) biological functioning; 2) affective states; and 3) natural living, and form the bases for different approaches to animal welfare research (Fraser et al., 1997). The biological functioning approach emphasizes basic health and normal function and includes measures having to do with health and productivity, stress response and normal (or lack of abnormal) behaviour (Broom, 1991). Animal welfare defined in terms of affective states, often referred to as the feelings-based approach, concerns the subjective experiences of animals with an emphasis on states of suffering (pain, fear, frustration), states of pleasure (comfort, contentment) and the notion that animals should be housed and handled in ways that minimize suffering and promote positive experiences (Duncan, 1993). The concept of natural living emphasizes the naturalness of the circumstances that the animal experiences and the ability of the animal to live according to its nature (Fraser, 2008). While the natural living approach provides another viewpoint for what constitutes a good quality of life for animals, it is more difficult to derive specific measures from it that can be used to evaluate welfare (Fraser, 2008).

When possible, each section in this review covers research results from all three approaches for assessing hen welfare. Many animal welfare issues, especially those occurring for longer periods over the lifetime of the animal such as housing system or space allowance, have mainly been evaluated in the literature using measures of biological function. Other animal welfare issues have been studied using empirical research involving subjective states, for examples, factors affecting fear and the degree of pain experienced during beak treatment. In general, criteria for "naturalness" are less frequently addressed in the scientific literature although considerations for freedom of movement, opportunities to engage in species-typical behaviour and daily activities have been considered here, and in particular when there is evidence that constraining these behaviour patterns results in signs of negative emotional states (e.g. fear or frustration) or results in disruption of biological function (e.g. stress response).

The mandate of the Scientific Committee was to address the implications for pullet and hen welfare within the topics identified. Few, if any, references are made to economic considerations or human health and welfare concerns as these were beyond the scope of the committee's mandate and were rarely addressed in the papers reviewed. The Code Development Committee, for which this report was prepared, represents considerable expertise in these areas, and is tasked with considering such factors in its discussions.

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1. REARING METHODS

CONCLUSIONS

1. **Early life experience significantly affects fearfulness in laying hens. Regular exposure to humans, human handling, and more complex environments during rearing can all significantly reduce fearfulness in pullets and hens.**
2. **Simulated brooding cycles of light and dark periods and dark brooders synchronize activity and increase resting behaviour of chicks.**
3. **As space allowance during rearing is increased, feed intake and body weight increase while feed conversion decreases. There are significant strain and rearing density interactions.**
4. **Hens reared in floor pens or aviaries appear to adapt to caging during lay but research is limited.**
5. **Birds reared without perches and complex spatial environments have difficulty adapting to non-cage systems during lay and this may result in reduced access to feed, water, perches, and nests.**

The early experiences of chicks and pullets not only affect the welfare of the young bird but they can also have lifelong effects on the health, behaviour, and welfare of the laying hen. This chapter reviews the scientific literature on housing and management factors in pullet rearing that may affect welfare throughout the life of the bird. Rearing factors affecting development of feather pecking and beak trimming effects on pullet well-being are covered in Chapters 5 and 6, respectively.

When assessing rearing factors that affect welfare, aspects of biological function, affective states, and natural living are all considered. Measures of the effects of rearing environment on biological function include growth rates, body weight uniformity, stress response, health immune function, and normal and abnormal behaviour in the growing pullet and measures of health, production, and abnormal behaviour in the laying hen. In terms of affective states, measures of fear and fearfulness in both pullets and laying hens are considered. In terms of natural living, consideration is given to research on how environment during rearing affects the performance of species-typical natural behaviour patterns throughout the life of the bird.

REDUCING FEAR

Fear can be a potentially damaging stressor especially if it is intense or persistent. Certain fear responses, such as violent escape, can compromise welfare by causing injury, pain, or death (Jones, 1996). Fear can impair the ability of birds to adapt to environmental change, making it difficult to utilize new resources or interact with conspecifics and stock people (Jones, 1996). Elevated fear responses have been shown to be associated with greater stress response and reduced egg production in laying hens (Barnett et al., 1992). Fearfulness is also associated with feather pecking (Jones, 1996). For all of these reasons, reducing fear in birds is of significant importance to their welfare.

Increasing environmental complexity has been shown to reduce fear related behaviour (reviewed in Jones, 1996). For example, chicks reared in enriched (i.e. chicks given mirrors or allowed to watch moving objects) rather than non-enriched visual environments (i.e. solid pen walls) showed less withdrawal from an illuminated light bulb introduced into the home pens (Broom, 1969), and chicks reared with objects that moved or made noise showed less freezing and defecation during a test that involved exposure to a moving, noisy stimulus (Candland et al., 1963). Similarly, chicks raised with a variety of objects (balls, strings, hanging objects) as opposed to barren environments displayed less immobility and more feeding, walking, jumping, and vocalization in an open field test and emerged sooner into an open area in the hole-in-the-wall test of timidity (Jones, 1982). More recently, Morris (2009) found that chicks reared in floor pens with auditory (music), visual (hanging decorations), nutritional (meal worms), and tactile enrichment (human contact) showed less fear of humans and novel environments as pullets; they also had better feather condition at 30 weeks of age.

The frequent and more varied stimulation normally experienced within the home environment might also explain why lower levels of fearfulness are found in adult layers housed in floor pens rather than in cages (Jones & Faure, 1981a), in aviaries rather than cages (Hansen et al., 1993), and in the lower rather than the top tiers of multi-deck cage systems (Jones, 1985; Hemsworth & Barnett 1989). Jones (1985) argued that birds in the top tier of cages are exposed to brighter lights and warmer temperatures, have more restricted visual fields, and are exposed to less extraneous stimulation (i.e. human caretakers, cleaning instruments and food trolleys etc.) than those caged below, whereas Hemsworth and Barnett (1989) suggested that the higher levels of fearful behaviour, greater stress response and lower productivity of hens in top compared to bottom tiers were more specifically due to fear of humans.

In addition to environmental complexity, a number of studies have shown that gentle handling during rearing can attenuate tonic immobility (TI) reactions in chicks and reduce their avoidance of the experimenter (Jones & Faure, 1981b). In fact, a variety of different types of handling or exposure to humans, including picking up and stroking, brief suspension by the legs, or regular visual exposure to a person standing in front of their cage all reduced the chicks' subsequent avoidance of humans compared to non-handled controls (Jones, 1993). Jones and Waddington (1993) noted that fear of humans was equally reduced in 20 day-old birds regardless of whether they were handled from 0 to 9,10 to 18, or 1 to 18 days of age, which suggests that there may not be a very early or a precisely defined sensitive period for which handling is effective. Jones (1996) proposed that regular handling reduces birds' fear of humans rather than decreasing general non-specific underlying fearfulness. Gentle handling reduced fear of humans but failed to affect chicks' responses to unfamiliar places and objects (Jones & Faure, 1981b; Jones & Waddington, 1992). Few studies have addressed practical methods for reducing fear of humans in commercial flocks. Fiks-van Niekerk et al. (2009) found that 5 days of exposure to a person walking with or without talking through the house or squatting and feeding the birds at 10 and at 20 weeks of age in commercial flocks had no effect on the responses of birds to human-approach or novel object tests. The researchers suggested that more research was needed to determine whether treatments imposed at different times or for longer durations during rearing would affect fearfulness during the laying period.

To further examine development of fearfulness in chicks, the effects of rearing with a broody hen compared to conventional rearing have been investigated. Rodin and Weschler (1998) found that frequency of flight response was significantly lower in hen-brooded chicks compared to chicks kept without hens in identical pens. Based on results from open field and human-approach tests, Shimmura et al. (2010) also concluded that fearfulness was lower in chicks brooded by hens compared to those brooded under a heat lamp. The chicks brooded by a mother hen also showed more time engaged in active behaviours including dust bathing and floor pecking and less time engaged in feather pecking. Similarly, Rodenburg et al. (2009) found that brooded chicks were indeed much less fearful and more active in an open-field test at 5 weeks of age than non-brooded chicks. Perré et al. (2002) compared the behaviour of pullets that were brooded for the first 53 days of life with non-brooded pullets. When tested at 14 and 29 weeks of age, brooded pullets approached a novel object more closely than the non-brooded birds; however, in contrast to other studies, the 2 groups did not differ in their responses to the TI and open field tests.

Fear responses of birds also vary with age and across strain independent of experience. Hocking et al. (2001) subjected 2 lines of commercial floor-raised pullets to several fear tests at 5 different times from hatch to 30 weeks of age. In general, birds showed less avoidance of novel objects as they matured but there were strain-by-age interactions in response to the TI test. Albentosa et al. (2003) found mixed results when comparing responses to different fear tests but mainly noted that fear levels generally declined as pullets matured. Some measures of fearfulness may also change depending on hen environment. Although Anderson and Adams (1992) found a decrease in fearfulness from 34 to 54 weeks of age in caged birds, Hansen et al. (1993) found that hens in cages showed a considerably stronger TI response than hens in aviaries at 70 but not at 30 weeks of age. It appears that there are many effects of age, strain, and environment on the development and expression of fearful behaviour; therefore, results are sometimes difficult to interpret. The TI test often does not yield clear or consistent results due to differences in methodology. The open field test was originally designed as a test of emotionality in rodents (Walsh and Cummins, 1976); hence, this test must be applied cautiously for chicks, pullets and hens due to differences among species. For instance, it is difficult to interpret whether more movement in the open field test should be interpreted as a more uninhibited, relaxed state, or whether the increase in movement represents escape responses.

Nonetheless, decreasing fearful reactions in poultry is important. During handling and depopulation, the fear and escape reactions of hens can increase their risk of being injured**.** Reducing fearfulness is, therefore, desirable for the alleviation of both the psychological and physical effects of handling during transfer to the laying house and at end of lay. Reed et al. (1993) assigned birds to either a control group or an enrichment group where birds were regularly exposed to human voice, handling, and coloured novel objects from hatch to 24 weeks of age (the age at which they were moved to cages for the laying phase). Birds from the enriched treatment displayed lower levels of fear reactions during handling tests at 26 weeks of age and received fewer knocks against the cage during a simulated depopulation at 27 weeks compared to non-enriched birds.

BROODER MANAGEMENT

Brooding by hens provides an essential function in maintaining chicks' body temperature during the first few weeks of life. In commercial conditions supplemental heat is required and is often provided by radiant heat lamps, which results in constant exposure to light. The daily natural brooding cycles of the hen increase the synchronization of chicks' activity (Roden & Weschler, 1998; Riber et al., 2007), which has been suggested to promote better rest and reduce the development of feather pecking by separating active from inactive birds (Gilani et al., 2012). Some of the positive effects of the broody hens can be achieved in commercial rearing systems through simulated brooding cycles of light and dark (Malleau et al., 2007) and by use of dark brooders (Riber et al., 2007).

Malleau et al. (2007) subjected layer and broiler chicks to either a long-day schedule of 19 h 20 min continuous light: 4 h 40 min dark or to a "simulated brooding cycle" that exposed chicks to the same day length but punctuated it with alternating 40 min light: 40 min dark periods. Supplemental heat was provided by dull emitter radiant heaters. Chicks on the brooding cycle rested more than chicks on the long-day schedule and had distinct patterns of activity; feed disappearance and growth rate were not affected. Malleau et al. (2007) suggested that the long periods of day light and large group sizes that chicks experience under modern husbandry systems may result in constant disturbance and lack of sufficient rest.

The concept of dark brooders was described in Gilani et al. (2012). In their study, dark brooders consisted of solid raised horizontal panels with heaters on their underside surrounded by black fringes to block out any light. They reported that the flocks reared using dark brooders had similar body weights and mortality rates at end of rearing but showed reduced feather pecking and better feather condition during rearing and into the laying period compared to flocks reared with regular gas brooders. Although there was some indication that fear of humans was lower in the dark-brooded flocks, data from fear tests in this study could not be statistically analyzed and were, therefore, inconclusive.

DENSITY AND HOUSING TYPE DURING REARING

Very few recent studies have addressed the effects of stocking density or housing type during rearing on the welfare of pullets reared in either cages or non-cage systems. Most studies were done several decades ago on early genetic stocks with laying hens subsequently housed in cages and stocked at densities that were much higher than those used today. In most studies stocking density was altered by adjusting the number of birds in a cage or pen, thereby also affecting feeder and drinker space allowances.

Effect of Density during Cage Rearing

Results of studies on effects of rearing density on pullet performance in cages are given in Table 1. Carey (1987) compared cage rearing densities of 311, 259, and 239cm^2/bird in one experiment and 311, 259, and 222cm^2/ bird in a second. The experiments included different group sizes at the various densities in both closed and open-sided houses and three strains of birds (strains not indicated). The higher stocking densities resulted in lower feed intake, lower 18 week body weight and greater age at 50% production and in the second experiment, higher mortality at 20 weeks of age. Rearing density did not affect production, mortality, or feed conversion during the laying period in either experiment. Anderson and Adams (1992) found that rearing densities of 221, 249, 277, and 304cm^2/ bird had no effect on 18 week body weight, uniformity, feed consumption, age at first egg, or mortality during the laying period in 3 strains of White Leghorn pullets. In a second experiment, these same authors found that body weight at 18 weeks was significantly lower when the same strains of birds were reared at 193 compared to 221cm^2/bird; rearing density did not affect subsequent hen-day egg production and hen fearfulness when the birds were stocked in conventional cages at 348cm^2/bird. Patterson and Siegel (1998) found that 2 strains of White Leghorn birds reared at 97.8, 116.1, 142.9, and 185.8cm^2/bird from 1 day to 6 weeks of age and 195.6, 232.3, 285.9, and 371.6cm^2/ bird from 6 to 18 weeks of age, respectively, showed a significant reduction in body weight at the highest cage density (195.6cm^2/bird) by 18 weeks of age. Feed intakes were lower but feed conversion rates were better with higher cage densities. Mortality, heterophil to lymphocyte (H:L) ratio (stress indicator), and humoral immunity were unaffected by more crowded conditions. Keshavarz (1998) had similar findings when White Leghorn birds given additional floor space (346 vs. 283cm^2/pullet) during the rearing phase (8 to 18 weeks of age) showed higher feed intake and body weight at 18 weeks. There was no effect on feed conversion and early egg size was not affected.

More recently Pavan et al. (2005) evaluated the effect of stocking brown pullets in cages at 275.9, 250.0, 228.6, and 210.5cm^2/bird from 0 to 6 weeks and 500.0, 416.7 and 357.1cm^2/bird from 6 to 16 weeks in a factorial arrangement. They found no significant effect of cage density on weight gain, feed intake, feed conversion, or uniformity during the growing period or on egg production traits during lay in conventional cages. Bozkurt et al. (2006) measured the effects of rearing 2 white and 2 brown strains at 3 cage densities (105.9, 134.8, 185.3cm^2/bird from day 1 to 4 weeks of age; 211.8, 274.5, and 370.6cm^2/bird at 4 to 16 weeks of age) and 3 cage positions (top, middle, and bottom rows). Body weight was affected by strain, density, and cage position as well as numerous interactions among the factors. Overall, birds housed at the intermediate density had the highest weight gain; birds at low density had the highest feed intake; birds at the highest density had better feed conversion and flock uniformity. Overall mortality was not affected by density but there were significant strain-by-density interactions. Effects of cage position were not consistent across strain or over time.

The general trend in the literature is for higher feed intake/poorer feed efficiency when growing pullets are provided more space. This could be due to the increased energy requirements needed to support more movement (i.e. exercise) or for thermoregulation, since birds stocked at lower densities may lose more heat. Less densely housed birds also often weigh more and therefore require more feed for tissue accretion and maintenance.

Table 1: Summary of Studies on the Effects of Rearing Density on Pullet Performance in Cages. Results of separate experiments within studies are divided by bolded lines. [a-d] Means within a column and experiment with no common superscripts differ (P<0.05)

Reference	Strain of birds	Space allowance (cm^2/bird)	Mortality (%)	Body weight (g)	Feed intake (g)	Feed conversion
Carey (1987) 2 separate experiments	Commercial (1- 147 days)	239	2.04[a] (days 7-147)	1343 at 147 days	6310[a] (days 1-147)	
		259	2.50[b]	1370	6490[b]	
		311	2.34[c]	1397	6850[c]	
		222	2.64[a] (days 7-147)	1279[a] at 147 days	6900[a] (days 1-147)	
		259	1.93[b]	1320[b]	7300[b]	
		311	1.37[b]	1338[c]	7620[c]	
Pavan et al. (2005)	ISA Brown 0-6 weeks	210.52		455.53	1021.04	2.24 (per kg of feed consumed)
		228.57		448.43	1029.94	2.29
		250.00		444.77	1015.00	2.28
		275.86		457.07	1045.55	2.29
	6-16 weeks	357 reared at 210		1458.0 at 16 weeks	4774.5 at 16 weeks	4.91 at 16 weeks
		357 reared at 228		1426.7	4663.0	4.90
		357 reared at 250		1421.1	4651.0	4.98
		357 reared at 275		1442.8	4729.0	4.92
		416 reared at 210		1445.3	4836.8	4.99
		416 reared at 228		1413.5	4693.3	4.92
		416 reared at 250		1460.5	4934.3	5.01
		416 reared at 275		1435.6	4867.4	5.06
		500 reared at 210		1459.8	4969.7	5.08
		500 reared at 228		1425.4	4780.9	4.95
		500 reared at 250		1420.4	4806.3	5.00
		500 reared at 275		1430.1	4886.7	5.19
Patterson and Siegel (1998)	DeKalb Delta 1-6 weeks	97.8		398[c] at 6 weeks		
		116.1		407[bc]		
		142.9		425[ab]		
		185.8		434[a]		
	DeKalb Delta 6-18 weeks	195.6		1210[bc] at 18 weeks		
		232.3		1242[b]		
		285.9		1329[a]		
		371.6		1357[a]		

	Hy-Line W-36 1-6 weeks	97.8		372 at 6 weeks		
		116.1		377		
		142.9		373		
		185.8		379		
	Hy-Line W-36 6-18 weeks	**195.6**		**1161^{d} at 18 weeks**		
		232.3		1182^{cd}		
		285.9		1186^{cd}		
		371.6		1215^{bc}		
	DeKalb Delta 2-6 weeks	97.8		279^{cd} wgt gain	745^{a} (g/bird)	2.67g feed intake : g weight gain (g:g)
		116.1		296^{bc}	784^{b}	2.64
		142.9		315^{ab}	849^{c}	2.7
		185.8		327^{a}	884^{d}	2.71
	DeKalb Delta 12-18 weeks	195.6		217^{c} wgt gain	2300^{d}	10.66
		232.3		245^{b}	2550^{cd}	10.46
		285.9		296^{a}	2749^{b}	9.30
		371.6		317^{a}	3161^{a}	9.99
	Hy-Line W-36 2-6 weeks	97.8		252 wgt gain	813^{a}	3.23^{b}
		142.9		254	928^{c}	3.66^{a}
		185.8		259	959^{d}	3.70^{a}
		1116.1		256	869^{b}	3.39^{ab}
	Hy-Line W-36 12-18 weeks	195.6		234 wgt gain	2114^{d}	9.06^{b}
		232.3		233	2357^{cd}	10.17^{ab}
		285.9		244	2603^{b}	10.66^{a}
		371.6		258	2436^{bc}	9.44a^{b}
Bozkurt et al. (2006)	Lohmann Brown 1-4 weeks	105.9	0.57	220.71 at 4 weeks	285.51 g/bird from 2-4 weeks	3.31 from 2-4 weeks
		134.8				
		185.3				
	ISA Brown 1-4 weeks	105.9	2.92	204.57 at 4 weeks	283.61 g/bird from 2-4 weeks	3.42 from 2-4 weeks
		134.8				
		185.3				
	Lohmann White 1-4 weeks	105.9	4.15	220.71 at 4 weeks	326.42 g/bird from 2-4 weeks	3.67 from 2-4 weeks
		134.8				
		185.3				
	Bovans White 1-4 weeks	105.9	6.98	195.58 at 4 weeks	291.05 g/bird from 2-4 weeks	3.81 from 2-4 weeks
		134.8				
		185.3				
	Lohmann Brown 4-16 weeks	211.8	3.72	1492.36 at 16 weeks	2999.31 g/bird from 12-16 weeks	7.37 from 12-16 weeks
		274.5				
		370.6				

Reference	Strain of birds	Space allowance (cm^2/bird)	Mortality (%)	Body weight (g)	Feed intake (g)	Feed conversion
	ISA Brown 4-16 weeks	211.8	4.97	1438.07 at 16 weeks	2843.23 g/bird from 12-16 weeks	8.05 from 12-16 weeks
		274.5				
		370.6				
	Lohmann White 4-16 weeks	211.8	8.13	1202.43 at 16 weeks	2805.20 g/bird from 12-16 weeks	11.93 from 12-16 weeks
		274.5				
		370.6				
	Bovans White 4-16 weeks	211.8	10.23	1115.45 at 16 weeks	2650.14 g/bird from 12-16 weeks	10.6 from 12-16 weeks
		274.5				
		370.6				
	All Strains 1-4 weeks	105.9-211.8	3.64	213.33[a] at 4 weeks	281.61[b] g/bird from 2-4 weeks	3.3[c] from 2-4 weeks
		134.8-274.5	3.79	205.72[b] at 4 weeks	285.39[b] g/bird from 2-4 weeks	3.54[b] from 2-4 weeks
		185.3-370.6	3.54	212.13[b] at 4 weeks	322.96[a] g/bird from 2-4 weeks	3.82[a] from 2-4 weeks
	All Strains 4-16 weeks	105.9-211.8	6.84	1275.34[a] at 16 weeks	2733.29[b] g/bird from 12-16 weeks	9.94 from 12-16 weeks
		134.8-274.5	7.03	1340.35[b] at 16 weeks	2808.23[b] g/bird from 12-16 weeks	8.63 from 12-16 weeks
		185.3-370.6	6.46	1320.54[c] at 16 weeks	2931.9[a] g/bird from 12-16 weeks	9.91 from 12-16 weeks
Keshavarz (1998)	Babcock B300 8-18 weeks	283 346		1261[a] 1284[b]	3995[a] g/bird 4157[b]	6.22 g:g 6.24

Effect of Density during Floor Rearing

In 2 experiments aimed at assessing the effects of group size and density during floor rearing on laying hen welfare and performance, Meunier-Salaün et al. (1984) reared medium hybrid birds on the floor and moved them into cages (4 birds/cage; density of 450cm^2/bird) at 19 weeks. In their first experiment, group size during rearing and placing hens in cages with familiar vs. unfamiliar birds were factors. Group sizes were 10, 60, or 500 birds (5882, 1000 and 1000cm^2/bird, respectively). In a second experiment, birds were housed at densities of 1000, 2000, or 3030cm^2/bird in groups of 60 birds. Egg production characteristics, foot health, skin injury, plumage condition, and mortality were not affected by any factor in either experiment. These results were in agreement with earlier findings by Wells (1972) who found no effects of rearing light hybrids in flocks of 400 at 700, 930, 1390, or 1860cm^2 of floor area per bird on egg production, mortality, weight, and feed consumption after transfer to either cages or to deep litter.

Effects of Feeder Space during Rearing

Few studies have addressed the effects of feeder space during rearing; however, in one study the amount of feeder space was shown to affect growth of pullets reared in cages and in floor pens. White Leghorn pullets were given 5.4, 4.0 or 2.7cm of feeder space (Anderson & Adams, 1994a). Treatment differences in body weight due to feeder space were observed by 12 weeks of age and by 18 weeks, body weights were significantly higher in pullets given 5.4 versus 2.7cm of feeder space with those given 4.0cm being intermediate in both types of rearing environment. There was no effect of feeder space on mortality, skeletal development, bone strength, or fearfulness. There were also no long-term effects on hen-day egg production or feed conversion when these pullets were subsequently moved to the layer house and housed in cages at 348cm^2/hen (Anderson & Adams, 1994b).

EFFECTS OF FLOOR VS. CAGE REARING ON HENS HOUSED IN CAGES

One of the concerns associated with moving birds from floor pens to cages is that birds' perceptions of space may be affected by their early experience. In a preference study, Lagadic and Faure (1987) reared birds on deep litter from hatch to 18 weeks of age before moving them to cages. At 12 months of age, hens were trained to increase their cage size from 1600 to 6100cm^2 by pecking at a key; the extra flooring was covered with either wood shavings or wire mesh. Hens were willing to work for extra space regardless of the type of flooring. Using this same operant set-up, Faure (1991) found that when tested at 50 to 66 weeks of age, birds kept in cages (4 birds/1800cm^2) during the laying period worked less to enlarge their cages than birds kept in floor pens (4 birds/6m^2) during lay. Faure concluded that hens in cages adapted to space restriction.

In two experiments Craig et al. (1988) compared the behavioural responses of floor-reared and cage-reared pullets after transfer to conventional cages stocked at 403cm^2/hen at 18 weeks (Experiment 1) or 372cm^2/hen at 19 weeks of age (Experiment 2). Birds were observed on days 1, 4, and 15 after transfer. In both experiments floor-reared pullets showed significantly more crouching, less movement, and lower feed consumption than cage-reared pullets on day 1. By day 4 floor-reared pullets still consumed less feed; by day 15 no differences were seen for crouching, amount of movement or feed intake. Cage-reared pullets had more feather pecking on day 1 but less on day 15 than floor-reared pullets. Birds from the 2 rearing environments did not differ in post-housing daily gain in body weight. Agonistic activity was greater among floor-reared than cage-reared pullets. In general, rearing environment had temporary effects on behaviour after pullets were transferred to their production environment. Craig et al. (1988) reasoned that the cage rearing environment resembled the laying house production environment in several ways but the floor rearing environment was generally different; hence, the early reduction in general activity shown by floor-reared birds indicated that they were initially more fearful of the novel cage environment than the cage-reared birds.

Jin and Craig (1988) compared the performance of 3 strains of conventionally caged White Leghorn hens reared in either cages (30 birds/cage at 145 and 310cm^2/bird at 0 to 2 weeks and 2 to 19 weeks, respectively) or floor pens (930cm^2/bird in groups of 120 birds). Birds reared in cages were heavier at 19 weeks and came into lay sooner but there were no differences in mortality during rearing. There were no carry-over effects in the laying period (birds stocked at 348cm^2 floor space) on any egg production traits or fear response to a person standing outside of the cage; feather condition was poorer at 60 but not at 75 weeks in the floor-reared birds. Anderson and Adams (1994b) reared White Leghorn pullets at densities of either 304cm^2 in cages or 735cm^2 in floor pens and subsequently moved them to conventional cages stocked at 348cm^2/bird. Rearing environment had no effect on hen-day production or feed conversion, but hens reared in cages produced heavier eggs with fewer body-checks (irregularities in egg shell formation) and were less fearful at the end of lay than floor-reared birds.

Few studies have examined the effect of rearing environment on production and welfare measures of laying hens housed in furnished cages. In 1 of 2 trials investigating mortality in 3 styles of furnished cages (group sizes ranging from 10 to 60 hens), Weitzenburger et al. (2005) compared mortality of LSL hens that were reared either on litter floors (no perches) or in standard rearing cages. Overall, mortality was significantly greater for those hens that had been reared in floor pens (7.9%) vs. cages (2.1%) with the highest mortality occurring in the larger groups that were reared in floor pens (10.1%). The major cause of death in this study was cannibalism; the authors, however, did not indicate whether or not the birds were beak treated. In a smaller scale study, Roll et al. (2008) reared brown strain pullets in either standard rearing cages or floor pens with litter (no perches), then placed them in 10-bird furnished cages. Egg production, feather condition, and mortality were not affected by rearing environment although the numbers of cracked and dirty eggs were greater for floor-reared birds; shell strength and thickness were lower at the end of lay for the floor-reared birds. In a commercial scale experiment comparing effects of rearing in aviaries vs. cages on the behaviour of hens housed in furnished cages, Janczak et al. (2013) found transient effects of rearing environment on comfort behaviour (greater in aviary-reared hens) and responses to fear tests (lower in aviary-reared); by 5 weeks after moving to adult housing, there were no treatment differences.

Moe et al. (2010) investigated the effects of rearing environment (floor vs. cage-reared) on adrenal activity, immune response and H:L ratio in laying hens housed in either conventional or furnished cages. There was no effect of rearing system on adrenal responsiveness (ACTH challenge) at 50 or 70 weeks of age but at 70 weeks of age, H:L ratios tended to be higher in hens reared on deep litter and were significantly higher in hens reared on litter and moved to furnished cages. Conversely, antibody production in response to immune challenges was greater in the hens that had been reared on litter. While results of H:L ratio indicated that floor-reared birds may have experienced more stress particularly when they were housed in furnished cages during the laying period, the immune response in floor-reared hens was better. The authors suggested that the effects on immune response may have been associated with pathogenic load found in the floor and furnished caged environment rather than stress due to the rearing system or housing system *per se*.

Walstra et al. (2010) also found that rearing chicks on litter may enhance some immune responses to infectious disease. Chicks were incubated and hatched in either suboptimal vs. optimal conditions and then reared in cages or in floor pens enriched with shavings, peat, and perches from 0 to 7 weeks of age. At 53 and 92 days of age, birds were challenged with Eimeria and infectious bronchitis (IB). Optimal incubation and hatch conditions followed by enriched floor rearing resulted in the least amount of weight loss, highest feed intake in the days after Eimeria infection, and highest weight gain after IB infection compared with all other treatment combinations. Whereas optimal prenatal incubation environments are thought to increase chick quality, and thus a stronger animal post hatch in general, the positive effects of the enriched rearing environment on performance and recovery following the Eimeria infection may be attributed to the microorganisms in the litter that were believed to stimulate development of the immune system.

FACILITATING PULLET ADAPTATION TO ADULT HOUSING

Hens and pullets are highly motivated to perch and prefer to use the highest perches available, indicating that vestigial anti-predator behaviour still exists despite many generations of domestication (Newberry et al., 2001). Chicks begin perching around 7 to 10 days of age (Workman & Andrew, 1989) and the amount of time spent perching steadily increases over time. Heikkila et al. (2006) found that the number of days to the first observed bout of perching was negatively related to the time spent under the heating lamp during the first few weeks of life. There was also a positive relationship between early daytime perch use and later perch use for night time roosting.

A number of studies have shown that there is a learning component to perching and to birds' abilities to navigate complex environments. Hens reared without perches were less likely to lay in nest boxes, even at ground level, than hens reared with perches; indeed hens that only had experience on one level had difficulty stepping up to another level (Appleby et al., 1988). Appleby and Duncan (1989) first proposed that perching requires learning to recognize that moving in more than 2 dimensions is possible; they also proposed that learning is easier during a sensitive phase when birds are very young. Gunnarsson et al. (2000) reared day-old chicks in litter pens with or without access to perches. At 8 weeks of age, all birds were given access to perches. At 16 weeks they were presented a series of consecutive tests, each test involving increasing difficulty for the bird to reach food located on alternating tiers placed at 40, 80, and 160cm above the ground. There was no difference between birds reared with or without perches on time to reach the food on the lowest tier. However, in tests requiring birds to access the higher tiers by jumping from one tier to the next, birds reared without perches took longer or did not reach the food.

Experience with perches in complex environments is particularly important for pullets destined for aviaries since a lack of ability to navigate 3-dimensional space increases the risk for emaciation, dehydration and floor eggs when food, water, and nest boxes are located on different levels (Tauson, 2005). Provision of perches also allows subordinate individuals the opportunity to avoid pen mates and increases space availability for the birds (Cordiner and Savory, 2001). Access to perches from the fourth week of life has been shown to decrease the later prevalence of floor eggs and cloacal cannibalism in laying hens housed in aviaries (Gunnarsson et al., 1999). Apart from behavioural effects, early access to perches may also benefit pullet and hen health. Pullets provided access to perches in pullet rearing cages from 1 day of age had greater bone mineral content of the tibia, sternum, and humerus as well as greater muscle deposition at 12 (Enneking et al., 2012) and 71weeks of age (Hester et al., 2013), with no effects on a number of stress responses measured during rearing (Yan et al., 2013). There are a variety of commercial rearing systems that provide access to perches and 3-dimensional space at different times during the growth period. The body of literature on early experience and adaptation to complex environments suggests that exposing pullets to perches, platforms and different levels early in development (during the first few weeks of life) may be critical for their behavioural and physical development.

The use of other furnishings in enriched layer environments may also be affected by early experience. Sherwin and Nicol (1993) found that litter-reared hens were more likely to lay outside of the nest area and to be less stable in their choice of nest sites when transferred to enriched cages during the laying phase than cage-reared birds. However, earlier transfer to laying cages reduced this effect and time of transfer to laying environment (16 weeks or earlier) was more important for the numbers of floor eggs than rearing environment. More recently, Roll et al. (2008) compared floor-reared and cage-reared birds on adaptation to furnished cages. After transfer at 18 weeks, birds were observed until 78 weeks. Time spent walking was higher and perching was lower in cage-reared hens than in floor-reared hens. The use of dust baths increased in general over the laying period but all dust bath parameters were higher in floor-reared vs. cage-reared hens.

Matching the rearing environment to the adult environment is thought to ease the transition to the layer house and reduce problems such as feather pecking and cannibalism especially in non-cage and aviary systems (van der Weerd and Elson, 2006). In a systematic review of mortality of laying hens in aviaries, Aerni et al. (2005) reported that genotype and rearing environment (if and when chicks were exposed to litter) accounted for the majority of mortality in non-cage systems. There has been interest in studying methods of adapting birds to aviaries. For example, birds reared in aviaries and furnished floor pens were transferred to laying aviaries at 17 weeks old and then Colson et al. (2005) measured mobility/space use and production performance through the laying period until 69 weeks of age. Aviary-reared birds used more platforms with feed troughs, flew and jumped more than floor-reared hens. They also laid more eggs than floor-reared hens, with fewer eggs laid outside of nests. The researchers concluded that aviary-reared hens used overall space better than floor-reared hens because of a better habituation of aviary-reared birds to the vertical level (i.e. more flights and jumps enabled them to find feed and nests more efficiently). In another study Colson et al. (2008) compared use of space, production and mortality of birds reared in floor pens furnished with platforms, perches, and manual feed hoppers located on the litter floor, birds reared in aviaries with platforms and manual feed hoppers located on the litter floor, and birds reared in aviaries with automatic chain troughs located on multi-tiered platforms. Hens were transferred to laying aviaries with automatic chain troughs on platforms at 17 weeks. Hens reared in floor pens used upper levels less, showed poorer accuracy in long flights and jumps, and spent more time on the lower levels compared to hens reared in aviaries. The mortality rate of floor-reared hens was higher than that of both types of aviary-reared pullets before transfer and higher than that of hens reared in aviaries with feeders located on platforms after transfer. Pullets reared in aviaries with feeders on the floor used lower levels more and made more longer flights than birds reared in aviaries with feeders on platforms before transfer but these differences disappeared after transfer. Following transfer, mortality was higher in hens reared in aviaries with feeders on the floor compared to those reared in aviaries with feeders on platforms. It was concluded that rearing pullets in aviaries rather than furnished floor pens ensured better adaptation to laying aviaries because of improved ability to navigate upper levels and to find feed.

A number of factors can influence the ranging behaviour of hens in free range systems. In some cases, birds housed in free range systems may be reluctant to leave the poultry house and to move out onto the range when given the opportunity; as a result, only a small proportion of hens in free range flocks are normally seen outside at any one time (Keeling et al., 1988). Only a few studies have addressed the effects of rearing experience on ranging behaviour of laying hens. Grigor et al. (1995) compared the behaviour of hens subjected to regular handling (caught, crated, and released into a floor pen), regular exposure to the outdoors (caught, crated, and released into an outdoor paddock) or no handling (controls) from 12 to 20 weeks of age. Treatment had little effect on fear tested by tonic immobility but birds handled and exposed to the outdoors emerged from a box more quickly and moved farther away from the box than handled and control birds when given an emergence test conducted outdoors. When comparing the behaviour of birds in a free range flock, the authors found that birds regularly observed outdoors were less fearful than birds never observed outdoors as measured by tonic immobility tests. More recently, Krause et al. (2006) tested learning and memory of 6 week old layer chicks exposed to 1 week of access to an outdoor area compared to chicks reared in identical floor pens but without access to the outdoors. Chicks with outdoor access were less fearful and learned to find a food reward significantly faster than controls but once the birds in both treatments learned the task, they did not perform differently in memory trials. As the literature on this topic is sparse, more research is needed to determine appropriate rearing methods for hens in free range systems.

More research in general is needed to better understand the optimal rearing practices that best prepare birds for their production environment.

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2. HOUSING: CONVENTIONAL, FURNISHED, AND NON-CAGE SYSTEMS

CONCLUSIONS

1. **All housing systems have both costs and benefits for hen welfare. In all systems, welfare improvements can be made through close attention to the specifics of the housing design, management, rearing conditions, and choice of strain.**
2. **Infectious diseases and internal and external parasites can occur in any housing system; the risks for these diseases to develop and spread are higher in free range and other non-cage systems compared to conventional and furnished cages. However, vaccination and health management strategies can affect prevalence of infectious diseases in these systems.**
3. **The risks of non-infectious disease such as fatty liver and osteoporosis are greater in conventional cages than in systems providing more freedom of movement.**
4. **Whether or not hens are beak trimmed, strain and level of management significantly interact with type of housing system to affect mortality. The general trend in the literature is that mortality increases in the order of cages (furnished and conventional), indoor non-cage systems and free range systems.**
5. **Foot problems can be found in all types of housing systems but type and severity differ across system. In general there is a greater risk for hyperkeratosis and excessive claw growth on wire floors whereas the risk for foot pad dermatitis and bumblefoot are greater on (wet) litter floors and with some perch designs.**
6. **The risks of injury, and in particular broken keel bones, are significantly greater in non-cage systems compared to conventional and furnished cages and the risk of broken keels is affected by system design. Additionally, there is a risk of keel damage when hens are provided perches but this is affected by perch design. The risk for broken bones during depopulation is greater in conventional cages compared to non-cage systems and this risk is affected by handling methods.**
7. **Egg production (or at least eggs collected) and feed conversion rates are similar for conventional and furnished cages and are better compared to non-cage systems.**
8. **Hens are motivated to perform nesting, foraging, perching, dust bathing, locomotion, and comfort behaviours (stretching limbs and wings). These behaviour patterns are significantly constrained in conventional cages due to lack of space and amenities. In furnished cages, nesting, perching and comfort behaviour appear to be well supported. However, foraging and dust bathing do not appear to be fully supported by scratch mats and this depends on the size and provision of sufficient litter or feed on the mat.**
9. **When hens are provided enclosed nest areas, the areas are generally well-used for egg laying. Hens with enclosed nesting areas spend more time sitting during the pre-laying period than hens without them.**
10. **Cages furnished with nest areas, perches and scratch mats generally maintain health and hygiene benefits of conventional cages while supporting the expression of some of the hens' motivated behaviour patterns.**

INTRODUCTION

Measures used to assess the welfare of hens in different housing systems can include aspects of biological functioning (e.g. egg production, health, physical condition, mortality, and stress indicators), affective states (e.g. conditions leading to pain, discomfort, fear, frustration, and pleasure), and natural living (e.g. ability to perform species-typical behaviour patterns). In the last decade, a number of literature reviews have been published on experimental studies concerning the welfare of laying hens in different housing systems (Barnett & Hemsworth, 2003; European Food Safety Authority [EFSA], 2005; Rodenburg et al., 2005; Lay et al., 2011; Freire & Cowling, 2013). Additionally, there have been several reports comparing various welfare measures in different housing systems from data collected on large-scale commercial farms across the European Union (Tauson, 2005; Elson & Croxall, 2006; Blokhuis et al., 2007; Rodenburg et al., 2008; Sherwin et al., 2010; LayWel). For this chapter we have mainly relied on these published reviews and reports. Additional primary references are used when there are discrepancies in the conclusions, a need to update the literature with more recent findings, or for clarification.

DESCRIPTION OF HOUSING SYSTEMS

A cage system is defined as one in which the caretaker does not enter the enclosure where the hens are housed. In Canada, conventional (unenriched) cages are generally small enclosures with wire mesh and sloping floors typically housing 4 to 8 hens. They provide equipment for feeding, drinking, egg collection, manure removal, insertion and removal of hens, and sometimes claw shortening. Furnished cages (also referred to as “enriched cages” or “enriched colony” systems) provide all of the equipment found in conventional cages with the addition of equipment that is intended to allow hens to express some of their behavioural priorities. These typically include perches, a defined nest area, a scratch mat or dust bath, a claw shortening device, and extra cage height. Furnished cages are larger than conventional cages and contain more hens, typically 10 to 30 hens in small and medium enriched cages whereas large enriched colony systems have group sizes ranging from 40 to upwards of 100 hens.

Non-cage systems (also referred to as “alternative” or “cage-free” systems) house larger groups of hens than cage systems (usually more than 1000 hens) and caretakers enter these systems to perform their duties. Indoor non-cage systems may or may not be combined with outdoor facilities. Single level systems include a ground floor area that is fully or partially covered with litter and/or perforated floors. There is only one level for the birds at any one point, even if this level is stepped. Multi-level systems such as aviaries consist of the ground floor plus one or more levels of platforms. At some point across the system, there are at least two levels available for birds. Similar to furnished cages, non-cage systems usually include communal nests and perches. Indoor-only systems are referred to as “free run” or “barn” systems. Free range systems provide access to an outdoor, uncovered area, usually with some vegetation. Hens have access to this outdoor area from fixed or mobile houses via doors or pop holes in the wall. Additionally, they may have a covered veranda.

There is considerable variation in the specifications of housing systems falling within the above general styles and the meaning of labels such as “free range” varies between countries depending on regulations, where present. Even in Europe, where conventional cages are no longer permitted, different housing systems must meet specific requirements and as those have evolved over the years, so have barn workers had to adjust their management practices. Because housing systems differ in multiple ways, it is often unclear which specific factors contributed to a difference found between housing systems. Therefore, caution is needed in interpreting and comparing results from different housing systems, countries, and years.

BIOLOGICAL MEASURES OF WELFARE AFFECTED BY HOUSING SYSTEM

Disease, Parasites, and Mortality

Infectious diseases of viral and bacterial origin, intestinal parasites such as coccidia and worms, and ectoparasites such as mites can occur in any housing system, although some systems increase the risk of these diseases to develop and spread (EFSA, 2005; Lay et al., 2011). Bacterial infections, viral diseases, coccidiosis, and red mites are generally reported to be higher in litter based and free range systems when compared with conventional and furnished cages (Fossum et al., 2009; Rodenburg et al., 2008). Contact with soil, litter, feces, and other vectors (e.g.

rodents, beetles, and equipment carrying infectious agents) increases the risk of infectious and parasitic disease. For example, hens with access to free range are more likely to excrete coccidial oocysts in their feces and have greater incidences of intestinal helminthes compared to hens that do not have access to free range. Free range birds also have exposure to wild birds that can potentially carry avian influenza, Newcastle disease, and ectoparasites (Lay et al., 2011). Based on a retrospective analysis of necropsy results from mortality collected from Swedish systems, Fossum et al. (2009) reported a relatively higher occurrence of bacterial and parasitic diseases in hens from litter based and free range systems and a relatively higher occurrence of viral infections in hens from indoor litter based systems compared to hens from cages (data from conventional and furnished combined). A Swiss survey (Kaufmann-Bart & Hoop, 2009) reported a consistent decrease in the proportion of hens submitted for necropsy that were diagnosed with viral disease, parasitism, and non-infectious diseases during the 12 year period following a ban on conventional cages. The relative change in prevalence of these conditions was attributed to improved vaccination and management in litter based and free range systems.

Occurrence of infectious diseases (Tauson & Holm, 2002; EFSA, 2005) appears to be similar in furnished and conventional cages, whereas non-infectious conditions such as fatty liver and kidney disease and osteoporosis are more prevalent in conventional cages than in systems providing greater freedom of movement (Lay et al., 2011). Intestinal parasites such as coccidia, roundworms (ascarids), cecal worms (*Heterakisgallinae*) and capillaria are usually not a problem in hens housed in conventional cages with wire floors, mostly because the fecal-oral transmission of the parasite is interrupted. Similarly, prevalence of ascarid infection appears to be very rare in furnished cages (Jansson et al., 2010), probably because of minimal fecal exposure. Lay et al. (2011) classified ectoparasites into 2 categories: nest dwelling and permanent. Nest dwellers live in the bird environment and travel to the birds to feed on blood only part of the time. Nest dwelling parasites like red mites survive well in complex environments with lots of small hiding places; therefore, non-cage systems are more prone to harbouring these organisms than suspended wire cages (EFSA, 2005). According to Lay et al. (2011), the rough order of risk from most to least for nest dwelling ectoparasites would be non-cage systems, furnished cages, and then conventional cages. Permanent ectoparasites, like the northern fowl mite and body louse, complete their entire life cycle on their host. There is currently insufficient information from non-cage systems to predict the relative risk for permanent ectoparasites in different housing systems (Lay et al., 2011).

The causes of mortality in laying hens include infectious and non-infectious disease and injuries. Cannibalism can contribute significantly to mortality; therefore, strain differences in cannibalism and whether or not birds are beak trimmed can interact with housing type to affect mortality rates. EFSA (2005) reported mortality rates from numerous experimental studies and field reports conducted between 1996 and 2004. Non beak-trimmed hens from experimental flocks had lower mortality in small furnished cages (1.4 to 3.2%) compared to conventional cages (3.9%) (Abrahamsson & Tauson, 1997) and in large furnished cages (3.5 to 5.5%) compared to conventional cages (6.8%) and aviaries (9.3%) (Zoons 2004 as cited in EFSA, 2005). Mortality rates of beak trimmed birds were lower on average (5%) in conventional cages than in barn and free range systems (8%) in a survey of commercial flocks in the UK (National Farmers' Union [NFU], 2003 as cited in EFSA, 2005). Sherwin et al. (2010) reported that mortality rates on commercial farms in the UK were lowest in furnished cages followed by conventional cages, free range, and barns, respectively, and Rodenburg et al. (2008) found mortality rates of 3% in furnished cages (2 out of 6 flocks were not beak trimmed) and 8% in non-cage systems (all 7 flocks were beak trimmed) in a survey of commercial flocks in The Netherlands, Belgium and Germany. Weeks et al. (2012) found that mean levels of on-farm mortality during the laying period, for a total of 1,486 flocks in Great Britain, were significantly lower in cages (5.39%) than in barns (8.55%), free range (9.52%) or organic flocks (8.68%) according to producer records at a median of 7 days before depopulation, with considerable variation between flocks in all systems. Similarly, Fossum et al. (2009) reported that mortality rates in Sweden (where hens are not beak trimmed) were lower in cage systems than in barn and free range systems. The general trend is that mortality increases in the order of cages (furnished and conventional), indoor non-cage systems, and free range systems (EFSA, 2005; Elson & Croxall, 2006). In contrast, systematic (Aerni et al., 2005) and quantitative (Freire and Cowling, 2013) reviews of experimental studies detected no difference in mortality between conventional cages and alternative systems, and the authors noted that mortality was mainly affected by whether or not birds were beak trimmed. However, these two studies did not include any extensive field reports. The LayWel report (Blokhuis et al., 2007), which was based on a large European database derived from both experimental and field reports, indicated a significant effect of beak trimming (mortality higher in non-trimmed flocks) and an interaction between housing system and whether the data came from commercial or experimental farms. This indicated that management practices have a large impact on mortality rates. The strain of bird also plays a role in mortality levels with white feathered genotypes typically displaying lower mortality rates than brown genotypes (EFSA, 2005; Blokhuis et al., 2007; LayWel).

Smothering can account for a significant amount of mortality in non-cage and free range flocks, when birds mass together, often on top of one another, leading to death by suffocation (EFSA, 2005; Bright & Johnson, 2011). Smothering may occur during panic and hysteria resulting from a disturbance such as a predator, loud noise or change in light intensity and from crowding in the nest box, which is most prevalent when hens are coming into lay (Bright & Johnson, 2011). More research is needed to determine the causes of smothering outbreaks.

Foot Health

Foot disorders and damage can be found in all types of housing systems but the type and severity differ from one system to another and are influenced by genetic strain and perch design (EFSA, 2005). Foot pad dermatitis (pododermatitis) is a condition in which the plantar surface of the foot is inflamed and sometimes ulcerated. Bumblefoot is a condition whereby a local infection causes an abscess to form on the plantar surface of the foot. These abscesses usually contain Staphylococcus bacteria and result in severe inflammation and swelling of the footpad. It often causes lameness and is considered to be painful (EFSA, 2005). Moist perches and wet litter, increase the incidence of bumblefoot by several fold compared to when these areas are kept dry (EFSA, 2005). Perch design alters weight distribution and therefore pressure on the footpad (Pickel et al., 2011) and has been shown to affect development of bumblefoot; designs that minimize localized pressure on the footpad, for example oval, flattened or mushroom shape vs. round, have been recommended (Struelens & Tuyttens, 2009). In several studies by Tauson and Holm (1998, 2001, and 2002), bumblefoot occurred at levels under 5% in small furnished cages, whereas in aviaries and traditional litter floor housing, levels were 3 to 4 times higher. Similarly, Elson and Croxall (2006) found that conventional and furnished cage systems generally had the lowest incidences of bumblefoot. Rodenburg et al.'s (2008) on-farm comparison of furnished cages with non-cage systems also indicated no differences in footpad dermatitis between different housing systems.

Hyperkeratosis is the hypertrophy of the corneal layer of skin and occurs on the toes and footpads of hens in conventional cages in particular. It is caused by compression load of the toe or footpad on the wire floor of cages. Lower incidences of hyperkeratosis have been reported in furnished cages compared to conventional cages (Abrahamsson & Tauson, 1997) and in aviaries compared to cages (Abrahamson & Tauson, 1995). Sloping wire floors have been implicated as exacerbating the problem of hyperkeratosis in conventional cages as compared to non-cage systems (Lay et al., 2011).

Particularly in conventional cages, laying hens may have excessive claw growth leading to breakage and even trapping of the claw either with or without damage to foot tissue. Shortening and blunting of the claws of caged hens can be done by fitting an abrasive strip on the baffle plate behind the feed trough. Hester et al. (2013) found that hens with low metal perches added to conventional cages had shorter claws overall, but more broken back claws compared to hens without perches. Litter in non-cage systems encourages scratching behaviour that prevents excessive claw growth (Lay et al., 2011). However, Michel (2002, as cited in EFSA, 2005) found that claw length of brown layers did not differ between conventional cages and aviaries. Claw wear may be influenced by specific conditions within housing systems that affect the amount of contact between the claws and abrasive surfaces, such as litter depth and the texture of concrete flooring. Claw length differs by strain, with the claws of medium heavy brown genotypes being shorter than those of white laying strains (EFSA, 2005). Consequently, excessive abrasive materials may cause too much claw wear, particularly in brown layers (EFSA, 2005). Data are lacking on the relative effectiveness of different designs of perches or claw shortening devices in current furnished cage designs on claw length.

Physical Condition

The prevalence of feather damage and body wounds is often related to the housing system and whether or not hens are beak trimmed. Sherwin et al. (2010) compared conventional cage, furnished cage, barn and free range systems in the UK in which the majority of hens were beak trimmed. Feather damage was lowest in free range hens and highest in barn hens, whereas the proportion of hens that were vent pecked was twice as great in free range systems as compared to the other 3 systems. In a Swedish study, ventral wounds were found on 42 to 49% of non-beak trimmed 80-week-old birds in aviary systems as compared with 21% in conventional cages while corresponding numbers for dorsal wounds were 39 to 68% and 21%, respectively (Abrahamsson & Tauson,1995). In a comparison of a single level litter system and furnished cages, Tauson and Holm (2001) reported comb wounds in approximately 61% and 14% of hens, respectively. The corresponding numbers for wounds on the rear part of the body were 23% and 5%. Elson and Croxall (2006) found that conventional and furnished cage systems were associated with the lowest incidences of comb wounds, proposing that a higher rate of comb wounds in aviaries and free range systems was due to higher levels of aggressive pecking. However, Rodenburg et al. (2008) found no differences in vent or comb wounds among different housing systems and serious wounds were rare. Similarly, Freire and Cowling (2013) detected no differences in body wounds between systems in their analysis. The use of solid sides between conventional cages can significantly improve feather condition due to less abrasion within cages and less feather pecking between cages (EFSA, 2005).

The main concern with osteoporosis is bone weakness and brittleness leading to easily fractured bones. In conventional cages severe osteoporosis can lead to vertebral compression fractures and paralysis (cage layer fatigue). Although improved nutrition has reduced cage layer fatigue, bone fragility related to lack of exercise is still a concern. Even brief static and dynamic loading exercise of bones as a result of taller cages, more floor space, and provision of low perches in cages can improve skeletal strength (Lay et al., 2011). Freire and Cowling (2013) reported that birds from furnished cages and multi-level indoor systems had stronger bones than those kept in conventional cages and Michel and Huonnic (2004) found stronger wing and leg bones in aviaries than conventional cages. Rodenburg et al. (2008) noted that birds in non-cage systems had stronger wing and keel bones than birds in furnished cages but no differences in leg bone strength.

Stronger bones can reduce the incidence of bone fractures, especially during depopulation (Lay et al., 2011). However, despite stronger bones in non-cage systems, a higher incidence together with a greater severity of old healed keel bone fractures is typically found in non-cage systems than furnished cages and conventional cages (Elson & Croxall, 2006; Rodenburg et al., 2008). This bone breakage is not necessarily caused by bone weakness but could result from bumping against housing fixtures and accidents when jumping from elevated perches and aviary tiers (Rodenburg et al., 2008; Lay et al., 2011; Freire & Cowling, 2013).

In a study comparing conventional cage, furnished cage, barn and free range systems, Sherwin et al. (2010) found that birds in every housing system had keel bone fractures. Newer bone fractures were 5 times more likely to be found in birds from conventional cages (with a prevalence of 24.6%) and were believed to be due to damage occurring during depopulation. The prevalence of old keel bone fractures was the worst in barn systems at 69.1% , followed by free range systems at 59.8%, furnished cages at 31.7% and then conventional cages at 17.7% (Sherwin et al., 2010). Body weight and keel protrusion were measured as indicators of possible emaciation. Hens from barn systems were the lightest and had the greatest prevalence of severe keel protrusion. However, the greatest proportion of hens with some degree of keel bone protrusion was noted in free range hens. Hens from conventional cages were heaviest and had the lowest incidence of severe keel bone protrusion. Wilkins et al. (2011) found that flocks housed in furnished cages had a lower prevalence of keel fractures at the end of lay (36%) than flocks housed in systems with multi-level perches (over 80%). The higher the maximum perch height, the greater the keel damage, with more damage occurring when perches were located over slats than litter. The height of slatted areas above the litter was also a risk factor for keel bone damage. Based on palpation, Richards et al. (2012) observed an increased incidence of keel bone damage in free range hens as age increased from 25 weeks (5.5%) to a range of 68 to 70 weeks (78.5%). They noted that greater severity of keel bone damage was associated with reduced use of pop holes (access to the range) during cool weather, which they speculated could be due to pain resulting from damage to muscle tissue surrounding the keel. Nasr et al. (2012; 2013) provided experimental evidence supporting the idea that keel fractures cause pain. Supplementing the diet of free range hens with omega-3 alpha linolenic acid dramatically improved bone health by comparison to feeding standard diets rich in omega-6 (40-60% reduction in incidence of keel bone fractures, Tarlton et al., 2013).

Measures of Stress

Lay and colleagues (2011) reported on relative levels of physiological stress found in experimental studies using various measures of stress response including plasma corticosterone, heterophil:lymphocyte (H:L) ratio, and antibody titres. Results did not differ consistently between conventional cages, furnished cages, and non-cage systems, suggesting that different outcomes depend on the exact conditions being compared in different studies. Freire and Cowling's (2013) quantitative analysis of hen housing studies also indicated that measures of stress were unaffected by housing system although there was some indication that immune response (antibody titre) was higher in birds housed in conventional cages. Fecal corticosterone concentrations in samples collected from commercial flocks in non-cage (barn) systems were significantly higher than those from furnished and conventional cages, with concentrations in samples collected from free range farms being intermediate (Sherwin et al., 2010).

In a number of studies, specific designs, group sizes, densities, or management practices within systems have been shown to affect different measures of stress response as much or more than housing system *per se*. For example, Craig and Craig (1985) found that plasma corticosterone level was affected by handling but not by housing conditions (floor pens vs. conventional cages). Guesdon et al. (2004, cited in EFSA, 2005) did not find any difference in the level of corticosterone after an ACTH challenge between hens housed in different models of conventional and furnished cages, whereas Guémené et al. (2004, cited in EFSA, 2005) found interactions among group size, stocking density, and specific cage model on baseline corticosterone and adrenal sensitivity. Lower stress levels as indicated by H/L ratios and corticosterone levels after an ACTH challenge have been reported in birds housed in solid sided conventional cages as compared to cages with wire mesh sides and to floor pens (EFSA, 2005).

Corticosterone measurement, with and without ACTH challenge, is subject to a lot of variation due to individual differences, environmental conditions during collection, age of bird, and the time between an acute challenge and sampling. Additionally, increased corticosterone levels indicate increased arousal, which may be due to either positive or negative experiences. Thus, caution must be taken when drawing conclusions regarding differences in corticosterone levels, which need to be viewed in the context of other welfare measures (EFSA, 2005). When experiencing stressful conditions, hens will sometimes delay oviposition resulting in extra calcium carbonate on the eggshell or deformed eggs. In Sherwin et al.'s (2010) comparison of conventional cage, furnished cage, barn and free range systems, eggshells with calcification "dusting" were found at the highest proportions in non-cage (barn) eggs and at the lowest proportions in eggs from furnished cages. Calcification dusting decreased linearly with age in the furnished cages but followed a "U" shaped relationship across the laying cycle in the other three systems suggesting that earlier and later phases of the laying period may have been more stressful for birds kept in conventional cage, barn and free range systems.

Production Measures

The EFSA (2005) report summarizes productivity data from trials and surveys involving at least 2 housing systems. Tauson and Holm (2001) compared flocks in a single level non-cage system and furnished cages. Egg mass was 3% lower and feed conversion rate was 4% higher in the non-cage system. In a German study, Leyendecker et al. (2002, cited in EFSA, 2005) compared conventional cages, furnished cages, and an aviary. The highest number of eggs was collected in the furnished cages and the lowest in the aviary. Feed conversion ratio was better in cages than in the aviary. Zoons (2004, cited in EFSA, 2005) also found that the highest number of eggs was collected in furnished cages, followed by conventional cages, and the lowest number of eggs was found in an aviary. When comparing conventional cages with aviaries, Michel and Huonnic (2003) collected more eggs from caged hens than from those in the aviary and a superior feed conversion ratio was shown in conventional cages. A UK survey (NFU, 2003, cited in EFSA, 2005) also reported that the highest egg numbers were collected in conventional cages (307 eggs/hen), followed by single level non-cage systems (298 eggs/hen). Mean feed intake was lowest in conventional cages (117 g/bird/day) followed by indoor non-cage systems (124 g/bird/day) and highest in free range hens (128 g/bird/day). Elson and Croxall (2006) observed that feed usage by hens in conventional cages and furnished cages was significantly lower than in non-cage systems. Body weight and eggs collected were higher in cages, whether conventional or furnished, than in non-cage systems.

When interpreting these results, it should be noted that misplaced and broken eggs can skew the data on number of eggs collected compared to the number actually laid (EFSA, 2005). In one study an average of 26% dirty eggs was found in free range systems and backyard flocks and, in another free range study, a mean of 10 to 12% broken and 5 to 15% dirty eggs was reported whereas, in conventional cages, the average of downgraded eggs was 6.5% including 1 to 2% dirty eggs (EFSA, 2005). The number of cracked and dirty eggs can also be higher in furnished cages compared to conventional cages, depending on system design (Tauson, 2005). Compared to commercial non-cage systems, De Reu et al. (2009) found, on average, lower bacterial contamination and a greater percentage of cracked eggs in commercial furnished cage systems; however, there was considerable variation within-flock and even between flocks using the same models of systems. In non-cage systems floor laying depends on many factors (e.g. lack of rearing experience with elevated perches and platforms, delays in placement of hens in the laying house, lack of nest enclosure, insufficient nest space, and other deficits in accessibility and attractiveness of nests relative to other potential oviposition sites) and, thus, the number of eggs laid on the floor can be highly variable. A UK report on aviaries indicated floor egg percentages greater than 10% and a report on perchery systems noted 2.8 to 9.3% (EFSA, 2005). Abrahamsson and Tauson (1998, cited in EFSA, 2005) executed 5 trials and noted a percentage of misplaced eggs in non-cage systems between 0.7% and 10.5%. The percentage of floor eggs in non-cage systems has decreased considerably over time as management practices to reduce their numbers have evolved with experience (Tauson, 2005).

BEHAVIOUR AS AFFECTED BY HOUSING SYSTEM

Nesting

During the hour or so prior to oviposition, hens perform a series of pre-laying behaviour patterns that include searching for a nest site, nest-building and sitting in the nest. There is a large body of literature showing the importance for laying hen welfare of nests and the ability to display nesting behaviour (Cooper & Albentosa, 2003; Weeks & Nicol, 2006; Cronin et al., 2012). In conventional cages lacking a defined nest area, hens of some strains show extended pre-laying locomotion which has been interpreted as a sign of frustration (Yue & Duncan, 2003) and hens perform little nest-building and spend less time sitting prior to oviposition compared to hens provided with nests (Cooper & Albentosa, 2003). A number of techniques have been used to measure hens' strength of motivation to obtain access to an enclosed nest site and these have consistently shown that this resource is a high priority for most laying hens (Cooper & Albentosa, 2003; Weeks & Nicol, 2006). When nest boxes or defined nesting areas are provided to hens in furnished cages and non-cage systems, these are generally well-used.

Perching

Perches serve a number of functions in hen housing systems such as increasing use of vertical space and providing opportunities for increased exercise and roosting off the ground at night. Hens denied access to perches may show signs of agitation and increased locomotion especially around dusk (Cooper & Albentosa, 2003). In one study hens in cages with perches spent approximately 25% of their time on the perch during daylight hours, and about 90 to 100% of their time perching at night (Cooper & Albentosa, 2003). Hens show relatively little motivation to work for access to perches during daylight hours, but are strongly motivated to work for access to perches at night (Olsson & Keeling, 2002). Perching is not possible in conventional cages, whereas hens perch in furnished cages and in non-cage systems to a considerable extent and are motivated to perch on whatever highest fixtures are available (Weeks & Nicol, 2006). Questions remain about how perch design, location, and degree of elevation satisfy their motivation to perch (EFSA, 2005).The addition of perches to a housing system can have positive and negative consequences. Perches improve bone strength but crash landings can lead to bone fractures. Strategic perch arrangement within a non-cage system with multiple levels could potentially reduce hen injuries by increasing the number of successful landings (Sandilands et al., 2009).

Foraging

Foraging behaviour comprises the locomotion, pecking and scratching associated with searching for and ingesting food. In free range systems, hens may spend much of their active day performing foraging behaviour by searching for, investigating, selecting, extracting and ingesting different food items such as grass seeds, earthworms, and insects as well as ingesting grit (Lay et al., 2011).Trough-fed hens housed in wire-floored cages often perform similar motor patterns such as ground pecking on the wire and scratching behaviour while feeding. Hens also show "contra free-loading" which is the tendency to work for food rather than accept "free" food from a feeder (Weeks & Nicol, 2006). Although Bubier (1996) found that time spent pecking and scratching was relatively constant even when hens had to "pay a cost" of squeezing through a narrow entranceway to access resources for foraging, other studies aimed at measuring strength of hens' motivation to obtain foraging substrate have been equivocal (Cooper & Albentosa, 2003; Weeks & Nicol, 2006). The performance of foraging behaviour requires space for walking and scratching and a particulate substrate which birds can manipulate (e.g. compost, peat, sand, wood shavings, straw). The opportunity to forage on litter both during rearing and in production may lower the risk of feather pecking and cannibalism if the litter materials stimulate foraging behaviour sufficiently. Litter accessibility and quality also affect foraging choices (Lay et al., 2011).

Dust Bathing

Dust bathing is a maintenance behaviour that contributes to feather condition by fluffing up the downy feathers and removing stale lipids prior to replacement with fresh lipids through oiling behaviour (van Liere & Bokma, 1987). In non-cage systems, hens dust bathe together in groups in littered areas at least every few days. Preference for certain materials is in part determined by previous experience and may vary between individuals but fine particulate matter like peat or sand is generally preferred over sawdust or straw. Hens with prior litter experience usually, but not always, spend increased time dust bathing when given a suitable substrate following a period without this substrate (Cooper & Albentosa, 2003; Weeks & Nicol, 2006). In conventional cages where there is no substrate for dust bathing, and even in furnished cages where a dust bath is provided, hens may "sham dust bathe" on the wire floor. Similar to results on motivation to obtain foraging substrate, tests for strength of hens' motivation to obtain substrates for dust bathing are equivocal (Cooper & Albentosa 2003; Weeks & Nicol, 2006).

Providing opportunities for dust bathing and foraging presents a challenge in furnished cages, prompting interest in the use of feed sprinkled intermittently on a pad as a substrate for both activities. The size, surface material and amount of feed provided on scratch mats can significantly impact their effectiveness to support these activities, and dust bathing is often observed on wire floors in furnished cages (Rodenburg et al., 2012). Alvino et al. (2013) found that caged hens with no prior litter experience performed longer dust bathing bouts in a box containing sand than on an Astroturf pad, with or without feed. The hens were also less likely to sham dust bathe on wire when provided with sand. The authors concluded that Astroturf, with or without feed, is not an adequate substrate for dust bathing in furnished cages but noted that experience during rearing might affect results.

Locomotion and Comfort Behaviour

Performance of locomotory, comfort, and thermoregulatory behaviours is greatly restricted in conventional cages depending on cage size and stocking density. Rebound levels of wing flapping, tail wagging, and stretching occurred when 6 singly held hens were moved to a larger space ($2310cm^2$) after several weeks of confinement in a small area ($847cm^2$) (Nicol, 1987). In addition, the intensity of the display of these behaviours was correlated with the duration of confinement when this was replicated, suggesting that hens in this study did not fully acclimatize to extreme spatial restriction. Furnished cages provide varying amounts of horizontal space for locomotion and comfort behaviours but continue to limit behaviours in the vertical plane such as wing flapping and flying. The specific design of a furnished cage is important; for example, perches that span the width (as opposed to the length) of the cage affect space available for walking because birds have to cross over perches (Struelens et al., 2008). In non-cage systems there is sufficient space for performance of a full repertoire of locomotory and comfort behaviours. However, more learning and memory is required to find and use resources; hens best adapted to these types of systems as adults are ones that gain experience in a similar housing system during their rearing phase (Lay et al., 2011).

Aggression

Freire and Cowling (2013) found no difference across experimental studies in the amount of aggressive pecking to the head or comb amongst birds housed in conventional cages, single-level indoor systems, multi-level indoor systems, outdoor systems and furnished cages. In Lay et al.'s (2011) review, they noted that stocking density can affect aggression in non-cage systems. At lower densities there can be localized areas of high density and other areas with fewer animals, triggering aggressive defence of resources by some hens. For example, some hens may be attacked if they walk onto a littered area, effectively confining them to the slatted areas. Higher densities cause hens to be more evenly distributed across all areas of the house, which may help explain their lower levels of aggression.

AFFECTIVE STATES AS AFFECTED BY HOUSING SYSTEM

Understanding affective states and emotions in animals is considered to be of critical importance to advancing animal welfare (Dantzer, 2002; Déseré et al., 2002). Although the conscious experiences of animals cannot be measured directly, the behavioural, physiological, and neurobiological indicators of emotion can be measured (Mendl et al., 2010). Negative states such as fear and pain are often accompanied by activation of a stress response or other autonomic changes and our understanding of these states in birds and mammals has advanced considerably in the last few years. The relationships among behavioural response and neurobiological processes associated with other negative states such as frustration and positive affective states are less well understood but are currently being explored in various species including hens (e.g. Nicol et al., 2011; Gygax et al., 2013; Leliveld et al., 2013). To date, most studies concerned with affective states in laying hens rely primarily on behavioural measures.

Fear

Indicators of fearfulness (the propensity to be frightened) include crouching, running or flying in response to perceived threats. Fearfulness has been assessed experimentally using a variety of validated tests, the most common of which is the duration of TI (EFSA, 2005). The EFSA (2005) review concluded that hens show less fear of humans and novel objects in the lower than upper tiers of multi-tier conventional cages. Additionally, Rodenburg et al. (2008) found that hens from non-cage systems spent less time in TI when handled than hens from furnished cages. Hansen et al. (1993) observed that the tonic immobility response was unaffected by housing system when birds were tested at 30 weeks of age but was lower in aviaries than conventional cages at 70 weeks of age. Campo et al. (2008) also found no differences in TI response between deep litter and free range hens at 36 weeks of age. Lay et al. (2011) noted that less flighty strains are typically used in non-cage than cage housing systems.

Frustration

Housing systems differ in terms of provision of resources that enable hens to show species specific behaviours such as foraging, dust bathing, perching and nesting. A state of frustration may arise when an anticipated resource is absent or when a bird can perceive but not access a resource; rather than leave the source of frustration, birds may persist in attempts to gain access (EFSA, 2005). Zimmerman et al. (2000) observed that a vocalization known as the gakel call increased when hens were expecting but deprived of food, water, or a dust bath. On this basis Zimmerman et al. (2003) concluded that hens can be frustrated when they are prevented from dust bathing. Frustration likely arises in furnished cages when hens are competing for access to limited resources such as dust bathing and foraging materials; some hens are successful in aggressive defense of such resources from others (Lay et al., 2011). There is a large body of literature demonstrating that hens are highly motivated to access a nest box and perform pre-laying behaviour (Cronin et al., 2012). Sherwin and Nicol (1993) noted that displacement behaviours and pacing behaviour were less frequent in cages furnished with nesting facilities compared with conventional cages and that hens expressed a full repertoire of pre-laying activities including sitting on the nest, nest-building behaviours, and crouching. In general, non-cage systems contain a greater variety of potential nest sites and elicit less behaviour interpreted to indicate frustration than systems that restrict the expression of nesting behaviour (EFSA, 2005).

Although many of the behavioural responses observed when hens lack resources to express nesting, foraging and dust bathing are considered to be signs of frustration, there have been few studies attempting to measure physiological indices of stress that can be associated with negative emotional states. Neither Yue and Duncan

(2003) nor Cronin et al. (2012) found any differences in extra-cuticular calcium on eggs or plasma corticosterone, respectively, between hens housed with or without a nest box or after hens experienced with laying in a nest box were restricted access to it. However, Cronin et al. (2012) did find a significant association between pre-laying behaviour and corticosterone; hens that spent more time sitting during the 2 hours before oviposition had lower plasma corticosterone than those hens that displayed more frequent bouts of sitting or were less "settled" before oviposition.

Pain

Potential sources of pain associated with different housing systems include feather pecking, cannibalism, aggressive pecks to the head, trapping of body parts in housing fixtures, diseases, parasitic infections, foot conditions, and bone breakage (see Feather Pecking and Cannibalism, and Bone Health chapters, and sections above on Disease, Parasites, and Mortality; Foot Health; and Physical Condition). Keel bone breaks, bumblefoot, and other painful conditions may cause difficulty in moving around and accessing resources such as food, water, nests, litter, and perches, especially in non-cage systems (EFSA, 2005). The higher incidence of old (healed) fractures in non-cage than cage facilities is of concern as an indicator of chronic pain, whereas the higher incidence of new breaks in hens from conventional cages raises concerns about painful injuries arising when catching hens with fragile bones during depopulation (Lay et al., 2011).

OTHER FACTORS AFFECTING HEN WELFARE IN DIFFERENT HOUSING SYSTEMS

Dust

Dust consists of skin, feathers, food debris, as well as fecal matter and litter material when present. When hens are active, dust levels are 5 to 15 times higher in aviary systems compared to cages (EFSA, 2005). Elson and Croxall (2006) and Rodenburg et al. (2008) reported higher dust levels in non-cage systems as opposed to conventional or furnished cage systems. Aerosolized dust can have a negative impact on bird health when inhaled and has been linked to elevated mortality (Lay et al., 2011). The largest dust particles (3.7 to 7.0 microns) are deposited primarily in the anterior portion of the respiratory system while the smaller, respirable dust particles (1.1 to 0.091 microns) are dispersed throughout the system including the lungs (Hayter & Besch, 1974; Donham, 1999, cited in EFSA, 2005). Histological preparations of end-of-lay hens showed pulmonary lesions of parabronchitis or interstitial pneumonitis that were more severe in birds from aviaries than cages (Michel & Huonnic, 2003).

Ammonia

Ammonia concentrations above approximately 25 ppm can have an adverse effect on the health and productivity of laying hens, for example by causing kerato-conjunctivitis (EFSA, 2005). Wathes et al. (2002) showed that when given the option of entering compartments with 0, 10, 20, 30, and 40 ppm NH3, hens preferred the cleanest air. Concentrations of ammonia are generally higher in housing systems containing composting manure or open storage of slurry inside the house than systems with manure belts or other means of regularly removing the manure. Tauson and Holm (2001) reported ammonia levels of 1 to 2 ppm in a furnished cage system with manure belts but 5 to 40 ppm in a single-level non-cage system with litter and a slatted floor over a manure storage pit. The EFSA (2005) also reported low NH3 concentrations (<2 ppm) in furnished cages. When using a litter drying system in a tiered wire floor aviary, Groot Koerkamp et al. (1998) found a relatively low concentration of ammonia (5 ppm) in the exhaust air.

Predation

In free range systems, birds may be subjected to predation by wild predators such as hawks and foxes. Losses of 0 to 21% due to predators have been reported and these attacks do not always result in a quick death (EFSA, 2005).

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3. SPACE ALLOWANCE AND GROUP SIZES FOR DIFFERENT HOUSING SYSTEMS DURING THE LAYING PHASE

CONCLUSIONS

1. **There are linear trends for decreased mortality and increased feed intake and egg production with increasing space allowances in conventional cages. The greatest benefits are obtained as space allowance increases between 350 and 450cm^2/hen but increases above 450cm^2/hen may also have positive results on production.**
2. **The average space envelope (horizontal cross sectional area) for standing behaviour is reported to average between 475 and 563cm^2/hen. As space allowance increases above these amounts, hens are observed to engage in a greater range of behaviour patterns.**
3. **The space requirement for behavioural expression is behaviour dependent and for most behaviours exceeds the space required for standing. As group size increases in cages, there is more free space for movement and behavioural expression as birds cluster in groups.**
4. **Research on the effect of group size in furnished cages on hen well-being is limited and results do not permit a conclusion to be drawn. However, measures of production and mortality are generally not affected by group sizes ranging from 10 to 60 birds in furnished cages.**
5. **A cage height of 45cm accommodates most behaviour patterns of light hybrid birds. A cage height of 55cm may be required to accommodate wing flapping.**
6. **Research indicates that hens can accommodate a range of feeder space. However, results from an epidemiological study indicate that feeder space below 10.7cm per hen in conventional cages reduces egg production.**
7. **Research on the feeder and nest space requirements of hens in furnished cages and floor housing is lacking.**
8. **Research on the waterer requirements for hens in cages and floor housing is lacking.**
9. **Space per bird ranging from 12 to 15cm of linear perch has been shown to be adequate but may not permit 100% roosting. Cross-wise perches and other perch arrangements that limit hen access reduce the effectiveness of perch space for roosting.**
10. **There are no clear data with respect to flock sizes and stocking densities for non-cage systems. System designs, distribution of birds within a system and environmental conditions have a greater effect on bird welfare than group size and stocking density.**

INTRODUCTION

Measures used to evaluate the welfare of hens with respect to space allowance and group size can include their biological function, their subjective experiences (affective states) and their ability to express natural behaviour. Assessment of biological function includes egg production, health, mortality, body and feather condition, and rates of injury, aggression, and feather pecking. In terms of affective states, sufficient space allowance will result in prevention of suffering due to pain, fear, and frustration and will allow hens to experience positive states. In terms of natural living, sufficient space allowance will allow hens to perform basic body movements and comfort behaviours such as stretching and preening as well as provide unrestricted opportunities for nesting, dust bathing, pecking, and scratching.

CONVENTIONAL CAGES

Early studies on conventional cage space requirements focused on production, mortality, and economic returns (Keeling, 1995; Barnett & Hemsworth, 2003). In much of this research, evaluation of biological function was incomplete, let alone failing to examine affective states and behavioural expression. Subsequent research examined a broader spectrum of response criteria that has been incorporated to varying degrees into recommendations for minimum space requirements. For instance, the US egg industry adopted voluntary minimum space requirements based on the recommendations of a scientific panel that reviewed existing literature focused on mortality, feather quality, stress, egg production, and other criteria for caged hens and also used industry experience when scientific data were lacking (Bell et al., 2004). Minimum space standards were also established for cage systems for laying hens in the EU (Commission of the European Communities, 1999). These standards were based on scientific research (e.g. Commission of the European Communities, 1996; Appleby, 2003), practical experience, and discussions of proposed regulations. Because of the above scientific reviews, this review of space requirements for conventional cages will emphasize research published since their completion.

Horizontal (Floor) Space Allowance and Group Size in Conventional Cages

Production characteristics have value in assessing bird space requirements for the obvious economic impact but reduced performance (biological function) can also be an indicator of reduced welfare. Jalal et al. (2006) compared production of White Leghorn hens fed different levels of dietary energy (2,800, 2,850, and 2,900 kcal of ME/kg) and housed in conventional cages at 342, 413, 516 and 690cm^2/hen. Egg production, egg mass, and ME efficiency of egg production were higher for hens housed at 690cm^2/hen than for birds in other space treatments regardless of dietary energy. Space allowance did not affect egg weight, hen weight, bone ash, or maintenance energy intake. Rech et al. (2010) compared a space allowance of 375, 450 and 563cm^2/hen and found no effect on egg production but egg size increased and mortality decreased linearly with increasing space. There was an interaction between bird genotype and cage space on feed efficiency. For Strain A, the poorest feed efficiency occurred at 450cm^2 with the 375 and 563cm^2 being equal, while for Strain B the 563cm^2 feed efficiency was poorer than for the more densely housed birds. Rios et al. (2009) studied caged birds (light hybrid) at 3 space allowances (321, 375 and 450cm^2/bird) over 3 periods (25 to 44, 45 to 64, and 65 to 84 weeks of age). The authors found that increasing cage density decreased feed intake and improved feed conversion at all points of study but egg production was only negatively affected by increasing housing density after the birds were approximately 45 weeks old. Mortality was higher for the 321cm^2 treatment (6.00%) than both 375 (1.05%) and 450 (1.25%)cm^2 densities. Rios et al. (2009) suggested that a space allowance of 375cm^2/bird be used up to 45 weeks of age and 450cm^2/bird thereafter. However, this conclusion can be questioned because despite not being statistically significant, increased housing density before 45 weeks of age numerically decreased egg production (95.41, 94.23, and 93.56% for 450, 375, and 321cm^2/bird treatments, respectively). Further, it is not practical to change housing density during an egg production cycle. Sohail et al. (2004) found that increasing space per hen (light hybrid; 310 vs. 413cm^2) increased feed intake, egg production, and egg weight and decreased the feed required to produce a dozen eggs; space allocation did not affect egg specific gravity or mortality. Similarly Anderson et al. (2004) found that two strains of light hybrid hens had greater hen-day egg production and egg mass when housed at 482 compared to 361cm^2/hen. At the greater space allowance, birds were observed to move more but no other differences in behaviour patterns were observed.

Experiments studying cage horizontal allowance (all of the above studies) are confounded if the variation in space is accomplished by changing the number of hens added to the same sized cages. For example, altered feeder and waterer space may be responsible for effects attributed to floor space. However, the finding that hens appear adaptive to changing feeder space suggests that this may not overly influence the results (Thogerson et al., 2009a; see Feeder and Water Allocation section below for more detail). The design of experiments can also be limited by the range of housing density examined. If a production trait such as egg production is maximum (Anderson et al., 2004; Sohail et al., 2004; Rios et al., 2009) for the highest space allocation, it is possible that egg production would have been higher at an even larger space allotment.

The horizontal cross-sectional area of a hen can provide information relevant to its space requirement and this space is dependent on the hen's size. The cross-sectional area of a medium hybrid hen was found to be 475cm^2 by

Dawkins and Hardie (1989) and more recently, Mench (2011) found similar values for light hybrid hens (mean 563cm^2, range 391 to 717cm^2). If animals are currently given a space allowance approximately equal to that of their body area, any increase in allowance increases freedom of movement. This only refers to local freedom of movement but is important for many basic behaviour patterns such as feeding, scratching, stretching, preening and sitting (Appleby, 2004).

There is evidence that laying hens have a need for a certain amount of individual space. Under high density conditions, hens will maximize this space by spacing themselves evenly (Albentosa & Cooper, 2003). However, at lower stocking densities, hens may space themselves more randomly or flock together due to the location of environmental resources. Hen spacing may also be behaviour dependent. For example, Keeling and Duncan (1991) suggest that birds are closer together when preening but further apart when foraging. Keeling (1994) studied the inter-bird distances for various activities at four stocking densities (600, 1200, 3000 or 5630cm^{2}per bird) in groups of 3. Behaviours measured were walking, ground pecking, preening, and standing. The author concluded that when there is adequate space, birds in a group position themselves at distances appropriate for an activity and will frequently carry out that activity. However, as space becomes restricted, the frequency of some types of behaviour is reduced (Nicol, 1987). Faure (1986) studied a group of 4 hens (medium hybrid) trained to key peck for extra space and suggested that 400cm^2 per bird was adequate for about 75% of the day (photoperiod) but hens worked for 1500cm^2 of space for 25% of the day. Lagadic and Faure (1987) reported similar results but found that birds (medium hybrid) worked for space greater than 450cm^2 for 50% of the day. Barnett et al. (2009) investigated the impact of individual furniture and horizontal space in enriched cages on corticosterone levels and immunocompetence. Although furnishings in enriched cages were well used, it was the additional space that was more important to the hens. Savory et al. (2006) suggested that space allowances less than 5000cm^2/hen impose some constraints on free expression of behaviour. Mishra et al. (2005) found that caged hens spent 97% of the day nesting, preening, drinking, feeding, standing, walking, perching, and resting and less than 0.1% of the day wing flapping, feather ruffling, wing stretching, and flying. Based on the premise that reduced space limits behavioural expression, low values for behaviours may reflect a space limitation rather than a lack of importance. Many conventional cages provide only 450cm^2 per hen, which according to the above research, is insufficient to provide space for a hen standing in a relaxed posture (563cm^2, Mench, 2011).

Another criterion that can be used to establish the space requirements of hens is the space needed to perform normal comfort activities. Dawkins and Hardie (1989) videotaped individual hens carrying out various activities and measured the minimum space required for each. The following mean space requirements were recorded: standing, 475cm^2; ground scratching, 856cm^2; feather ruffling, 873cm^2; wing stretching, 893cm^2; preening, 1150cm^2; turning, 1271cm^2; and wing flapping, 1876cm^2. Although these values are helpful, they do not represent what each hen needs in a group setting. Appleby (1998) studied group size and space allowance in the Edinburgh Modified Cage using medium hybrid brown hens. Based on behaviour and resource use, it was concluded that a minimum space of 675cm^2/ hen was required in the main cage area with a total space (including the nest) of 915cm^2/hen. In a later study, Appleby (2004) used theoretical models to suggest that 675cm^2 be a practical minimum in the main area of the cage but that the total space requirement depended on group size. It was suggested to provide 800cm^2/bird for groups of 8 or more (plus 175cm^2/bird of litter area), 850cm^2/bird for groups of 4 to 7 (plus litter) and 900cm^2/bird (plus litter) for groups of 2 or 3.

Using 3-D kinematics, which measures behaviour variables in 3 dimensions, Mench (2011) studied one hour of videotaping of 9 mature white strain hens individually housed in an 8361cm^2 pen (Table 2). She reported the mean space requirements per bird for the following behaviours: standing in a relaxed posture, 563cm^2; turn 180 degrees, 1315cm^2; lie down, 318cm^2; wing flap, 1378cm^2. She also found that the wingspan of the birds ranged from 36 to 46.5cm. Although there is some variance from the data of Dawkins and Hardie (1989), possibly due to hen body size, there is similarity. Savory et al. (2006) investigated the space requirement for preening, walking, standing, and ground pecking. They concluded that space less than 775cm^2/bird resulted in some restriction of walking and ground pecking while standing and preening increased. Nicol (1987) reported that when space restricts wing stretching, feather raising, tail wagging, leg stretching, and wing flapping, hens exhibit rebound behaviour and perform these activities much longer when finally given the opportunity in more space. Albentosa and Cooper (2004) reported a significant reduction in number of wing or leg stretches hens performed at 762cm^2/bird compared with pairs of birds housed at 3048cm^2/bird.

Based on the principle of clustering and synchrony of activities in laying hens (Collins et al., 2011) and space modeling based on group size (Appleby, 2004), Mench (2011) suggested the use of a formula to calculate hen space requirements. The author suggested that the following formula could be used to calculate space requirement per hen for different group sizes:

- Imperial - $322in^2 + ((n-1) \times 87.3in^2)/n$ where $322in^2$ is the maximum space required for wing flapping, n= number of hens in a group, and $87.3in^2$ is the mean space occupied by a bird standing.
- Metric - $2077cm^2 + ((n-1) \times 563cm^2)/n$ where $2077cm^2$ is the maximum space required for wing flapping, n= number of hens in a group, and $563cm^2$ is the mean space occupied by a bird standing.

Cage Height

Albentosa and Cooper (2004) studied the effect of two cage heights (38cm and 45cm) in enriched cages on the activities of brown strain hens. The authors reported no effect of height on activities such as yawns, head scratches, head shakes, wing and leg stretches, wing raises, body shakes and tail wags. They suggested that their cage height choices were not sufficiently different to permit detection of behavioural differences. Overall, they recorded a very low incidence of comfort behaviours, which may have been affected by limited cage height. In a follow up study, Albentosa and Cooper (2005) suggested that there was a preference for the 45cm minimum cage height when birds were given the choice of 38 vs. 45cm. Albentosa et al. (2007) evaluated the effect of cage height (38 and 45cm) and stocking density (609, 762, 870, or $1016cm^2$/bird) on laying hen behaviour. Their results showed that the range of cage and stocking densities studied had little effect on behaviour, except that the feeding bouts were longer for the $609cm^2$ /hen grouping and yawning and head scratching were more common in cages that had a minimum height of 45cm. Dawkins (1985) noted that 25% of head movements were 40cm above the cage floor and 15% were at a level between 35 and 41cm. Although it was clear that birds could reach higher than what was recorded, it was not obvious that they would benefit from more vertical space.

Mench (2011) reported that the greatest height required by hens was for wing flapping, which ranged from 40 to 60cm. As reviewed in Mench (2011), Nicol (1987) observed hens kept in cages of varying heights (30, 42.5, and 55cm). Wing flapping was only observed at the tallest cage height. Albentosa and Cooper (2004) compared 38cm tall cages to 45cm tall cages and observed wing flapping only in the latter. In both studies, however, wing flapping was extremely rare and there were no statistically significant differences between treatments, so these data are only suggestive.

Cage Floor Slope

Tauson (1998) found severe damage to the exterior part of the foot digits (hyperkeratosis and inflammations) in more than 60% of birds that were kept in cages having floors with steep slopes (>20%, >11.3°), compared with only 1 to 3% damage on floors with gentler slopes (<14%, < 8°). It was also found that, at a stocking density of $480cm^2$ per hen, the optimal cage floor slope was about 10% (5.7°) both for egg quality traits (cracked and dirty eggs) and for foot condition. Further significant improvement in foot condition could not be detected until the slope was further decreased to 3% (1.7°). However, at that slope, eggs did not roll out efficiently and egg quality could not be maintained (Tauson, 1998). Indeed studies of hens in cages have cited slopes anywhere from 14% (8˚) (Appleby et al., 2002) to > 26% (>15˚) (Tauson, 1984). In a survey of different cages, Garner et al. (2012) found cage floor slopes ranged from 7.5% (4.3°) to 23% (13.6°) and that 80% of all cage floors had slopes in the range of 10% (5.7°) to 17.5% (10°).

Feeder and Waterer Allocation

Hens in cages have shown a preference to eat synchronously (Webster and Hurnik, 1994) suggesting that without adequate feeder space, more submissive birds may be prevented from feeding with the group. However, Albentosa et al. (2007) could not confirm this preference for medium hybrid hens housed in furnished cages and suggested that further investigation was required on importance of synchronized feeding and factors that affect its occurrence. Thogerson et al. (2009a) provided 5.8, 7.1, 8.4, 9.7, 10.9, or 12.2cm of feeder space/hen, and found that light hybrid hens with reduced feeder space spent less time feeding, synchronized their feeding bouts to a lesser extent, made fewer switches at the feeder (i.e. hens changed from feeding to not feeding), and shared the feeder less. Feather score, body weight, and body weight uniformity were not affected by feeder space allowance and they reported little aggressive behaviour and a low level of mortality. It was concluded that hens did not respond to reduced feeder space by excluding cage mates with aggression from the feeder but instead desynchronized their feeding behaviour. In a similar study, using the same feeder space allowances, Thogerson et al. (2009b) found that hens with reduced feeder space allowance utilized more feed and had poorer feed conversion. Body weight was similar among feeder space treatments and there were no obvious trends in egg size. Therefore, the authors suggested that the lowered feed efficiency might be due to greater feed wastage. Decreasing feeder space also did not affect bone mineralization or cause physiological stress. Garner et al. (2012) used information from 165 to 168 commercial houses to study the effect of age and house design on egg production and weight in White Leghorn hens. In this research, feeder space ranged from approximately 5 to 12cm per hen. Egg production increased with increasing feeder space up to 10.7cm and egg case weight decreased (0.27kg/cm) with increasing space.

Research is lacking on waterer space allowance.

FURNISHED CAGES

Horizontal (Floor) Space Allowance

The horizontal space requirement to perform specific behaviours in furnished cages is similar to that described above for conventional cages and will not be repeated in this section. In addition to horizontal floor space, furnished cages are also equipped with a nest box, perches, and litter/scratch area.

Tactacan et al. (2009) compared hen performance in conventional cages (5 hens at 562cm^2) with hens in furnished cages (24 hens at 642cm^2) and reported no difference in production performance. Hens in furnished cages had better bone quality probably due to greater activity. Widowski et al. (in preparation) found no difference in egg production, feed intake, egg quality traits, bone strength, or mortality when hens were stocked at 516 vs. 750cm^2/hen in furnished cages housing 55 and 80 vs. 28 and 40 hens, respectively. However, feather condition scores and cleanliness were significantly poorer at the higher stocking density.

Group Size

Laying hens appear to be able to discriminate between different individuals within their own social group (Bradshaw, 1991). The maximum number of flock mates that can be recognized is not known but estimates indicate less than 100 individuals (Nicol et al., 1999). Lindberg and Nicol (1996) reported that hens in a larger space preferred groups of 5 over groups of 120. However, the reverse was true if the space in the group of 5 was restricted. Keeling et al. (2003) studied the impact of group size (15, 30, 60 and 120 hens) in layers housed in floor pens at a constant density (achieved by adjusting pen size) and with a constant amount of feeder, drinker, nest and perch space per bird, and found that body weight and egg weight were lowest for the 30 bird pens. They suggested that their results were related to the social structure of the different sized groups. More specifically, they proposed a hierarchical social structure for the smallest group (15) and a tolerant social system for the largest 2 groups (60, 120), but that the 30 bird group was too large for a stable hierarchy and too small for a tolerant social system to exist. They further suggested that group sizes approximating 30 could be problematic in commercial production and by extension to furnished cages. This hypothesis is supported by Hughes et al. (1997) and Estevez et al. (2002), but may not hold true under all conditions. Widowski et al. (in preparation) found no effects of cage size (groups of 28 and 40 vs. 55 and 80) on egg production or welfare indicators, although feed intakes were higher in the smaller cages. Barnett et al. (2009) compared the effects of housing 8 birds/cage at densities of 750 and 1500cm^2/hen, and

16 birds/cage at 750cm^2/hen, in furnished cages. Hens housed in groups of 16 had higher egg corticosterone concentrations and aspects of their immune response were reduced compared to groups of 8 hens at either 750 or 1500cm^2/hen. The larger cage, regardless of housing density, increased coracoid bone strength suggesting a beneficial effect of more space on this characteristic. The authors concluded that group size had a greater potential impact on welfare than space allowance within the range of treatments used.

Other research on furnished cages has also used variable group sizes, but the results can't be reliably attributed to number of hens per cage because of differences in cage design. They are reported for interest and completeness. Wall (2011) studied the performance of several strains housed in furnished cages in groups of 8, 10, 20, and 40. There was no difference in production or mortality but cracks and dirty eggs increased with group size. Vits et al. (2005) studied performance of two laying strains housed at EU standards in 3 furnished cage systems. The Aviplus and Eurovent 625A cage designs housed groups of 10 or 20 hens whereas the Eurovent 625a cage design housed groups of 40 and 60 hens. The highest egg production of 89.4% was recorded for the groups of 10 (Eurovent 625A) whereas the proportion of cracks was higher (0.7%) in groups of 60 hens compared to the others. Also, smaller group sizes tended to consume more feed in the Aviplus system. Weitzenburger et al. (2005) used the same strains and cage systems and noted that mortality was greater (5.2%) in the small Eurovent 625A groups than the larger groups in the Aviplus and Eurovent 625a cage systems. However, within each cage type, the different group sizes had no effect on mortality due to cannibalism.

SPACE REQUIREMENTS FOR SPECIFIC AMENITIES

Nest Boxes

Wall (2011) compared the use of nests in four furnished cage designs and four (8, 10, 20, and 40) group sizes supplied with 150cm^2 (23in^2) of nest space per hen. In this study 95% of the hens in the 8 and 10 group size used the nests. In the larger group sizes, more eggs were laid in the scratch area and nest use was strain dependent. Closing the dust bath during peak egg laying was important. However, in the larger groups, up to 56% of the hens rejected the Astroturf lined nests and laid their eggs on the litter mat resulting in more dirty eggs. It is also the case that nesting behaviour synchrony decreases with group size (Appleby, 2004). The ratio of nest spaces needed per bird declines with group size, such that in a group of 12 or more, only about half as many nest spaces are needed as there are birds (Appleby, 2004). Appleby (1990) suggested a 625cm^2 nest, to accommodate 2 birds at a time, for a group of 5 birds (125cm^2/bird). Hunniford et al. (2013) found that when hens were provided either 70 or 100cm^2/hen of nest space in large furnished cages, group size/cage design but no nest space allowance affected nest use and there was more aggressive pecking around the nest in larger group sizes. Nest box use was lower in large cages (77.1%) as compared to small cages (91.5%). The remaining eggs for all treatments were laid in the scratch area (Hunniford et al., 2013). Wall et al. (2002) using 2 strains of birds in groups of 6, 14, and 16 with 208cm^2 nest space per hen, reported that Astroturf nest floor lining cannot be reduced to 50% of the nest floor area without affecting nest use. Nest use was significantly higher when 100% of the nest floor was lined with Astroturf.

Perch Space

Perch characteristics and their impact on bird behaviour have been reviewed (Struelens and Tuyttens, 2009). Roosting is a highly synchronous behaviour, particularly at night (Appleby & Hughes, 1990). Therefore, the space needed is determined in part by the number of hens and their body width (Appleby & Hughes, 1990; Duncan et al., 1992; Appleby et al., 1992; 1993), which in turn will vary with hen size. Although several studies have shown that 14cm of perch space per bird is necessary for medium hybrid strains to increase roosting activity (Appleby et al., 1993; Abrahamsson et al., 1996) and decrease foot and feather damage (Appleby, 1995), other studies have found that 12cm perch length per bird is sufficient for lighter hybrids to achieve a high frequency of night perching (Tauson, 1984; Tauson & Abrahamsson, 1994; Wall et al., 2002). However, it has been argued that this is insufficient room to allow synchronous perching activity due to the fact that birds occupy at least 18cm of space while sitting (Sandilands et al., 2009) and because hens prefer to space themselves approximately 5cm apart when perching (Savory et al., 2002). Appleby (1995) compared 12cm and 15cm perch space per bird and concluded that although both were used equally, perch arrangement might be as important as space. Aspects of perch arrangement such as distance to the back cage wall, distance between perches and the use of cross-wise perches can influence the use of perch space. Struelens et al. (2008b) found that cross-wise perch designs were not used as effectively as linear perches and that hen selection of roosting positions with these designs was more disturbed. For clarification, the findings for required perch space are based on linear measurements.

Feeder and Waterer Space

Minimal research has been completed on feeder space and waterer requirements of hens in enriched cages.

Scratch/Dust Bath Space

There are few studies addressing the amount of space required in the dust baths or scratch mats in furnished cages. Herwig and Widowski (2013) found that the majority of pecking, scratching and dust bathing occurred on the wire floors rather than on scratch mats when space allowances on scratch mats ranged from 31 to 89cm^2/hen.

Cage Height

The discussion on cage height in the conventional cage section is relevant to furnished cages with the primary difference relating to the presence of perches in the furnished cages. Perches must be sufficiently high to permit eggs to roll under them (Struelens & Tuyttens, 2009) and yet the distance between the perch and cage ceiling must be sufficient to permit use of the roosts. Struelens et al. (2008a) examined the behaviour of hens given roosts at various heights in furnished cages varying in height and concluded that a minimum distance of 19 to 24cm was required between the ceiling and the perch for most hens to roost. In a 45cm high furnished cage with a perch 24cm below the ceiling, the perch could be as high as 21cm above the cage floor. Therefore, the presence of perches need not increase cage height unless an increased perch height is used.

NON-CAGE HOUSING

Horizontal (Floor) Space Allowance

Research on the horizontal space allowance in non-cage housing systems is difficult because of the size of operations required to adequately study this area (1,000's of hens) and the more complex and less uniform nature of systems being used (e.g. nature of flooring, use of vertical space, etc.). Fundamental space requirements as noted above in conventional cages are readily met in most of these systems but additional criteria such as barn environmental control (moisture, dust, ammonia) and bird behaviour and well-being are end points relevant to establishing space allowance.

Barns

Relevant research is currently not found.

Aviary

In Carmichael et al.'s (1999) study of stocking density (9.9, 13.5, 16, or 19 birds/m^2) and resource use in perchery systems, it was found that there was no effect of bird density on the proportion of birds on slatted floors or elevated perches but as the density increased, the proportion of birds on the littered area decreased. This suggests that fewer birds were in the littered area when the demand for this resource exceeded supply. Behaviours which decreased with increased crowding included moving, foraging, and dust bathing while standing increased because of increased crowding. Behaviours which did not change included resting, preening, pre-laying and comfort behaviours. The proportion of birds feeding and drinking did not differ across the different density groups. The authors concluded that "Bird welfare at19 birds/m^2 may have been slightly impaired". Channing et al. (2001) studied 5 different flock sizes (323, 374, 431, 572, and 912 birds) at a constant density (18.5 birds/m^2); the researchers found that colony size did not affect bird distribution among the different areas of the perchery. Birds moved around in the pen as a synchronized group in constant flux, therefore causing temporary areas of high and low density throughout the day. Colony size did have some influence on bird behaviour. Overall, there was a tendency for reduced feeding behaviour and increased standing in the smallest and largest colony size. Nicol et al. (1999) stocked birds at densities of 6, 14, 22 and 30 birds/m^2 in a perchery system. Each perchery had a total floor area of 2.3 x 5.2 m and an additional perch area of 1.0 x 4.0 m. The perch area comprised 4 tiers of perches directly above each other at 40cm height intervals. Egg production and plumage condition were best at the lowest density. Plumage condition worsened with increasing flock size and density and was proposed to be due to mild feather pecking. Aggressive pecking was most common in the smaller flocks at the lowest stocking densities, possibly because these birds attempted to form social hierarchies. Birds in the larger flocks at higher densities appeared to adopt non-social, non-aggressive behavioural strategies.

In contrast, Zimmerman et al. (2006) observed that initial levels of feather pecking and aggression were highest in the low stocking density (7 birds/m^2) of their aviary. Feather pecking and aggression increased with age but only in the high stocking density treatment (12 birds/m^2). This was further complicated by flock size in that the high stocking density treatments showed more aggression, preening, and allopreening but more so in small flocks than in large flocks. The authors concluded that overall, they did not believe that the welfare of laying hens was compromised by housing at 12 birds/m^2, in comparison with housing at 9 or 7 birds/m^2 in single-tier aviary systems.

Free range

Establishing scientific requirements for space allowance under free range systems is not possible because environmental conditions on each site vary greatly. In addition to the outcomes used to establish space allocation noted above, relevant factors for consideration are plant growth, environmental concerns regarding nutrients from excreta, and hygienic conditions (Knierim, 2006). The relationship of these factors to bird welfare have not been studied but modeling exercises have suggested that free range in general has a small contribution to animal welfare in comparison to feeding level, space per hen, perches, water availability, and nests (De Mol et al., 2006). However, natural behaviours that are especially prevalent in the outdoor run are sunbathing, locomotion, exploratory and foraging behaviour, running, and flying (Knierim, 2006). It generally appears that in larger groups, fewer hens go outside; although the prevalence of outdoor use varies between investigations suggesting further influencing factors. As cited in Knierim (2006), Fürmetz et al. (2004) concluded that at least 15m^2 outdoor area per hen should be available to properly run mobile free range systems, where houses are moved to allow maintenance of vegetation. As noted above, this estimate is highly sensitive to the environment of the free range location.

Hegelund et al. (2005) reported that on average, 9% of the flock used the range area in their study, but there were large variations both within and between flocks, and this was partly influenced by climatic factors. Range use was affected by temperature, wind, precipitation, and season. The number of hens on the range decreased with increasing wind speed and with precipitation, and showed a parabolic relationship with temperature; this means that the number of hens on the range increased until temperature reached about 17˚C, after which the number decreased. There was also a tendency for reduced numbers of hens on the range later in the day and with increasing flock size (Hegelund et al., 2005). Usage was found to decrease during the day, which was unexpected, because other studies have found the number of hens on the range to peak every evening (Davison, 1986; Bubier & Bradshaw, 1998). However this difference might be explained by different recording times within each study.

From Hegelund et al. (2005), there appeared to be a tendency for the percentage of hens outside to decrease as flock size increased. A similar tendency was shown in a survey conducted by Grigor (1993 as cited in Hegelund et al., 2005) investigating flock sizes from 1 to 7000. There appeared to be bi-modal cut-off points – one when flocks exceed 500 hens and another when flocks exceed 4000. A clear relationship between flock size and use of the range area was also found in flocks studied by Bubier and Bradshaw (1998), where average range use went from 42% in a flock of 490 birds compared to 5% in a flock of 2450 birds.

Group Size – Non-Cage Systems

The number of hens used in group size research is not relevant to larger scale farms where flocks consist of thousands of birds housed together. The adoption of non-social, non-aggressive behavioural strategies by birds is likely to occur in larger flocks.

SPACE REQUIREMENTS FOR SPECIFIC AMENITIES – NON-CAGE SYSTEMS

Nest Boxes, Feeders and Waterers, Perches

Research is lacking on the requirement for nest boxes, feeders and waterers and perches in floor housed laying hens.

Table 2. Area and height requirements of hens performing various behaviours
(Modified from Mench, 2011)

	Area			Height			
Behaviour	Unit	Mean ± SEM	Range	Unit	Mean ± SEM	Range	n
Stand	in^2	87.3 ± 1.2	60.6-111.1	in	13.7 ±0.5	12.0-16.2	9
	cm^2	563.2 ± 7.7	391.0-716.8	cm	34.8 ± 1.3	30.5-41.1	
Turn	in^2	203.9 ± 3.6	143.5-339.6	in	15.2±0.9	12.1-20.6	9
	cm^2	1315.5 ± 23.2	925.8-2191.0	cm	38.6 ± 2.3	30.7-52.3	
Lie down	in^2	49.3 ± 0.99	45.0-52.0	in	-	-	8
	cm^2	318.1 ± 6.39	290.3-335.5	cm	-	-	
Wing flap	in^2	213.6 ± 2.9	165.6-287.0	in	19.9±0.8	14.8-22.5	9
	cm^2	1378.1 ± 18.7	1068.4-1851.6	cm	50.5 ± 2.0	37.6-57.2	
Wingspan	in^2	16.7 ±1.6	14.2-18.3	in	-	-	9
	cm^2	107.7 ± 10.3	91.6-118.1	cm	-	-	
Wing flap + 1 in (2.5cm)	in^2	244.0 ±13.1	192.5-321.9	in	20.9±0.8	15.8-23.5	9
	cm^2	1574.2 ± 84.5	1241.9-2076.8	cm	53.1 ± 2.0	40.1-59.7	

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4. BONE HEALTH

CONCLUSIONS

1. **Increasing calcium levels in feed to 2.5% or above, at least 2 weeks before first egg in the pullet house, decreases osteoporosis.**
2. **Feeding at least 33% of the calcium in the ration as large particle calcium (>2.5mm dia) decreases osteoporosis.**
3. **Ensuring that there is no deficiency in Ca, P, or vitamin D will decrease risk of osteoporosis but treatment with these nutrients after onset of the condition has little effect on bone quality in affected hens. There is evidence that nutritional supplementation slows the progression of osteopenia to osteoporosis in hens that are not yet clinically affected.**
4. **Bone strength is negatively related to egg production and shell strength.**
5. **Bone strength is a heritable trait that can be selected for in breeding programs. Genetic markers for bone strength have been identified that may be of use in future selection programs.**
6. **Manipulating lighting programs in the growing period have little effect on bone strength in the second half of the production period.**
7. **Conventional cage housing results in the weakest bone strength of all housing types and the highest number of new fractures at depopulation. However, it results in the lowest number of old healed fractures occurring during lay.**
8. **Housing hens in furnished cages results in improved bone strength compared to housing them in conventional cages and results in the least number of total fractures, considering old healed and new.**
9. **Non-caged housing results in the strongest bones and the lowest number of new fractures at depopulation compared to other types of housing systems. However, it results in the highest number of old healed fractures and the highest level of fractures in total.**
10. **The amount of load bearing exercise available during the laying period is the major contributor to increased bone strength and this is found more in extensive types of housing.**

INTRODUCTION

Bone metabolism in laying hens differs from that of other animals because of the high demand placed on hens as a result of eggshell production. Osteoporosis and susceptibility to fractures are metabolic problems that affect laying hens kept in all types of housing systems. Osteoporosis involves the progressive loss of structural bone due to changes in the mechanisms of bone formation and turnover that begins at sexual maturity and continues throughout the hen's period of lay (Whitehead & Fleming, 2000; Whitehead, 2004).

Birds have three types of bone tissue in their long bones (e.g. femur, humerus): cortical bone that forms the tough outside shell, trabecular bone that is woven through the interior of the bone acting like struts to provide strength, and medullary bone that acts as a reservoir for the calcium needed for daily eggshell production but has little inherent strength (Fleming et al., 1998). Before a bird comes into lay, the majority of bone tissue formation and resorption involves the structural trabecular and cortical bone types but at sexual maturity, estrogen and testosterone cause the hen to begin producing medullary bone (Whitehead, 2004). Medullary bone is produced at the expense of structural bone and over the course of an intense production period, the amount of structural components decrease, making them more fragile and prone to osteoporosis (Whitehead, 2004). Osteopenia, a pre-cursor condition, is understood to be bone loss from 1 to 2.5 SD below peak bone mass; beyond 2.5 SD below peak bone mass, the condition is referred to as osteoporosis (Beck & Hansen, 2004). Because of the close relationship between estrogen, estrogen receptors, and osteoporosis (Beck & Hansen, 2004), and the fact that there is a decrease in estrogen receptors through life, with a significantly lower number of receptors at 70 weeks of age compared to early in life (Hansen et al., 2003), the risk of osteoporosis increases as birds age. As such, welfare concerns resulting from osteoporosis risk should be considered when determining the length of time a laying hen remains in production.

If the hen goes out of production, hormone levels fall, structural bone formation resumes, and skeletal regeneration can take place (Whitehead, 2004).

The main factors influencing the severity of osteoporosis are genetics, nutrition, and housing type. Housing type plays a significant role in providing opportunities for load bearing exercises, which are known to affect the level of osteoporosis. Housing also has an impact on fractures, affecting bones most often fractured, and the time in the hen's life when fractures are most likely to occur.

Welfare concerns related to bone health in laying hens are due to osteoporosis, which may in turn lead to bone fractures. Animal welfare can be considered using three separate schemes: affective state (feelings), natural living, and biological functioning. Poor bone health impacts the hen's affective state by causing pain (Webster, 2004). While it is not known if osteoporosis is a painful condition for hens, there is experimental evidence indicating that bone fractures are painful to them (Nasr et al., 2012b). Fractures and osteoporosis rarely occur in wild type hens. Thus, laying hens have not evolved to adapt to these confined housing conditions (Rubin et al., 2007). Fractures themselves inhibit natural activities such as flying, perching, or climbing depending on the site of the fracture (Sandilands, 2011). Fractures and osteoporosis decrease biological functioning by causing stress to the animal, causing the hen to repair the fracture, and decreasing activity levels, egg production, egg quality, and liveability (Nasr et al., 2012a).

NUTRITION EFFECTS

Kappeli et al. (2011a) studied the effects of nutrition on keel bone deformities in laying hens. The researchers investigated the effect of 25-hydroxycholecalciferol (HyD, a vitamin D supplement) on keel bone deformities in aviary-raised Leghorns in 2 experiments. Although none of the birds showed any keel bone deformities during the rearing phase, moderate to severe deformities gradually appeared and reached levels of 35% in the first experiment and 43.8% in the second experiment at the end of lay. In the first experiment, HyD had no significant effect on the prevalence of keel bone deformities. In the second experiment, HyD, again, had no effect on keel bone deformities yet there were differences between strains. The authors concluded that there is a significant effect of breed and that genetics may be able to exert stronger effects on improving bone strength than nutritional manipulation. It is likely that the amount of vitamin D in commercial layer feed is already sufficient and the consumption of additional levels of, or different, metabolites cannot further improve bone mineralization in laying hens (Kappeli et al., 2011a). Nutritional deficiencies of calcium, phosphorus, or vitamin D3 have been shown to result in loss of medullary bone (Wilson & Duff, 1991). Rennie et al. (1997) reported similar findings when they found that none of their nutritional treatments (oystershell, fluoride, 1-25-dihydroxycholecalciferol, ascorbic acid, and various levels of phosphorus, crude protein, and vitamin K) affected trabecular (structural) bone volumes. Thus, Rennie et al. (1997) concluded that nutritional manipulation had little effect in the prevention of osteoporosis in laying hens. More recent work by Tarleton and others (2013) indicates that fracture rates can be significantly reduced by the manipulation of Omega 3 fatty acid levels.

Although the type of nutritional component may not exert significant effects, the timing at which nutritional factors are imposed has shown some evidence of affecting bone health favourably. In a case study, Mayeda and Ernst (2008) studied the causes of health problems at a commercial egg farm and discovered that a significant number of mortalities were caused as a result of osteoporosis (i.e. collapse and infolding of the ribs due to fractures at the junction of the sterna and vertebral components). The researchers tried ameliorating the problem with an experimental feeding program. The grower ration contained 1.1% calcium and 0.48% phosphorus; when birds came into lay, the layer feed contained 3.8% calcium and 0.47% phosphorus. Mayeda and Ernst (2008) proposed changing the feeding program by providing hens a pre-lay diet of 2.3% calcium and 0.4% phosphorus and then increasing the calcium to 4.09% and phosphorus to 0.48% when hens came into lay. Necropsy of mortality indicated that the alternate feeding program reduced mortality due to osteoporosis. Therefore, the timing of nutritional intervention is an important factor. Fleming (2008) advised against waiting until sexual maturity because intervention at that point mainly will affect only medullary bone formation. Adequate inclusion of calcium, vitamin

D and phosphorus are important during the rearing period in order to maximize bone strength before the excessive resorption that takes place during the laying period (Fleming, 2008). Like Mayeda and Ernst (2008), Fleming (2008) suggested not to wait until birds come into lay before increasing calcium levels and that there are no detrimental effects resulting from an increase in calcium levels at 14 weeks of age. In addition, vitamin D is not generally the limiting factor in mineral absorption in poultry diets but ensuring that there is no deficiency is imperative. Avoiding phosphorus deficiencies is also essential and its balance with calcium in poultry diets must be carefully calculated (Fleming, 2008). For example, in starter diets the Ca:P ratio should be approximately 2:1 (Whitehead, 2001). Fleming (2008) goes on to say that so long as calcium, vitamin D, and P are adequate, calcium dietary inclusion rates in particular should be increased to layer-diet levels well before sexual maturity, as most dietary interventions seem to be largely ineffective if hens are already in lay. This is because any effects will only be seen in medullary bone, which provides limited increases in bone strength.

Incorporation of high levels of calcium too early in life can result in detrimental physiological effects, especially urolithiasis and gout. Wideman et al. (1985) demonstrated that introducing rations high in calcium well before sexual maturity (in this case at 7 weeks of age) causes a significant increase in mortality due to uroliths throughout the flock's life. Due to the relationship of estrogen increase and bone remodeling, 3 weeks prior to first egg production would be an approximate minimum age for calcium increase in the ration (Beck & Hansen, 2004).

It has been shown that the form in which calcium is presented also plays a role. In Roland's (1986) review it was stated that when comparing different sources of calcium of similar particle size, the majority of researchers concluded that oyster shell and limestone were of equal value for eggshell quality. Saunders-Blades et al. (2009) found that larger calcium particle size increased bone mineralization; therefore, bone quality improved. Scott et al. (1971) speculated that larger particle sizes of calcium remain in the crop and gizzard for longer periods of time than finer ground calcium sources resulting in calcium being available to the hen for longer periods of time. Large calcium particles may thus be beneficial to the hen during the dark period when she does not consume feed but has high calcium requirements due to eggshell formation (Etches, 1987).

In an experiment that investigated multiple factors for their effects on bone characteristics, Fleming et al. (2006) found that feeding limestone in particulate form to caged birds increased breaking strength of the tibiotarsus and decreased osteoclast numbers compared to birds fed only powdered limestone. A later study by Fleming (2008) found similar results when he compared hens fed particulate limestone to hens fed flour-fine limestone; results showed that the number of osteoclasts was reduced and tibiotarsus breaking strength and radiographic density increased in the group of hens fed particulate limestone (Fleming, 2008). Fleming et al. (2006) stated environmental and nutritional interventions must be introduced and upheld at key points in the hen's life.

GENETIC EFFECTS

There is considerable variation in the bone health of laying hens with commercial strains generally having weaker bones than traditional strains (Hocking et al., 2003). Differences in bone strength between specific strains have been noted on numerous occasions. Riczu et al. (2004) found bone breaking strength of both the radius and humerus in a brown strain to be higher compared to a white strain, at 66 weeks of age. Silversides et al. (2006) found strain differences in trabecular and cortical densities as well as breaking strength of the humerus with an unselected strain of Brown Leghorn having stronger bones than either a commercial white strain or a commercial brown strain. Budgell and Silversides (2004) compared number of hens with old breaks before transport, breaks that happened during depopulation and transport, and breaks that occurred during slaughter from a sample of two commercial and one heritage line of caged hens that were processed at 72 weeks of age. The commercial brown strain and the commercial white-egg strain had significantly more old breaks and transport breaks compared to the Brown Leghorn heritage line. However, birds from all 3 lines showed breaks during processing.

Bone strength is a heritable trait. Using end-of-lay commercial White Leghorns, Bishop et al. (2000) found that bone strength can be improved by selective breeding. The procedure used for generating these lines was based on selection of progeny for a bone index which included tibial and humeral breaking strength as well as keel radiographic density. Evidence for a QTL affecting certain bone characteristics such as humeral and tibiotarsal breaking strength have been identified in White Leghorn lines divergently selected for increased bone strength

(Dunn et al., 2007). Fleming et al. (2006) noted that genetic selection could be used to create lines of birds that are more or less resistant to osteoporosis.

In a 3-generation intercross between White Leghorns and wild type jungle fowl, Rubin et al. (2007) identified several significant QTL affecting bone strength and bone mineral density of the femoral bone. Fleming et al. (2006) found no interaction between genetics and environment with respect to bone characteristics but Fleming (2008) found that genetics and nutrition can have additive effects on bone strength.

Bone strength is inversely related to egg production and hens susceptible to osteoporosis had significantly higher eggshell thickness indicating that these hens had more active bone resorption to supply eggshells (Kim et al., 2012). This is a result of the inverse relationship between the amount of medullary bone and cortical bone wherein the quantity of medullary bone increases at the cost of cortical bone during the egg production cycle. Thus, structural bone loss and the development of osteoporosis in laying hens are associated with the modeling and remodeling of medullary bone, which serves as a primary calcium source for eggshell formation (Wilson & Thorp, 1998; Cransberg et al., 2001).

HOUSING AND MANAGEMENT EFFECTS

Housing type has a significant effect on the severity of bone weakness. Cages limit the amount of physical activity and this lack of exercise contributes to the development of bone fragility (Whitehead & Fleming, 2000). In a survey of end-of-lay hens in the UK, Gregory and Wilkins (1989) reported that almost 30% of hens had one or more broken bones during their lifetimes. A later survey by Gregory and colleagues (1994) reiterated these findings when they found that on average, 10% of hens received fractures while living in battery cages and another 17%, during depopulation and transport.

Changes in bone strength during the laying period are influenced by the type of exercise birds receive. Knowles and Broom (1990) found stronger tibia and humerus breaking strengths in birds housed in terrace or perchery systems vs. in cages. The increase in humerus strength was particularly apparent in the perchery system where birds had the greatest wing movement. Fleming et al. (1994) shared similar conclusions when they compared battery cages with 3 different perchery systems. Considerable improvements in a wide range of bone characteristics were observed in birds housed in percheries with the greatest improvement seen in humerus strength. This was more pronounced in the perchery containing many high perches compared with the litter and wire system that contained only relatively low perches. Thus, opportunity for flight was an important factor in improving humerus strength. Similarly, Moinard et al. (1998) found no difference in tibial breaking strength in caged hens having different floor spaces and/or cage heights; they did find, however, stronger humeral bones with the 60cm high cage treatment compared to the 40cm high treatment. It has been suggested that weight bearing exercises like jumping on and off perches can increase bone mass (Shipov et al., 2010) and volume (Hughes et al., 1993). Therefore, the effects of exercise and alternative housing systems have been studied as potential means of alleviating osteoporosis.

Newman and Leeson (1998) found that tibial strength increased within 20 days of transfer of hens from cages to an aviary system. Also, after 20 days in the aviary, the bone ash values were intermediary between birds only held in cages or in an aviary. It was also found that bone calcium content was not influenced by the birds' environment. There is good evidence that providing perches in conventional and furnished cages improves leg bone strength (Hughes & Appleby, 1989; Nørgaard-Nielsen, 1990; Gregory et al., 1991; Hughes et al., 1993; Barnett et al., 1997). The greatest improvements in bone strength happen when hens are given the opportunity for a wide range of load bearing activities. Barnett et al. (1997) noted that the femur, humerus, and tibia of hens were significantly stronger in birds kept in floor pens with perches compared to conventional cages with and without perches while the inclusion of a perch in conventional cages only increased the strength of the femur. Jendral et al. (2008) measured femur, humerus, and tibia bone breaking strength in hens that had been kept in conventional cages, cages fitted with a nest box and perch, and colony cages offering a nest box and perch with or without access to an elevated area for dust bathing. Hens housed in conventional cages had lower femur and tibia breaking strength compared to the other treatments; breaking strength was higher for all 3 bones of birds in the colony cages with access to the elevated dust bath. These data suggest that among cage systems, those that provide the greatest opportunities for load bearing exercises promote the strongest bones. However, load bearing exercise has less effect on pullet bones. Whitehead and Wilson (1992) used exercise as a way of stimulating bone growth during rearing but neither housing birds in pens nor giving them extra exercise through use of a carousel improved bone quality at the start of lay compared to cage rearing. Enneking et al. (2012) found increased bone mineral content in pullets raised in cages with perches compared to controls, but the difference was not significant until 12 weeks of age.

There is evidence that the type of housing affects both the prevalence and the timing of bone fractures (Knowles & Wilkins, 1998; Gregory et al., 1990; Sandilands et al., 2008). Gregory and Wilkins' (1989) survey on caged hens noted that almost 30% of the hens had recent breaks and 5% had old breaks at the time of slaughter. Some of the problems are due to cage and door design as described in Tauson (1985) and Elson (1990); legs, wings, and other body parts can get caught in doors and gaps between cages, causing broken bones, especially during depopulation. However, cage design modifications may help decrease the incidence.

Moinard et al. (1998) noted that the incidence of broken wings was much lower in a taller cage; the authors stated this may have partly been due to the fact that the higher cages had larger openings which would result in fewer broken bones during depopulation. Birds from non-cage systems have stronger bones and experience fewer breaks during depopulation and slaughter but they have higher incidence of old breaks compared to caged hens (Gregory et al., 1990; Knowles & Wilkins, 1998). Wilkins et al. (2004) estimated that old breaks of the keel and furculum ranged between 50 to 78% of birds sampled from free range flocks and between 62 to 72% of birds sampled from flocks housed indoors on litter and wire flooring.

A recent study by Wilkins et al. (2011) specifically investigated the amount of old breaks sustained by hens in a number of housing systems differing in internal design and the provision of perches. All systems were associated with high levels of keel damage even though there was quite a bit of variation in the effect that systems had on different parts of the skeleton. Birds from furnished cages had the lowest level of keel damage (36%) but also had significantly weaker bones. Birds from all systems containing multi-level perches had the highest level of keel deformities (80%) and highest keel damage severity scores.

In a study involving different combinations of stocking density and flock size in single-tiered aviaries, Nicol et al. (2006) found that 60% of hens had fractures by the end of lay and the incidence was not affected by stocking density or flock size. Sandilands et al. (2008) compared bone breakage at depopulation in commercial flocks that were housed in conventional cage, furnished cage, indoor non-cage, and free range systems. The researchers found that new breaks, especially in the wings, were highest in conventional cages (24%) while old breaks, primarily of the keel, were more prevalent in furnished cages (33%) and most prevalent in non-cage systems (54% on free range and 52% in non-cage barn systems).

Although there is plenty of evidence to show that non-cage systems are associated with keel damage, this is not always the case. Donaldson et al. (2012) studied the effects of aerial perches on keel bone injuries in free range laying hens and found that there was a significant interaction between individual farms and perch treatments (i.e. high keel damage scores increased in the perch treatment on some farms but not others). Their results showed no clear effect of access to perches on the level of keel bone injuries. The authors suggested that individual variation in bone strength contributed to differences in susceptibility to keel injuries. They concluded that the use of aerial perches in free range systems does not uniformly contribute to keel bone damage. Kappeli et al. (2011b) also noted the high amount of variation that occurred among Swiss layer flocks. The overall prevalence of keel bone deformities including slight ones ranged from 20 to 83% while the prevalence for moderately or severely deformed keel bones ranged from 6 to 48%. The housing systems were either aviaries or deep litter floor pens, the majority with access to outdoor runs. Aviary housing was associated with a higher prevalence of total, and severe or moderate deformations, compared to floor pens.

The prevalence of old bone breaks associated with non-cage systems is believed to result from the physical trauma that occurs from flight crashes, falls, or being pushed off perches (Whitehead & Fleming, 2000). This is because birds in alternative systems have more freedom of movement (Leyendecker et al., 2005). Consequently, they gain more momentum when flying, which causes greater impact when striking perches or other house equipment (Vits et al., 2005). The keel bone is usually the first part of the body to make contact with equipment due to its anatomical position on the bird (Scholz et al., 2008). Histopathology reports of keel bone deformities indicate that they are due to trauma and not because of developmental problems (Fleming et al., 2004). Handling of spent hens has an impact on the number of new fractures suffered when hens are being caught. When studying commercially caught hens from the same system, Gregory and Wilkins (1989) showed that gentle handling could reduce fracture rates to 14% from 24%.

Design and location of environmental enrichments in laying hen barns also has impacts on bone health. Pickel et al. (2011) showed that perch shape and material had significant effects on pressure exerted on the keel bone. Perch size and shape also had a significant effect on the surface area of the keel bone contacting the perch. Peak pressure and contact surface area are suspected to be criteria that affect keel bone deformities. Keel bone deformities are suspected to have different causes than keel fractures. Keel bone deformities result from poor perch design and pressure on the keel bone (Pickel et al., 2011). Keel fractures, on the other hand, are considered to result from crash landings and trauma (Whitehead et al., 2000). Square perches had the lowest peak force and highest contact area, and prototype perches used in the experiment were shown to significantly decrease peak pressure and increase contact area when compared to commercially available perch configurations. Wilkins et al. (2011) demonstrated that fixture layout impacted the number of old breaks in laying flocks. Aerial perches (>180cm above the floor) and A Frame perches were associated with significantly higher keel fractures while barns with lower perches had fewer fractures. Jendral et al. (2008) demonstrated that providing a raised dust bath in furnished cages resulted in a significant increase in bone density and breaking strength compared to furnished cages with only perching enrichments. More research is needed to optimize the positive effects on bone health that can be gained by providing environmental enrichments in laying houses.

It is, therefore, apparent that with different systems come different risks of skeletal damage. Sherwin et al. (2010) compared the welfare of layers in 4 different housing systems – conventional cage, furnished cage, barn, and free range systems. With respect to skeletal damage, it was found that each housing system had advantages and disadvantages but overall, hens in conventional cages sustained more fractures at depopulation than birds in any other system and birds in furnished cages had the lowest prevalence of problems in general. Rodenburg et al. (2008) ran a direct comparison on furnished cages and non-cage systems and measured a number of bone and behavioural parameters. Birds in non-cage systems had stronger bones; however, birds in furnished cages had lower incidences of bone fractures. Sandilands et al. (2009) recognized this "trade-off" when they wrote that housing layers in extensive systems compared to cages improves bone strength but is also associated with a greater level of bone fracture, especially of the keel bone. The authors proposed reducing the prevalence of bone fractures by improving housing design and genetic selection.

Manipulation of photoperiod has been investigated as a management tool to influence bone strength. Since structural bone decreases as hens age, Hester et al. (2011) tried to minimize the onset of osteoporosis by delaying sexual maturity. They hypothesized that this might allow pullets to develop a stronger skeletal frame before commencing egg laying; this in turn would lead to improved skeletal mineralization at the end of lay. Pullets were exposed to 3 lighting programs which decreased the photoperiod at different rates from 2 weeks to 16 weeks of age – rapid, moderate, and slow. The longer step-down lighting program resulted in a delay in sexual maturity, indicated by longer bones, but did not improve bone mineralization at 66 weeks of age. Silversides (2006) found no improvement in tibial breaking strength at 74 weeks of age when photostimulation was delayed. Hester et al. (2011) concluded that pullet lighting regimens had no effect on bone mineralization in end-of-lay hens.

Midnight feeding has been investigated as a management tool to influence bone strength. Riczu and Korver (2007) found no impact on bone density when midnight feeding was used in a flock of commercial breeds of hens from 17 weeks of age through the entire lay cycle. The control flock in this trial showed no evidence of osteoporosis and the authors proposed that midnight feeding may not be a benefit in flocks that are not susceptible to osteoporosis, but it may still be beneficial if a flock is prone to bone weakness.

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5. FEATHER PECKING AND CANNIBALISM

CONCLUSIONS

1. **Beak trimming is an effective method for reducing cannibalism and severe feather pecking. Welfare trade-offs include increased difficulty in performing normal beak-related activities including feeding and preening as well as the pain associated with the procedure. Pain is affected by the timing and method used (see Beak Treatment chapter).**
2. **Genetic selection against feather pecking behaviour, feather damage, and mortality due to beak-inflicted injuries, is effective in lowering the risk of feather pecking and cannibalism.**
3. **Encouraging foraging behaviour by providing attractive, friable litter throughout rearing and adulthood reduces the risk of severe feather pecking behaviour and cannibalism. For free range flocks, the risk is reduced by steps taken to increase use of the range.**
4. **There are potential protective effects of rearing pullets with access to dark brooders for minimizing the risk of severe feather pecking, and of providing adult hens with access to shaded nest sites for minimizing the risk of cloacal cannibalism. Epidemiological research suggests that cloacal cannibalism can be reduced by the use of lighting programs that prevent early induction of sexual maturity. By reducing visibility, light intensities below 5 lux can control beak-inflicted damage. Welfare trade-offs if applied throughout the house include impacts on eye health, preference of hens for good visibility when active, risk of injurious pecking when lights are raised for flock inspection, and potential welfare risks resulting from difficulty judging landings from perches (see Housing chapter).**
5. **Nutritional deficiencies increase the risk of severe feather pecking and cannibalism. Ensuring intake of a nutritionally balanced diet with a crude protein content of at least 124g/kg of feed and with essential amino acids, minerals, and other nutrients meeting or exceeding (U.S.) National Research Council (1994) guidelines, reduces the risk of cannibalism and severe feather pecking. Other nutritional factors that reduce the risk of these behaviour problems include providing feed in mash rather than pelleted form and providing access to silage, pasture, or other sources of dietary fibre.**
6. **Provision of perches from an early age (within the first 4 weeks post-hatch) can reduce the risk of injurious pecking in adult hens, apparently by facilitating use of elevated perches and enclosed nests. The risk of injurious pecking is lower when perches are more than 45cm above the floor; this enables perching hens to avoid being pecked by active birds below them. Trade-offs include increased risk of keel bone damage despite stronger bones and fecal contamination of birds below the perches (see Housing chapter).**
7. **Cannibalism and severe feather pecking develop and spread through a combination of individual and social learning. The risk of these behaviour problems increases with group size, at least up to around 200 hens. It may be mitigated by furnishings that separate hens performing different activities, and rapid removal of dead and injured birds. Once established, these behaviours are harder to control.**
8. **Although there are no strategies that guarantee the prevention of injurious pecking, the greater the number of protective management factors implemented, the lower the risk of feather pecking and cannibalism.**

INTRODUCTION

There are multiple forms of feather pecking and cannibalism observed in laying hens. Self-plucking is observed in some strains of hens when singly-housed but the term "feather pecking" (also called "feather picking") is generally applied to behaviour whereby one hen pecks at or pulls out the feathers of another. Occasional non-damaging, exploratory gentle feather pecking is commonly observed in laying hens and pullets and does not seem to bother the recipient. In chicks, it appears to constitute normal social exploratory behaviour (Riedstra and Groothuis, 2002). Stereotyped gentle feather pecking involves one bird persistently following another and delivering repeated gentle pecks at its plumage (Newberry et al., 2007). Although also not damaging to the feathers, this repeated feather pecking raises concerns about the welfare of the bird giving the pecks due to its abnormal, compulsive appearance. The receivers of these pecks quietly walk away giving the appearance of being mildly disturbed by the continued pursuit of the pecking individual (Newberry et al., 2007). Most literature does not distinguish between these forms of feather pecking.

The most serious form of feather pecking is severe feather pecking whereby hens grasp and forcibly pull, break, or remove feathers, sometimes eating them. The recipients respond with immediate avoidance, often accompanied by squawking, suggesting that the feather pulling causes pain (Gentle & Hunter, 1991). The resulting feather damage impairs thermoregulation leading in cooler climates to increased feed intake and reduced feed efficiency (Leeson & Morrison 1978; Herremans et al., 1989). Feather loss also compromises the skin-protecting function of the plumage, which may increase the risk of scratches and, in free range birds, sunburn. Additionally, damage to the tail and flight feathers of the wings impairs flying ability and may increase the risk of fractures in cage-free hens.

Cannibalism, the behaviour of pecking and consuming blood and tissues of conspecifics, poses a very serious welfare problem in laying hens because the recipient acquires injuries which, if extensive, result in death. Feather breakage and removal through the act of severe feather pecking can cause bleeding, leading to cannibalism of the skin and underlying tissues (Blokhuis & Arkes, 1984; Cloutier et al., 2000; McAdie & Keeling, 2000). In addition to injurious pecking of feathered body areas as a sequel to severe feather pecking, cannibalism can also occur independently of feather pecking in the form of toe pecking (Leonard et al., 1995, Rodenburg et al., 2009), comb/head pecking (related to social aggression, Leonard et al., 1995; Cloutier & Newberry, 2002a), or cloacal cannibalism (Hocking et al., 2004; Newberry, 2004). The latter, also called vent pecking, can lead to internal infections, prolapse, and in severe outbreaks, rapid evisceration of the victim. This behaviour typically appears after the onset of lay in association with oviposition (Yngvesson et al., 2004).

Welfare concerns from these behaviours include compromised health and biological function (mortality, injury, plumage damage, depressed immune status, susceptibility to infection), abnormal behaviour, and negative feeling states (fear and pain in recipients, possible negative feeling states leading to the behaviour in perpetrators). There are multiple risk factors for these behaviours including beak form, lighting, genetics, nutrition, foraging opportunities, and flock size. These factors are reviewed below, ending with a section on effects of environmental factors experienced during rearing.

BEAK TREATMENTS AND OTHER PHYSICAL DETERRENTS AS CONTROL MEASURES[1]

In hens with intact beaks, mortality due to cannibalism has been reported to affect a variable proportion of the flock, exceeding 30% in some cases (Allen & Perry, 1975; Curtis & Marsh, 1992; Craig & Muir, 1996). Severe feather pecking and cannibalism are often controlled by beak trimming, a management tool typically involving removal of a proportion of the upper beak and less of the lower beak. When performed correctly by trained personnel, beak trimming can reduce beak-inflicted injuries and mortality, lower feed intake, and improve feed efficiency (Blokhuis & van der Haar, 1989; Glatz, 1990; Maizama & Adams, 1994; Hughes & Gentle, 1995; Gentle et al., 1997). In a genetic line in which the incidence of severe feather pecking and cannibalism was already low, a further reduction in these behaviours due to beak trimming was not detected (Craig & Lee, 1990).

[1] For details regarding beak trimming procedures, age when trimmed, severity of trim, post-trim pain, etc., please refer to the chapter on Beak Treatment. The focus here is effects on cannibalism and feather pecking.

Although beak trimming is beneficial in reducing welfare problems arising from cannibalism and feather pecking, it is generally performed without anaesthesia, raising concerns about pain arising from the procedure. Evidence suggests that the age at trimming, method used and depth of cut affect the degree of pain experienced (see Beak Treatment chapter).

There are different explanations as to why beak trimming reduces beak-inflicted damage. Structurally, the altered beak no longer possesses the sharp hook used to puncture and tear skin and flesh (Newberry, 2004) and the two mandibles no longer oppose each other in a manner that allows precise grasping and manipulation of objects with the beak. Beak trimming disrupts nociceptors and mechanoreceptors in the tip of the beak resulting in a loss of sensory feedback along with reduced tactile discrimination that could lead to less effective pecks (Desserich et al., 1983; Gentle & Breward, 1986). If the trimmed beak is painful resulting in less powerful pecks (Dennis & Cheng, 2010), damage to other birds would be less likely. Simply increasing feeding time through beak trimming may reduce time devoted to pecking at other birds (Newberry, 2004). It has been proposed that if beak trimming is performed at an early age, birds are less likely to learn to peck feathers (Hughes & Michie, 1982). However, beak regrowth after early beak trimming has been associated with outbreaks of cannibalism in adult hens (reviewed by Glatz, 2000). Furthermore, severe feather pecking and cloacal cannibalism can develop in adults with no juvenile history of these behaviours (Newberry, 2004; Newberry et al., 2007), likely influenced by hormonal changes associated with sexual maturation (Hughes, 1973). Although beak trimming reduces the severity of beak-induced injuries within a flock, it does not eliminate the motivation of birds to peck at their flock mates (Blokhuis & Van Der Haar, 1989) or completely eradicate beak-inflicted damage (Pötzsch et al., 2001). A variable and seemingly unpredictable risk of feather pecking or cannibalism remains, especially in non-cage housing systems (e.g., Appleby et al., 1988; Gibson et al., 1988; Keeling et al., 1988).

Examples of alternatives to beak trimming aimed at reducing injuries due to feather pecking and cannibalism by physically interfering with pecking include peepers, anti-picking spray, and abrasive materials. Savory and Hetherington (1996) applied plastic anti-pecking devices to the birds' beaks that interfered with beak closure; therefore, damaging pecks were reduced. However, the devices were associated with behaviours indicative of discomfort and sometimes fell off. Another strategy has been to apply distasteful substances such as coal tar or commercial anti-picking spray to victims (Pötzsch et al., 2001; Harlander-Matauschek & Rodenburg, 2011). Distasteful preparations deter feather pecking in the short term but can lead to a rebound of pecking when they wear off, requiring re-application at least every 2 weeks to maintain protection (Harlander-Matauschek et al., 2010). Whether beak-inflicted damage can be reduced by blunting of the beak tip through foraging in sand or pecking at particles on an abrasive surface is unclear. Beak trimming and other physical deterrents control the symptoms of feather pecking and cannibalism without addressing the underlying reasons for the behaviour (Newberry, 2004; Harlander-Matauschek & Rodenburg, 2011).

EFFECT OF LIGHTING

Dimming the light below 5 lux is one of the most common methods used to control severe feather pecking and cannibalism (Prescott et al., 2003). Higher light intensities increase the risk of both feather pecking and vent pecking in cages (Hughes & Duncan, 1972) and non-cage systems (Green et al., 2000; Pötzsch et al., 2001). In caged hens with lighting in the range of 0.9 to 7 lux, Allen and Perry (1975) noticed that feather pecking appeared at an earlier age in cages located at higher light intensities and then spread to adjacent cages. Similarly, Tablante et al. (2000) observed that cannibalism was clustered in cages at the top tier where light intensity was highest. Kjaer and Vestergaard (1999) found that over the period from 0 to 46 weeks, severe feather pecks by hens in floor pens were 2 to 3 times more frequent under 30 than 3 lux, accompanied by higher mortality from 16 to 46 weeks at the higher light intensity. Damaged feathers (McAdie & Keeling, 2000) or feathers that are different in colour or appearance from other hens (Bright, 2007) attract pecks, probably explaining why reducing visual stimuli by lowering the light intensity helps to control severe feather pecking.

The risk of severe feather pecking was 11.5 times higher in commercial non-cage flocks if the light intensity was increased for flock inspection (Green et al., 2000). This risk is probably greatest in flocks for which the lights have been dimmed to control an existing pecking problem. In the same flocks, provision of lights (as opposed to no lights) inside nests to encourage nest use increased the risk of feather pecking 4.8 fold (Green et al., 2000) and the risk of vent pecking, 9.6 fold (Pötzsch et al., 2001). The latter findings could be explained by increased visibility of the exposed cloacal mucosa immediately following oviposition (Savory, 1995; Yngvesson et al., 2004). If the nest area is shaded, brighter light in activity areas may have positive effects by promoting foraging and reducing floor laying. In a Swedish study of hens with intact beaks in 81 commercial flocks, exposure to natural daylight through windows appeared to be associated with less plumage damage and cannibalism relative to covering the windows (Yngvesson et al., 2011).

Controlling severe feather pecking and cannibalism by keeping hens in permanently dim or monochromatic lighting can lead to ocular disorders, abnormal behaviour, increased mortality, and reduced productivity (reviewed by Prescott et al., 2003). Kjaer and Vestergaard (1999) noted that stereotyped gentle feather pecks were 20 times more frequent at 3 than 30 lux over the period from 0 to 46 weeks. Also, hens prefer to feed in well-lit conditions. When offered feed at <1, 6, 20, and 200 lux, hens spent the least amount of time eating and consumed the least amount of feed at <1 lux and they were willing to work 2.3 times harder to gain access to brightly lit (200 lux) than dimly lit (<1 lux) feed (Prescott & Wathes, 2002). Gover et al. (2009) found that the spatial visual ability of hens was similar over the range of 1.79 to 57.35 candle m^2 (approximately 2 to 52 lux) but acuity declined below this level of illumination, which suggests that light levels would need to be below 2 lux to provide effective control against injurious pecking. If so, flock inspection raises a challenge given an increased risk of pecking when lights are turned up for flock inspection (Green et al., 2000). Furthermore, there is the issue of how to deal with cannibalism problems in free range systems (Hovi et al., 2003) considering that even on a dull day, the outdoor light intensity is considerably higher than indoors.

The findings of Gover et al. (2009) on spatial visual acuity are consistent with findings on the ability of hens to navigate between perches at different light intensities. Comparing 0.8, 1.5, 6.0, and 40 lux, Taylor et al. (2003) observed that hens were more hesitant to jump between two perches 1m apart and vocalized more at the 2 lower intensities. When comparing 0.6, 1.8 and 32 lux, there was again an effect of light intensity on jumping between perches of different colours spaced 0.75m apart with the biggest difference occurring between 0.6 and 1.8 lux. Moinard et al. (2004) observed no difference in the ability of hens to judge landings onto unobstructed perches under incandescent and fluorescent lights giving 5, 10 or 20 lux, although they questioned what would happen under more difficult conditions such as jumping towards crowded perches. These findings are relevant to the use of dim light to control injurious pecking in non-cage housing, especially taking into account the risk of keel bone fracture in hens (see Housing chapter).

Red light is also used to control feather pecking and cannibalism (Schumaier et al., 1968; Savory, 1995; Pötzsch et al., 2001). Based on studies of vision and eye function of laying hens (Prescott & Wathes, 1999; Lind & Kelber, 2009), red light probably controls feather pecking and cannibalism by lowering visibility and visual contrast. The use of red contact lenses to control beak-inflicted damage resulted in high mortality due to failure of hens to find food when they were moved to the layer facility (Adams, 1992). A high proportion of the lenses fell out; this was thought to result from hens scratching them out due to eye irritation. D'Eath and Stone (1999) observed that social discrimination between familiar and unfamiliar hens was impaired under red vs. white light at both 5.5 and 77 lux, probably because the comb and wattles were less distinct under red light.

GENETIC FACTORS

Many studies have indicated strain differences in feather pecking behaviour, cannibalism, plumage condition, and correlated traits. (e.g. Nicol et al., 2003). In a comparison of two strains of hens differing in duration of cloaca eversion following egg expulsion (Hori & Kamei, 1986), cloacal cannibalism was higher in the strain with the greater duration (Kawai et al., 1987). Therefore, controlling these behaviours through genetic selection seems like a promising alternative to beak trimming (Kjaer & Sørensen, 1997; Muir & Craig, 1998; Ellen et al., 2008; Rodenberg et al., 2008). Heritability estimates for feather pecking have been highly variable, ranging from 0 to 0.56, influenced by bird age when measurements are taken and whether plumage condition or feather pecking behaviour are used as the selection criteria (Kjaer & Sørensen, 1997; Jendral & Robinson, 2004; Kjaer & Hocking, 2004). Craig and Muir (1993) reported a high heritability estimate of 0.65 for pecking leading to severe injury or death.

The heritability of feather pecking and cannibalism has been confirmed by the divergent selection of several lines of birds differing in their tendency to show these behaviours (Kjaer & Hocking, 2004). Kjaer et al. (2001) decreased feather pecking behaviour and improved plumage condition by individual selection over 3 generations. A significant reduction in deaths due to cannibalism was achieved when related hens with untrimmed beaks were held in small groups in cages under bright lighting and selected for high group survival (Kuo et al., 1991; Muir & Cheng, 2004; Ellen et al., 2008). Group selection over 6 generations resulted in a drop in mortality from 68% to 8% (Muir & Cheng, 2004). Testing of family groups of hens with intact beaks in commercial environments is now reported to be a routine component of commercial selection programs (Lay et al., 2011).

Quantitative trait loci (QTL) studies have revealed some alleles associated with feather pecking behaviour (Labouriau et al., 2009), with different genes being associated with the performance and receipt of feather pecks (Wysocki et al., 2010). Genetic analyses are complicated by the involvement of a multitude of causal factors and genetic linkages with other sets of physiological and behavioural traits (Jensen et al., 2005; Su et al., 2006; Wysocki et al., 2010). A large scale QTL analysis of Red Jungle Fowl and White Leghorn crosses did not reveal any significant QTLs for feather pecking behaviour (Jensen et al., 2005). Buitenhuis et al. (2003) also failed to find QTLs with strong effects on feather pecking, suggesting the involvement of many genes or a strong effect of environmental factors on this behaviour (Jensen et al., 2005). Biscarini et al. (2010) identified 57 single-nucleotide polymorphisms associated with feather damage to the back/rump and/or belly of cage mates, one of which is a component of the serotonin 2C receptor gene. Involvement of the serotoninergic system in feather pecking has also been suggested by neurobiological studies (van Hierden et al., 2004; Kops et al., 2013).

So far selection against injurious pecking in commercial lines has focused on phenotyping rather than marker-assisted selection (Jensen et al., 2005). For a typical 4 line cross, more than 10,000 pure line hens are evaluated individually per line and another 15,000 hens are evaluated in family groups in commercial environments, making phenotyping time consuming and expensive (Lay et al., 2011). A range of behavioural tests has been investigated with the goal of developing phenotypic selection tools for the early identification of birds likely to develop feather pecking and cannibalistic behaviour (Cloutier et al., 2000; Albentosa et al., 2003; Uitdehaag et al., 2008). Results were not consistent, casting doubt on the usefulness of such tests as predictors of feather pecking. A challenge is that exploratory gentle feather pecking is performed by most birds when young and is not a reliable predictor of severe feather pecking even though it may lead to severe feather pecking in some birds (Rodenburg et al., 2004; Newberry et al., 2007; Hughes & Buitenhuis, 2010). Hocking et al. (2004) did not find strong correlations between feather pecking or cannibalism and behavioural time budget variables, fear responses, social behaviour, or pecking at inanimate objects. However, strains selected for either high or low feather pecking or survivability have shown some differences in behaviour, adrenal function and neurobiological responses to stress (Korte et al., 1997; Rodenburg et al., 2002; van Hierden et al., 2002; Cheng & Muir, 2004; Kops et al., 2013). For example, genetic selection for low mortality in group housing was associated with increased activity in an open field test at 5 to 6 weeks of age, suggestive of reduced fearfulness (Rodenburg et al., 2009). These findings raise the possibility of incorporating such traits into selection programs.

NUTRITIONAL FACTORS AND FORAGING OPPORTUNITIES

Feeding management and nutritional factors can play substantial roles in feather pecking and cannibalism. Hughes and Whitehead (1979) reported cannibalism in hens receiving diets low (0.003% Na) or intermediate (0.03% Na) in sodium but not at control levels (0.13% Na).

Diets deficient in protein can also increase the incidence of injurious pecking. Schaible et al. (1947) demonstrated that the addition of protein supplements such as casein, gelatin, liver meal, blood meal, soybean oil meal, and cotton seed meal to diets low in crude protein (CP), phosphorus, and fibre reduced the incidence of feather pecking and cannibalism in pullets. Ambrosen and Petersen (1997) observed that feeding layers a low protein diet (111g CP/kg of feed) without the addition of synthetic amino acids resulted in 17.6% mortality due to cannibalism, whereas mortality was 2.5 % when layers were fed a diet higher in protein (193g CP/kg of feed). Increasing CP above 124 g/kg did not produce any further improvement in survivability, whereas a treatment of 120g CP/kg of feed was terminated due to high cannibalism and mortality (Al Bustany & Elwinger, 1987).

Given that hens have dietary requirements for essential amino acids and also use dietary protein for synthesis of non-essential amino acids, the above results may relate more to the balance of amino acids and sufficiency of essential amino acids than to the overall CP level *per se*. For example, reducing levels of arginine from 6.9% to 3.9% in the diet of 4-week-old cockerels increased the level of cannibalism from none to 21%; returning the arginine levels to 6.9% reduced cannibalism (Siren, 1963). Since abnormal feathering can attract feather pecking behaviour (McAdie & Keeling, 2000), proper feather development is of prime importance. The major amino acids involved in the synthesis of feather keratin are methionine and cysteine and deficiencies result in abnormal feathering (Robel, 1977; Deschutter & Leeson, 1986). Elwinger et al. (2008) noted that feeding hens a diet relatively low in protein and methionine resulted in poor feather condition and an elevated incidence of pecking injuries. By contrast, high dietary levels of tryptophan can suppress damaging feather pecking behaviour (Savory, 1998; Savory et al., 1999). Tryptophan is a precursor for serotonin and this suggests that feather pecking may be associated with anxiety related to low serotonergic neurotransmission (van Hierden et al., 2004). There is no consistent evidence that plant-only protein sources alter the risk of feather pecking and cannibalism in comparison with diets containing animal protein (Savory et al., 1999; McKeegan et al., 2001).

There is evidence that dietary fibre is beneficial in reducing the risk of severe feather pecking and cannibalism (Aerni et al., 2000; Hartini et al., 2002). Bearse et al. (1940) reported that increasing the crude fibre content from 29 to 123g/kg of feed by replacing corn with oat hulls decreased feather pecking and cannibalism. Similarly, increasing crude fibre levels from 80 to 130 and 180g/kg of feed by substituting oat mill feed for corn reduced feather pecking and cannibalism (Esmail, 1997). Van Krimpen et al. (2009) also noted reduced feather damage when oat hulls were provided to increase hen intake of insoluble non-starch polysaccharides, which they attributed to improved gut function. Johansson (2008) observed less feather pecking in caged layers when a nutritionally balanced diet was supplemented with barley silage. Steenfeldt et al. (2007) found that providing hens with access to 3 types of high fibre supplements (maize silage, pea silage, and carrots) decreased pecking at feathers, skin, and cloaca; reduced severe feather pecking behaviour; and improved plumage quality at 54 weeks of age. Kalmendal and Wall (2012) also observed reduced vent injuries in hens given supplemental roughage.

There is a relationship between feather eating and feather pecking behaviour (McKeegan & Savory, 1999). Birds from high feather pecking lines were more motivated to manipulate and eat feathers than their low feather pecking counterparts (McKeegan & Savory, 2001; Harlander-Matauscheck et al., 2006; Harlander-Matauschek & Hausler, 2009). Harlander-Matauscheck et al. (2006) hypothesized that feathers, being mainly indigestible, would have similar effects to dietary fibre and reported that feather eating increased the speed of feed passage. Hetland et al. (2005) found that appetite for coarse wood shavings and feathers was dependent on the fibre level of the diet. Birds on low fibre diets consumed more wood shavings and feathers and showed greater accumulation of coarse fibre structures in the gizzard. They concluded that birds ate feathers in the absence of sufficient dietary fibre, most likely to compensate for the lack of structural components in their feed. More research is needed to explain the role of feather eating in feather pecking behaviour.

Ensuring that all hens receive nutrition that meets National Research Council (1994) requirements is important for maintaining proper growth and flock uniformity and for avoiding abnormal feather growth and bilateral asymmetry. In addition to feather pecking being directed towards abnormal, dishevelled feathers (McAdie & Keeling, 2000), hens are more likely to peck individuals that are relatively lower in body weight and more asymmetric (Yngvesson & Keeling, 2001; Cloutier & Newberry, 2002b; Campo et al., 2008). Green et al. (2000) and Pötzsch et al. (2001) reported that making 3 or more changes of diet during lay was a risk factor for feather and vent pecking, possibly because a change from more preferred to less preferred feed can lead to increased activity and redirected pecking behaviour (Dixon et al., 2006).

Providing opportunities to perform foraging behaviour can reduce the risk of severe feather pecking and cannibalism (Blokhuis, 1986; Huber-Eicher & Wechsler, 1997, 1998; Klein et al., 2000). In epidemiological research, Nicol et al. (2003) found an increased risk of feather pecking in flocks that were restricted from litter areas to prevent floor eggs and Green et al. (2000) reported more feather pecking when there was an absence of loose litter at the end of lay. Normal foraging behaviour includes pecking at both nutritive and non-nutritive substrates (Blokhuis, 1986). If birds are housed in an environment lacking ground pecking substrates, pecking may be directed at the feathers of other birds instead (Blokhuis, 1986; Huber-Eicher & Wechsler, 1997). This can also occur if available substrates do not fully satisfy the birds' motivation to perform different aspects of foraging behaviour such as seeking, investigating and manipulating. Providing substrates that encourage sustained foraging behaviour helps to minimize pecking at other birds (Newberry, 2004). For example, Huber-Eicher and Wechsler (1998) found that less feather pecking and cannibalism occurred when chicks were given long-cut straw bundles rather than short-chopped straw, and polystyrene blocks rather than polystyrene beads, as foraging substrates. The beneficial effects of providing environmental enrichment objects in reducing cannibalism and improving feather condition (Yasutomi & Adachi, 1987; Church, 1992; Gvaryahu et al., 1994; Jones et al., 2002) may also derive from satisfaction of the exploratory aspect of foraging behaviour.

Multiple studies have noted that feeding mash instead of pellets reduces the risk of feather pecking and cannibalism (Bearse et al., 1949; Jensen et al., 1962; Savory, 1974; El Lethey et al., 2000; Lambton et al., 2010). Birds engage in more feed-directed behaviour when fed finely ground mash compared to coarsely ground mash, crumbles, or pellets (Savory, 1974; Savory, 1995; Aerni et al., 2000) suggesting that birds that spend more time eating fulfill their need to forage, which may in turn decrease bird-directed pecking behaviour (Blokhuis & Arkes, 1984). Similarly, Van Krimpen et al. (2008) proposed that increased time spent feeding explained their observation of delayed feather damage in hens fed low energy, coarsely ground diets rich in non-starch polysaccharides.

OTHER ENVIRONMENTAL EFFECTS

Cannibalism and feather pecking can be found in all types of housing systems including cages, pens, aviaries, and free range systems (e.g., Swarbrick, 1986; Appleby et al., 1988; Cloutier et al., 2000; Hovi et al., 2003). Within the housing environment, the availability of perches can reduce the risk of these behaviours. Wechsler and Huber-Eicher (1998) reported a lower incidence of severe feather pecking when hens were given higher (70cm) rather than lower (45cm) perches. Bilčík and Keeling (2000) noted that hens resting on low perches (20cm) were subject to feather pecking by hens active on the floor. In small cages housing 4 hens, Moinard et al. (1998) reported an elevated risk of cloacal cannibalism in cages equipped with 20cm high perches than in cages without perches. In that study, injurious pecking was also elevated in cages that were 60 vs. 40cm high.

In free range flocks, the more hens using the range, the lower the risk of feather pecking (Green et al., 2000; Bestman & Wagenaar, 2003; Nicol et al., 2003), which may result from increased fibre consumption, the opportunity to supplement the diet, and reduced proximity to other hens when foraging. In aviary-housed flocks, provision of access to a range planted with clover also reduced feather pecking by comparison with hens kept indoors (Shimmura et al., 2008). Green et al. (2000) found less feather pecking when at least 50% of the flock was using the outdoor area on fine, sunny days. Range use was also promoted by smaller flock sizes (up to 500 hens), younger age at purchase, and a higher percentage of cover (e.g. trees, bushes, hedges) in the range (Bestman & Wagenaar, 2003). A reduced incidence of feather pecking was associated with the presence of cockerels in free range flocks (Bestman & Wagenaar, 2003) probably because the presence of males on the range encouraged more females to use the range. However, whereas agonistic behaviour was reduced, Odén et al, (1999) found no benefit of including males in the flock for controlling feather pecking.

There is circumstantial evidence that feather pecking and cannibalism spread through flocks by social learning (Allen & Perry, 1975; Tablante et al., 2000). When birds from a high feather pecking strain and a low feather pecking strain were either mixed or housed with birds of their own strain, there was some indication of social transmission of gentle feather pecking (McAdie & Keeling, 2002). Zeltner et al. (2000) observed an increase in feather pecking in pullets after introducing known feather peckers and Cloutier et al. (2002) experimentally demonstrated both individual and social learning of cannibalistic behaviour in pullets. These findings emphasize the importance of management to minimize opportunities for learning these behaviours, for example, by minimizing the risk of accidental injuries that lead to bleeding and immediately removing injured and dead birds (Newberry, 2004).

In hens kept in floor pens at 4 different group sizes (15, 30, 60, and 120 birds), the most feather pecking and cannibalism occurred at the largest group size (Bilčík & Keeling, 2000; Newberry et al., 2007). Several other studies have indicated higher feather pecking and/or cannibalism in larger groups over the range of 3 to 8 hens (Hughes & Duncan, 1972; Allen & Perry, 1975), 3 to 16 hens (Hetland et al., 2004) and 72 to 368 hens (Nicol et al., 1999). This effect of group size may be due to the presence of more potential victims as well as the presence of more observers that can learn the behaviour through social transmission (Newberry et al., 2004). Gunnarsson et al.

(1999) detected no association between group size and cloacal cannibalism in aviary-housed flocks ranging in size from 225 to 9,954 hens suggesting that other risk factors take precedence in large flocks. Effects of flock size on opportunities for social learning may be mitigated by furnishings that separate nesting and resting hens from actively foraging hens.

Several other factors have been associated with feather pecking and cannibalism in epidemiological studies. In a study of free range and organic layers, factors associated with earlier onset of severe feather damage included the use of chain feeders, elevated levels of carbon dioxide and ammonia, higher feed intake, and higher sound and light levels (Drake et al., 2010). Green et al. (2000) found that feather pecking was associated with a temperature in the hen house of less than 20^{0}C and the inspection of the flock by one person rather than multiple people. The use of nipple drinkers rather than bell drinkers was protective for both severe feather pecking (Green et al., 2000) and cannibalism (Pötzsch et al., 2001). Lambton et al. (2013) investigated the effect of 46 potentially protective management factors for injurious pecking. They found that the greater the number of protective management factors implemented, the lower the plumage damage, gentle and severe feather pecking, mortality, and likelihood of cannibalism.

EFFECTS OF REARING EXPERIENCE

The substrate provided during the rearing phase can influence the development of feather pecking and cannibalism. Blokhuis and van der Haar (1989) found that birds reared on wire flooring had a higher frequency of feather pecking during the laying period than birds reared on litter. In a study by Johnsen et al. (1998), chicks reared on a mixture of sand and straw for the first month of life had less plumage damage at 19, 33, and 45 weeks of age compared to birds reared on straw alone, and this latter group of birds had less plumage damage than birds reared on wire. The wire-reared hens feather pecked more at 5 and 40 weeks of age than conspecifics from the other 2 groups; they were more fearful and more likely to succumb to mortality due to cannibalism compared to hens reared on sand and straw or straw alone. Nørgaard-Nielsen et al. (1993) found that rearing with access to sand and peat for dust bathing also reduced the later tendency to feather peck compared to birds reared on straw alone. However, in an aviary system, early access to litter lowered mortality but did not affect cannibalism (Aerni et al., 2005). Nicol et al. (2001) reared chicks on wire floors from hatch and then replaced the wire flooring with solid floors covered with wood shavings at different ages and for different durations. Exposure to shavings for a minimum of 10 days reduced feather pecking compared to keeping hens continually on wire throughout the rearing and adult phases. However, adult hens housed on shavings performed much more ground pecking and less feather pecking than birds on wire regardless of rearing experience indicating that hens were strongly influenced by their current flooring substrate.

Glatz (2000) noted that unpublished studies using enrichment devices introduced to caged layers at 30 weeks of age failed to reduce feather pecking; this suggested that enrichment devices need to be introduced to the birds earlier in life. Indeed, McAdie et al. (2005) showed that string enrichment devices virtually eliminated feather pecking if provided continuously starting from 1 day of age whereas feather pecking was very pronounced among birds that never received string to peck at. Introduction of string at 22 or 52 days of age produced intermediate effects.

Light exposure during development may affect future feather pecking and cannibalism. Riedstra and Groothuis (2004) exposed Leghorn eggs to light ranging from 750 to 1000 lux or darkness in the last week of incubation. After hatching, the light-exposed chicks showed more gentle feather pecking than did their dark-incubated cage mates leading the authors to propose avoiding light exposure of embryos during the last week of incubation. In contrast, early post-hatch habituation to litter areas with relatively bright light could help to reduce fear and stress sensitivity, possibly helping to prevent the development of abnormal feather pecking behaviour (Rodenburg et al., 2009). The finding that onset of lay prior to 20 weeks of age has been associated with an increased risk of vent pecking (Pötzsch et al., 2001) suggests that the risk of cloacal cannibalism can be reduced by delaying onset of lay. The timing of sexual maturation can be controlled using short photoperiods and delaying photostimulation with increasing day length (Newberry et al., 2004). Proper body weight management that avoids underweight pullets reduces the probability of uterine prolapse that leads to cloacal cannibalism (Glatz, 2005).

In a preliminary report, Johnsen and Kristensen (2001) noted that chicks reared with dark brooders (allowing chicks to rest in a warm, dark, enclosed space clearly distinct from surrounding well-lit activity areas) showed lower levels of severe feather pecking than those brooded under heat lamps. Jensen et al. (2006) subsequently reported that the use of dark brooders for the first 5 weeks resulted in no observed severe feather pecking over the period from 0 to 23 weeks, whereas this behaviour rose in frequency in chicks brooded under heat lamps. Likewise, mortality was almost non-existent in the dark brooder group whereas it rose with age in the heat lamp group. Plumage and skin damage scores and the frequency of gentle feather pecking, were also higher in the heat lamp group. Gilani et al. (2011) investigated the dark brooder concept in 10 flocks on two commercial organic farms. By comparison with gas brooders, the dark brooders were beneficial in reducing severe feather pecking and improving plumage condition of birds with intact beaks over the period from placement to 35 weeks of age, with no adverse effect on growth, body weight uniformity, or mortality at the end of rearing. Dark brooders more closely simulate natural brooding by the mother hen and improve behavioural synchrony between birds, reduce disturbances during resting, and result in calmer birds (Riber et al., 2007; Gilani et al., 2011). To avoid chilling, attention has to be paid to ensure that the chicks find the dark brooders when first placed in the rearing facility (Gilani et al., 2011).

In an epidemiological study, an association was found between provision of perches by 4 weeks of age and reduced prevalence of cloacal cannibalism in non-cage systems during the production period (Gunnarsson et al., 1999). Hens with early access to perches (starting at placement of chicks in the rearing facility) were more likely to access feed located on upper tiers (80 and 160cm above the floor) at 16 weeks of age (Gunnarsson et al., 2000) and to take refuge on perches if an aversive stimulus (squirt with a water pistol) was applied to the cloaca to simulate a cannibalistic attack (Yngvesson et al., 2002) than birds given access to perches starting from 8 weeks of age. These findings suggest that early perch experience may lower the risk of cloacal cannibalism in hens that have not been beak trimmed because the hens are more likely to use nests and perches when first moved to the layer house.

Gilani et al. (2013) investigated factors associated with severe feather pecking on British free range indoor non-cage and organic rearing farms. During the rearing period, risk factors included a lower proportion of hens foraging, shorter photoperiod, more diet changes, less caretaker experience, lower ceiling height, intact beaks, and organic farming (which the authors speculated may have been due to provision of a lower percentage of litter space relative to slatted floor space). None of these rearing factors were associated with the risk of exhibiting severe feather pecking in adulthood, and no association between stocking density during rearing and current or future feather pecking was detected. Rearing at lower densities did reduce early feather pecking and cannibalism in two studies (6.5 vs. 13 pullets/m^2, Hansen & Braastad, 1994; < 10 vs. ≥ 10 pullets/m^2, Huber-Eicher & Audige, 1999) but this effect did not carry over into the laying phase (Hansen & Braastad, 1994). On Swiss organic farms, adult hens had less feather pecking damage when they had been reared on the same farm rather than being purchased from elsewhere at 16 to 18 weeks of age (Bestman & Wagenaar, 2003). Drake et al. (2010) also reported that remaining on the same farm during rearing and laying delayed the onset of severe feather damage. Both Drake et al. (2010) and Gilani et al. (2013) found that feather damage at the end of rearing was predictive of future feather damage during lay.

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6. BEAK TREATMENT

CONCLUSIONS

1. **Beak treatment that removes approximately one-third to one-half of tissue from the tip of the nares to the end of the beak at a young age (<10 days of age):**
    a. **May affect bird behaviour and growth for a period of time following treatment application but does not have long term negative effects on production, behaviour, or the development of beak neuromas. The alterations to bird behaviour and the reductions in growth rate can be attributed to pain or discomfort, reduced efficiency of feeding, or adjusting to a reduced beak sensing ability.**
    b. **Improves long term welfare of flocks of hens by reducing the effect of feather pecking, increasing feather coverage (indicator of reduced feather pecking and providing protective covering of skin), and effectively controlling cannibalism in laying hens when it occurs.**
    c. **Improves feed efficiency by reducing maintenance costs due to improved feather cover and by reducing feed wastage.**
2. **Beak trimming (hot-blade) and beak treatment (infrared) are techniques that if improperly applied can cause acute and chronic pain and reduced welfare in laying hens.**
3. **When performed properly neither hot-blade trimming nor infrared treatment of beaks results in long term pain but the majority of scientific literature suggests that the infrared technique is more precise, reduces the development of abnormal beaks, and causes less pain or discomfort after application.**

INTRODUCTION

Beak treatment is performed primarily to reduce the incidence of cannibalism in birds that reach sexual maturity, including laying stock. The beak contains nerve fibres and receptor cells, so removal of the tissue results in pain, sensory loss, and alterations to the bird's ability to feed. This chapter reviews the current scientific literature on beak treatment and will focus on the two techniques used in commercial production in Canada – hot-blade trimming and infrared treatment.

To assess the impact of beak shortening on bird biological function, criteria such as body weight, feed intake, mortality, egg quality, and stress response are discussed. Behavioural assessments are discussed in relationship to the affective state of birds. In terms of natural living, beak treatment alters the bird's beak morphology; the resulting loss of sensory input and mechanical function are discussed.

The beak of the chicken is a relatively complex organ. It aids the bird in a number of functions including its ability to grasp feedstuffs, preen the body (important for feather maintenance), perform behavioural actions such as nest building, act as a tool in confrontations (defensive or offensive) with other birds, remove ectoparasites and explore the environment (Gentle et al., 1990). In the egg industry, removing the tip of the beak (beak trimming or beak treatment) is a common and a very effective tool for reducing cannibalism and/or feather pecking (Savory, 1995; Guesdon et al, 2006). The welfare concerns of treating the beak include causing acute or chronic pain for the bird (Breward, 1984) and the loss of sensory reception from the beak (reviewed by Gentle, 1986a). In more extensive housing systems, beak treatment results in a reduction in ability to remove ectoparasites and beak treated birds often have a higher population of mites on their bodies (Chen et al., 2011). Currently, the most common methods of beak treatment in Canada are the hot-blade trimming and infrared treatment. These techniques may have different impacts on the bird and there are a number of variables within each technique (such as age of treatment, severity, etc.) that can also alter the effects.

Terminology Definitions

- Sensory or free nerve endings – normally occurring receptor cells or groups of cells that respond to various stimuli and transmit to the brain. These include (not limited to):
  - Nociceptors –which respond to painful stimuli
  - Mechanoreceptors –which respond to mechanical pressures or vibrations
  - Thermal receptors –which respond to temperature changes
- Neuroma – when nerve tissue is damaged, a mass of regenerating nerve tissue (nerve bundle) may form. These have the capability of firing at random, and the sensation may be painful. Sometimes called “amputation neuroma”.
- Trigeminal nerve system – responsible for many of the sensations in the beak of the bird. It is important in feeding behaviour, innervates many mechanoreceptors in the beak and has a nociceptive component.
- While nociception involves the physiological response that occurs to painful stimuli, pain itself requires a conscious processing of the physiological process.

Beak Anatomy

The beak is composed of a number of layers. The outer layer, termed the rhamphotheca is keratinized tissue and as seen in Figure 1, appears to be thicker near the beak tip. The epidermis lies inside the rhamphotheca and the dermis, inside the epidermis. The dermis contains blood vessel and nerve tissue (Gentle & Breward, 1986; Lunam, 2005; Cheng, 2006).

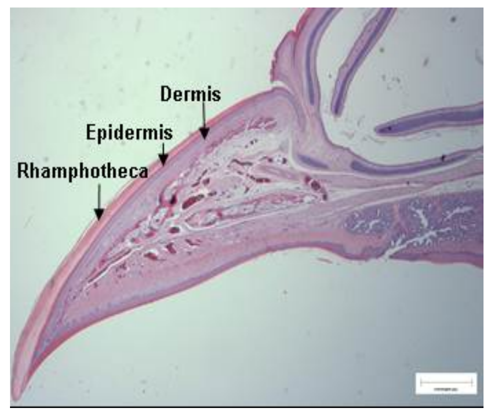

Figure 1. Beak anatomy demonstrating the individual layers inside the beak. University of Saskatchewan

Figure 2 demonstrates the internal tissue components of the beak and it is clear that it is well innervated with nerve endings including nociceptor and thermal receptors, mechanoreceptors (Herbst & Grandry’s corpuscles), blood vessels, premaxillary bone tissue (centre area), and other tissues (Cheng, 2006; Kuenzel, 2007). Kuenzel (2007) noted that with removal of up to 50% of the beak (% of the remaining beak from end of the nasal opening to tip of beak as compared to the entire beak), there would be removal of some, but not all, of the mechanoreceptors, nociceptors, and blood vessels.

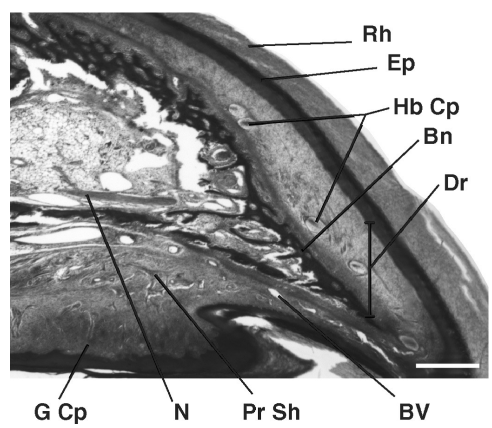

Figure 2. A sagittal section near midline of the upper beak of a 2-week-old chick. The bill tip is to the right. Scale bar, 400 _m. Bn = bone; BV = blood vessel; Dr = dermis; Ep = epidermis; G Cp = Grandry’s corpuscle; Hb Cp = Herbst corpuscles; N = nerve; Pr Sh = perineural sheaths; Rh = rhamphotheca. Kuenzel, 2007. Poultry Science. Reprinted with permission.

DESCRIPTIONS OF HOT-BLADE AND INFRARED TREATMENTS

Hot-Blade Trimming

Traditionally, beak trimming has been performed by the hot-blade (HB) method. The age at which birds can be treated with HB trimming can vary. Many birds are trimmed either manually or with an automated equipment system at the hatchery at 1 day of age. Both top and bottom beak are trimmed in this case. In turn, trimming may be done on farm either as an initial trim, or if regrowth seems substantial, as a re-trim procedure. Trimming is usually performed by 10 days of age but it can occur later (e.g. 5 weeks). If trimming occurs later in life, usually the upper beak only is trimmed. Virtually all commercial birds in Canada are trimmed at the hatchery.

The HB trimming technique employs a guillotine style blade that is maintained at approximately 750˚C. The beak of the bird is exposed through a small hole on a guideplate. Choosing a smaller or larger hole will determine the amount of beak removed, so it is important that research articles comparing final length of beak state the guide hole size used, as the length may simply be reflecting the technique used at the hatchery rather than being a result of beak trimming alone. After the beak tip is placed in the hole, the hot blade cuts and cauterizes the beak tissues simultaneously (Jendral & Robinson, 2004) with cauterization usually requiring about 2 seconds (Christmas, 1993). Blade temperature and the length of cauterization are critical aspects of successful HB trimming. Insufficient cauterization leads to hemorrhage while excessive exposure to the hot blade causes varying amount of tissue damage past the site of cutting (Lunam et al., 1996). The manual HB procedure requires skilled and consistent personnel to ensure the efficacy of the treatment and reduce variability (Dennis & Cheng, 2012). If an automated machine is used, vaccination of the chicks can be combined with the beak trimming procedure, which can reduce handling stress and improve precision through the loss of human error.

Coagulated blood mixed with fibroblastic scar tissue eventually grows over the wound. A few days after trimming, the epidermis begins to regenerate and develops over the scar tissue. Ultimately, this is replaced by new dermis (Gentle, 1986a; Gentle et al., 1997).

Blade temperature

In the scientific literature, only limited information is available on blade temperature comparisons. Maizama and Adams (1994) conducted 2 experiments to study the effects of beak trimmer blade temperature, as well as age of trimming (7 or 10 d), on the performance of 2 white bird strains. Blade temperatures of 1450°F (787°C) and 1200°F (649°C) were compared. Feed consumption was affected by blade temperature but data were only shown for week 18, so care must be taken with interpretation. During this period birds trimmed with the hotter blade ate more than did those trimmed with the cooler blade. No impact was noted on egg production, feed efficiency, or mortality during the laying period. There were interactions between strain and temperature; it was concluded that strains may differ in feed efficiency and mortality response to different beak trimming temperatures. This is important information and suggests again that Standard Operating Procedures used for HB trimming be genotype specific. The temperatures used in this study resulted in differing lengths of beak (hotter blade resulting in shorter beak) and this was not taken into account when information such as feed intake was discussed. Beak condition was also not mentioned, so it is not possible to know if cauterization occurred properly or if tissue was excessively damaged by the heat. In a separate experiment where blade temperature was examined in conjunction with age of trimming, no impacts were seen on productivity parameters.

Infrared treatment

More recently, an automated infrared (IR) beak treatment technology has been developed and is thought to result in a more precise trim (Carruthers et al., 2012). The procedure is performed at the hatchery and equipment is leased and monitored by the supply company. Chicks are placed in holders that secure the beak by means of a short sheath with guard plates protecting all but the beak tip. Mechanical fingers hold the head still. The unprotected beak tissue is then exposed to an infrared energy light. The affected tissue dies and over time (approximately 10 to 14 days) gradually softens and is eroded away (Marchant-Forde et al., 2008; Dennis & Cheng, 2012). Settings can be varied on the IR machines to adjust treatment severity, including the power of the infrared energy, thickness of the guide plate, and mirror angles. A simple comparison of beak lengths after trimming may only be reflecting the management choices made at the hatchery with regards to operation of equipment rather than effects of the technique in general.

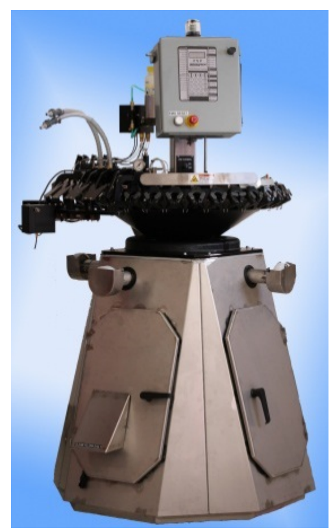

Figure 3: Infrared beak treatment equipment. Included with permission of Nova-Tech Engineering.

As with the automated HB machine, IR equipment automation allows vaccination to be completed at the same time, reducing the need for handling and the possibility of human error. It is hypothesized that, unlike the HB equipment, the slow beak erosion may allow the chick to accomplish behaviours requiring the beak (e.g. feeding behaviour) for a period after treatment. This adjustment period may be particularly beneficial when birds are learning to eat. However, not all data support this belief (Marchant-Forde et al., 2008). Other benefits are the elimination of open wounds that contribute to bleeding, inflammation and pain (Dennis & Cheng, 2012). Having the ability to modify the equipment for strain variation can also reduce abnormalities on healed beaks and improve precision of trim.

IMPACTS OF BEAK TREATMENT

HB Trimming

Research comparing HB trimmed birds vs. untrimmed controls has shown a number of impacts, although these are not always consistent across treatments. It is unfair to group all HB trimmed birds into one group as many factors can influence the impact of this trimming. The primary factors to consider are the age at which the chicks are trimmed and the severity of the treatment.

Mortality reduction with HB trimming

The primary purpose of beak trimming laying hens is to reduce the incidence of feather pecking and/or cannibalism. Although not all studies have shown a reduction in cannibalistic mortality (Gentle et al., 1997), it is important to understand that this behaviour does not occur in every flock but rather is sporadic in nature.

Works that have shown a reduction in mortality are nevertheless common. Hartini et al. (2002) found 0.14% mortality in HB trimmed birds and 13.4% in untrimmed control birds. The above experiment was conducted with conventional cages but research has shown that HB trimming can be an important tool in other housing systems as well. Guesdon et al. (2006) compared HB trimmed birds vs. untrimmed controls in two conventional cage systems and two furnished cage systems. All systems showed a reduction in mortality with the use of beak trimming (conventional cages, trimmed vs. untrimmed – 4 to 5% vs. 50 to 51%; furnished cages, trimmed vs. untrimmed – 4 to 8% vs. 40 to 43%). Mertens et al. (2009) examined layers in aviary systems. Birds were either intact or trimmed at 6 weeks of age and then fed 2 differing diets. Mortality in the aviaries was 1.6% and 2.6% for the 2 groups of trimmed birds and for the untrimmed controls, 21.5 and 25.8%.

Age of treatment

A concern associated with beak trimming is neuroma formation in the beak stump. These have been implicated in chronic pain following beak trimming as neuromas generate spontaneous neural activity in hens (Breward & Gentle, 1985). Neuroma formation involves initial degeneration and then regeneration of axons into disorganized tangled bundles of nerves as axon sprouts come in contact with scar tissue. Breward and Gentle (1985) found evidence of neuroma formation in adult birds trimmed with HB equipment; however neuromas may not form in the beaks of birds that are trimmed when very young. Gentle et al. (1997) found no evidence of neuromas in chicks that were HB beak trimmed at either 1 or 10 days of age. Activity was reduced for the week following treatment but no long term-effects were noticed. Trimming did not result in any long-term changes in productivity parameters. The conclusion of the authors was that when birds are trimmed at a very young age, there is minimal impact on the birds. Lunam et al. (1996) examined beaks of birds trimmed at hatch and found neuromas at 10 weeks of age. However, these regressed with no evidence of neuroma formation when re-evaluated at 70 weeks of age. It was suggested that when beaks are trimmed at hatch or day 1, axon sprouts may degenerate and neuromas can regress. Gentle (1986a) and Grigor et al. (1995) suggest that beak trimming during this time frame may not cause permanent nerve damage and have recommended this time period if HB trimming is to be used.

Although studies suggest that trimming at younger ages decreases the likelihood of permanent nerve damage, the amount of tissue removed is more easily controlled when birds are beak trimmed at an older age, as birds are physically larger. At older stages, there is also a lower probability of beak regrowth (van Niekerk et al, 1999). Birds trimmed of approximately 1/3 of both upper and lower beaks at 5 weeks of age have been seen to develop neuromas in the beak stump, which possibly results in chronic pain (Gentle, 1986a). It also appears that when trimming occurs after 4 weeks of age, there are more long-term adverse effects on behaviour, feeding activity, and weight gain (Duncan et al., 1989). Breward and Gentle (1985) HB trimmed adult birds, removing approximately 1/3 of beak tissue. These birds had well-formed neuromas in the beaks 20-30 days post treatment. The authors also detected spontaneous firing of neurons in the beak, suggesting pain.

The age of HB trimming also plays a significant role in how well birds recover from the procedure. When beak trimming is performed on day 1 at the hatchery, the trimming and handling stress during the growing phase is avoided. However, trimming on day 1 could increase the risk of mortality (Gentle, 1986a; Hughes & Gentle, 1995) and the probability that beaks will regrow (Gentle, 1986a). When Kumar and Nagra (2005) beak trimmed birds at 4, 8, 12, and 16 weeks of age, they found that the percentage of beak regrowth decreased as birds aged, with the 12 and 16 week age groups showing no beak regrowth at all. Again the degree of beak trimming can play a role in regrowth.

An attempt to quantify the stress involved with HB trimming was conducted by Glatz and Lunam (1994) using heart rate of sham treated birds, HB treated and untrimmed birds at 0, 10, or 42 days of age. At 0 days of age, no differences were found between the HB treated birds and the sham treated birds. It is possible that hatching alone or the handling of the chicks is so stressful that it induces maximum heart rate. These data indicate that heart rate may not be a good indicator of stress in day-old chicks. Differences were seen at the later ages, indicating that HB trimming in older birds is stressful.

The age of trimming also can impact behaviour. Jongman et al. (2008) trimmed chicks at day of hatch, and found no reduction in feeding or pecking behaviours, which the authors attributed to lack of long-term indicators of pain. Dennis and Cheng (2010) compared HB treated birds trimmed at 2 days of age to untrimmed birds in their time spent pecking and force of pecking. Observations were then conducted at 3, 4, and 5 weeks of age. They found trimmed birds pecked less and pecked with less force at 3 weeks of age but by 4 and 5 weeks, no differences were noted. They attributed the differences noted at 3 weeks to either pain or an adjustment period to physical alteration of the beak. Persyn et al. (2004) found that pullets HB trimmed at 7 to 10 days changed their meal patterns. Trimmed birds ate smaller meals and had shorter intervals between feeding. Duncan et al. (1989) trimmed hens at 16 weeks of age and found a reduction in the incidences of feeding, drinking, and preening behaviours, possibly indicative of pain.

Severity of treatment

Struwe et al. (1992) compared intact pullets with 3 levels of HB trimming at 10 days of age (4mm, 4.5mm, or 5mm gauge). They found no difference in body weight for the first 7 weeks. Feed usage was the highest for untrimmed birds and those trimmed at the 4mm level, but no differences were noted by 21 weeks. Adrenal weights at 21 weeks of age (as a measurement of stress) were significantly higher in untrimmed birds. They concluded that stress level was highest in this group and suggested that it may have resulted from an outbreak of feather pecking noted in the untrimmed hens.

Lunam et al. (1996) treated birds at hatch with varying levels of HB trimming and combined it with varying cauterization times. The treatments used were: 1) 1/2 the upper and 1/3 the lower beak removed with 2 seconds of cauterization; 2) 2/3 upper and 1/2 lower beak removed with 4 seconds of cauterization; and 3) untrimmed. Neuromas were found in the beaks of all trimmed treatments at 10 weeks of age but the neuromas found in treatment 1 regressed and were not found at 70 weeks of age. Neuromas were found in the severely trimmed beaks at 70 weeks of age. More deformities were also noted on the beaks of the severely trimmed birds. The authors concluded that using a more moderate, or less severe, trim allows neuromas to resolve which may result in pain being felt for a shorter period of time.

Glatz (2003) collected hens (70 weeks of age) with various beak lengths from beak trimmed commercial flocks. He removed and studied hens with short upper beaks, long upper beaks, and birds with uneven growth of top beaks and compared feed consumption between the groups. Birds with short upper beaks consumed the least feed, with the uneven birds being intermediate. The uneven beaked birds ate at the slowest rate. The hens with the shortest beaks pecked at the waterers more.

Gabrush (2011) used HB trimming to remove 20, 40 or 60% of the beak tissue at 1 day of age in Leghorn chicks. This resulted in a reduction of 14, 31 or 39% in these birds as adults. While behaviour indicated pain in all HB trimmed birds, a reduction in body weight was noted in the 60% removal birds by 8 days of age. This reduction in weight remained until no significant differences were noted at 59 weeks of age.

Duration of cauterization

Little scientific work has been published on the critical duration of cauterization. Lunam et al. (1996) used either a 2 second or a 4 second cauterization time combined with two severities of trimming. They found that the more severe trim (2/3 of beak tissue) and longer cauterization time led to neuroma formation still seen at 70 weeks of age. Because of the design of this study, it is impossible to know if neuromas were the result of the cauterization time, severity of trim, or a combination of both. It is also possible that an inappropriate temperature may cause damage to the beak past the point of initial trim (Gentle, 1986b).

Fear levels

Mielnik et al. (1992) compared the tonic immobility (TI), used as a fear assessment, of HB trimmed birds treated either once at 9 days or trimmed twice at 9 days and 16 weeks to intact birds at 16 weeks of age. No differences in TI were found indicating fear levels were similar.

Effects on pain stimulation

Because there are many nociceptors located in the beak tip (Lunam, 2005), it is important to determine whether pain results from beak trimming and if it does, the extent of the pain. Hot blade trimming results in a change in the numbers of nerve fibres in birds. Dubbeldam et al. (1995) examined chicks that were HB trimmed at 1 day, 8 days or 6 weeks of age. Trimming itself resulted in a change in the numbers of differing types of fibres with a higher number of small myelinated fibres and a reduction in large fibres. Large fibres have a faster conductive velocity and may be more important in identifying innocuous stimuli through such factors as touch or pain (Fink & Oaklander, 2006). Age of trimming had no effect on the relative numbers of fibre types. It is not specified if neuromas formed in the beaks of the birds trimmed in this work, so it cannot be concluded whether these differences result in altered beak sensitivity.

Painless phase

Electrophysiological studies have proven the presence of nociceptors in the chicken beak which respond to thermal stimuli (Breward, 1983). Gentle (1991) recorded large discharges from the trigeminal nerve (in particular from the sensory afferent fibres), which innervates the beak of the bird, immediately following HB trimming of adult hens (16 weeks of age) and these unusual discharges lasted between 2 to 48 seconds. Following that, no abnormal patterns were noted in the nociceptors tested for the period of 270 minutes, which the author suggests corresponds to a pain-free period. Gentle and colleagues (1991) counted the number of pecks delivered by birds to a visually attractive stimulus before and 6, 26, and 32 hours after HB trimming. They noted no reduction in number of pecks 6 hours after trimming, but saw a significant reduction after 26 hours had passed. This reduction in pecking behaviour was considered a type of guarding or pain related behaviour. The authors interpreted their results to mean that there is a pain-free period immediately following the trimming procedure, which, in some birds may last as long as 26 hours. Other supporting evidence includes work by Glatz et al. (1992) who found evidence of a painless phase when trimming occurred at day of hatch, with behavioural evidence of pain appearing to begin approximately 24 hours after the HB procedure. After this period trimmed birds not given analgesics showed a significant reduction of feed intake compared to those given analgesics.

Acute and/or chronic pain

There is evidence that HB trimming results in long term pain, but again, consideration must be made of the specific technique used, age of bird, severity etc. Breward and Gentle (1985) trimmed 1/3 of the upper and lower beaks of 5- week-old Brown Leghorns using the HB method. Spontaneous electrophysiological neural activity was recorded from the intramandibular nerve from 5 to 83 days post trimming. Neuromas were also noted by 20 to 30 days, and these two findings likely indicate pain. The research did not go beyond this time frame, so it is not known if the neuromas regressed or remained through adulthood.

Besides neurological evidence, there is also behavioural evidence that beak trimming may cause pain. Eskeland (1981) as reported by Gentle (1986a) found that compared to non beak-trimmed birds, those that were beak-trimmed displayed increased nesting time, although this may also be due to a reduced ability to manipulate nesting material. Gentle (1986a) also reported on unpublished data from Slee, Duncan, and Breward who found that trimming birds reduced the time spent ground pecking, dust bathing, and preening for at least 5 weeks after the procedure. The age of trimming was not reported. Duncan et al. (1989) trimmed birds at 16 weeks of age and found that behaviours requiring the beak such as feeding, drinking, preening, and pecking at their cages were decreased after birds were beak trimmed, whereas time spent sitting dozing and inactive standing increased. These behaviours did not return to pre-treatment levels until 5 weeks after the trimming procedure. The authors proposed that pain or discomfort resulting from beak trimming led to the changes in behaviour. Jongman et al. (2008) observed Leghorn chicks that were HB trimmed at 1 day of age. Half of the birds were re-trimmed at 14 weeks of age. Pecking and feeding behaviours were monitored at 10, 20, and 60 weeks and then at 8 and 52 weeks in the separate group of birds that were re-trimmed (HB) at 14 weeks. Pecking behaviour at food and novel objects after trimming and re-trimming was not different and gave no evidence of chronic beak pain. It did not appear those birds with re-trimmed beaks were different than those trimmed only once. These two experiments have resulted in different behavioural impacts, but it should be noted that Duncan and colleagues' (1989) measurements ended at 5 weeks, whereas Jongman and colleagues' (2008) measurements began at 10 weeks post trimming. Findings by Dennis and Cheng (2010) were intermediate to the two above; they found that chicks that were HB trimmed at 2 days of age and then tested on a force plate at 3, 4, and 5 weeks of age spent less time pecking at feed and used less force than untrimmed counterparts at 3 weeks of age. These differences disappeared at 4 and 5 weeks of age. Freire et al. (2011) used an analgesic to reduce pain in HB treated birds (0 days) and compared their pecking ability for a 9-day period to birds with intact beaks. Despite analgesic treatment, trimmed birds still showed a reduction in the amount of pecking and in pecking force. The authors concluded that the change in pecking noted in beak trimmed birds may be a result of the loss of mechanoreceptors rather than pain.

Together, these data suggest that HB beak trimming alters feeding behaviour but that the length of time that birds are affected depends to a large degree on bird age at trimming and severity of trimming. When trimmed at a young age, evidence of pain may be noted but it is generally short term. Evidence of lifelong pain is not seen. Trimming at older ages can show evidence of lifelong pain.

IR Treatment

Age of treatment

Because of the nature of the infrared equipment, all treatment using this technique must be performed at the hatchery on day of hatch. The amount of treatment using the IR machine is controlled by a combination of the thickness of the head plate, intensity of the light, and the mirror settings.

Severity of treatment

Dennis and Cheng (2012) compared energy and head plate settings used for IR treatment in a 2 (2 plate thicknesses, where a thicker plate results in a more moderate trim) x 3 (3 energy levels) factorial experiment. Hens treated with the thicker plate and intermediate energy level were the heaviest throughout the trial. A more severe treatment resulted in shorter beak length and in this case no differences in body weight were noted at 5, 10, or 30 weeks of age but feed wastage was higher with less severe treatment. Using a loose feather to examine the ability of birds to manipulate the object, it was noted that more severely treated birds did more damage to the feather. The authors hypothesized that this may indicate reduced sensitivity in these birds as they were not able to manipulate the feather well.

Pain

McKeegan and Philbey (2012) measured nerve activity of IR treated and intact (control) hens at 10, 30, or 50 weeks of age. A total of 386 nerves were tested for spontaneous firing, including mechanoreceptors, thermoreceptors and nociceptors. No treatment effect was found. No pathological changes were noted on IR treated beaks compared to control birds. Beak histology completed at 4 weeks of age showed evidence of healing, with re-epithelialisation and bone remodeling occurring in the lower beak. Reinervation with mechanoreceptors was seen in the area of healing at the tip of the lower beaks in 2 of the 6 tested birds. There was also evidence of some nerve regeneration in a small number of IR treated birds. As no neuroma formation was seen at any age of bird, the authors concluded that chronic pain did not result from the IR treatment.

Angevaare et al. (2012) compared IR treated and untrimmed chicks. No description of the severity of treatment from the IR machine was given and the treatment was described as routine. Mortality was low in IR treated chicks, (1 of 40 birds), and in this bird the tip of its tongue was damaged. This could indicate that settings were too severe. IR treatment caused a reduction in body weight to 8 weeks of age. Fewer physical symptoms of sexual maturity were seen in the IR treated birds at 17 weeks than in the untreated birds suggesting that IR treatment resulted in a delay in sexual maturity. The intact birds were able to eat more efficiently when monitored at 89 to 106 days of age, as they could pick up approximately 63% more food in a single peck than IR treated birds.

Freire et al. (2008) used an analgesic (carprofen) in the diet to mask potential pain. They then evaluated pecking force of hens, beak treated with IR or left intact, at 11 weeks of age. Consumption of the analgesic, carprofen, in the diet had no effect on pecking force. The IR treated birds did not consume more carprofen containing feed than did intact birds, which would be expected if the IR treatment resulted in pain.

Gabrush (2011) attempted to alter the amount of beak tissue treated using either varying intensities of IR treatment or varying hole sizes at a commercial hatchery to achieve a 20, 40 or 60% reduction. No differences in final beak length were found of any treated birds. When treated using varying hole sizes, body weight remained similar to untreated pullets until 28 days of age, when the 40 and 60% treated birds were lighter. This difference was also seen at 77 days of age, but no differences were noted after that date up to and including the 60 week weight. When variation in IR intensity was used to affect beak length, body weights of untreated and treated pullets were not different at 8 days of age. At 15 and 22 days of age, the 40 and 60% treatment groups weighed less than the untreated control, but no differences were noted when the birds were older. These differences may indicate pain, but since the time is similar to the period when beak tissue is sloughed, they may also indicate difficulty in manipulating feed stuffs.

COMPARISON OF HOT-BLADE AND INFRARED TREATMENTS

A number of studies have now been conducted comparing chicks treated with an IR machine vs. those trimmed with HB machines. In each case it is important to understand both the severity of the beak treatment and age at HB trim as these factors may influence the results.

Gentle and McKeegan (2007) compared broiler breeder chicks treated with an IR machine, chicks HB trimmed at 7 days of age, intact control chicks and intact control chicks that were sham treated on the IR machine and housed in groups of 10. There was no effect of treatment on any of a wide range of behaviours including locomotory, nutritive feeding and drinking, exploratory, and comfort behaviours of the chicks. Of the beak treated birds, regrowth of the beak tissue was the least on the 7 day HB trimmed chicks. Body weight of the HB trimmed birds was lower at 28 and 35 days than all other birds.

Dennis et al. (2009) compared the effects of Leghorn chicks IR treated at the hatchery to HB trimming at 7 to 10 days of age on production, aggressive behaviour, and stress physiology at 30 weeks of age. Birds were housed in 5-bird cages. There were no differences in body weight, egg production, fluctuating asymmetry, or heterophil:lymphocyte (H:L) ratio but IR treated birds were better feathered, indicating that feather pecking may have been reduced. Aggression was lower in IR treated birds housed in brighter light intensity (top cage row), but not in the lower intensity housed birds.

In another study, Dennis and Cheng (2010) found that White Leghorn chicks, housed in 12-bird cages and HB trimmed at 7 to 10 days of age spent more time eating but weighed less than infrared treated birds, suggesting a reduction in feeding efficiency in HB trimmed birds. However, the paper states that the beaks of the IR treated birds were longer than those of birds treated with the HB technique and it is possible that that the HB trimming was sufficiently severe to impact feeding ability. This explanation is supported by Dennis et al. (2009) who found no differences in eating or drinking behaviours between HB and IR treated birds monitored at 30 weeks of age.

In a further study comparing IR treatment (2 plate thicknesses and 3 energy levels) of White Leghorn chicks to chicks trimmed with HB between 7 and 10 days of age, Dennis and Cheng (2012) found HB trimmed birds, housed in 12-bird cages had the highest feed wastage. No description of beak length immediately following HB trimming was given. HB trimmed birds and those more severely treated with the IR machine spent less time walking at 5 weeks of age, which the authors stated may be related to pain or discomfort. HB trimmed birds spent less time drinking than any IR treated birds to 10 weeks of age.

Carruthers et al. (2012) conducted on-farm studies to examine the variability in beak length and numbers of abnormalities on beaks of White Leghorn birds trimmed with a HB at 1 day of age or an IR machine. It was found that IR treated beaks were more consistent in length and had fewer "abnormalities" (cracked beaks, asymmetrical regrowth, blisters, etc.) than HB treated beaks.

Marchant-Forde et al. (2008) compared layer birds treated with HB (procedure at 1 day of age), IR, or untreated (controls). In this case, the IR treated beaks were shorter than the HB trimmed beaks. Birds were paired in identical cages. More abnormalities were noted in birds trimmed with the HB machine than with the IR equipment. Both treatment techniques resulted in a reduction in feed intake, with the IR birds consuming the least until 4 weeks of age. Reasons for the reduction in feed intake could include pain, inability to grasp feed, and loss of beak sensitivity (Gentle et al., 1982). The IR treated chicks were lighter at 2 weeks of age (95.72 g) than either the HB treated (102.44 g) or control chicks (108.21 g), but differences dissipated after 4 weeks of age. After 5 weeks of age, the body weights were not different. Treated birds (both HB and IR) were less active than the control birds to 1 week of age, with IR treated birds being the least (less time eating and drinking) and controls the most active. HB treated birds (less beak removed) were intermediate in their activity levels. These differences in activity suggest acute pain following either beak treatment.

Marchant-Forde and Cheng (2010) compared laying hen pullets treated with HB and IR on day 1with untrimmed birds. The goal of treatment was to remove 1/2 of the beak tissue. No open wounds were observed on the IR treated beaks. HB treated beaks were still healing 2 to 3 weeks after treatment and the upper beaks healed faster than the bottom ones. More regrowth occurred with the HB treated beaks than with the IR treated beaks. Body weight was initially reduced for all treated birds; HB treated birds remained smaller than the untrimmed birds until 9 weeks of age, whereas the IR pullets were equal in weight to control birds by 3 weeks.

In a large scale study using 2,400 birds, Honaker and Ruszler (2004) compared Leghorns treated with IR and HB (7 days of age) to intact birds. No details were given regarding the amount of tissue removed, so care must be taken with data interpretation. IR treatment reduced pullet body weight and feed consumption, and increased pullet mortality over the HB treated birds, but not the controls.

CONSEQUENCES OF BEAK TREATMENT TO BEAK ANATOMY AND FUNCTION

Sensory Input

It is unclear from the literature whether sensory receptors regrow within the beak tip after treatment. Some studies have reported permanent removal of sensory receptors after beak trimming (Gentle 1986a; Gentle, 1986b; Cunningham, 1992) while others have found reinnervation to occur after IR treatment (McKeegan & Philbey, 2012). The loss of sensory input has been linked to reduced feed intake (Glatz and Lunam, 1994), pecking efficiency (Gentle et al., 1982), and a compromised sense of touch and temperature (Gentle, 1986a). However, the technique used, and when HB is the technique – the age at which beak trimming is carried out as well as the severity of trim can influence the presence of sensory receptors in the regrown beaks. Gentle (1986b) found that beaks of HB trimmed birds (1/3 of their upper and lower beaks at 5 weeks of age) were devoid of sensory receptors and free nerve endings based on histological examination but that regeneration occurred so that by 20 to 30 days post treatment, nerve fibre bundles and neuromas were found.

Scar Tissue and Beak Damage

Age

In Gentle's (1986b) study mentioned above, histological examination revealed that the dermis was devoid of sensory receptors and free nerve endings. The beaks consisted completely of scar tissue and neuromas were evident at 70 days post trimming. In contrast, trimming birds at a younger age resulted in faster regeneration of beak tissue with relatively little scar tissue formation. When Gentle et al. (1997) studied the effects of removing 1/3 of both upper and lower beaks (HB) from birds at either 1 or 10 days of age, it was found that upper beaks of all trimmed birds tested were devoid of scar tissue at 42 days of age. Although nerves and sensory corpuscles were observed in the dermis of the regenerated tissues, they were absent in the immediate few millimeters of the remaining beak tip. It was also noted that regardless of the amount of beak regrowth, all beak trimmed birds showed a similar reduction in feather pecking. The authors hypothesized that the reduction in feather pecking was due to altered sensory feedback rather than beak length.

Re-trimming the beak is a practice that sometimes takes place in an effort to prevent cannibalism and feather pecking following beak regrowth. Lunam et al. (1998) investigated the effects of moderate HB trimming of birds at hatch followed with re-trimming at 14 weeks of age. Sensory receptors and nerve fibres were seen near the tips of the trimmed upper and lower beaks at 28 weeks of age. Herbst corpuscles and nerve bundles were seen in the lower beak (Lunam et al., 1998). Sensory receptors and nerve fibres were observed in the dermis of the re-trimmed beak tip in 66-week-old birds (Glatz et al., 1998). This coincided with a return to normal feeding and pecking behaviour and it was suggested that this was indicative of partial restoration of sensory input (Lunam, 2005). Lunam et al. (1998) suggested that trimming at hatch or an early age as well as conservative re-trimming at 14 weeks of age minimizes scar tissue and allows for some re-innervation of free nerve endings into the beak tip.

Effects on Production

Beak treatment may impact productivity parameters such as feed intake and body weight (reviewed in Hester & Shea-Moore, 2003; Hester, 2005). Once again, the degree of impact will depend on the age of the bird at treatment, and the severity of the trim.

HB trimming

Glatz (1987) found that removal of 3mm of beak tissue (considered a moderate trim) of hens already in lay depressed feed intake for 9 to 10 days after the trim; feed intake then returned to pre-trim values. Removal of less tissue (2mm) did not affect feed intake.

Beak trimmed pullets and laying hens have improved feed efficiency when compared to intact birds. Craig et al. (1992) documented that feed consumption by HB trimmed hens was reduced and feed conversion improved in comparison to intact controls. Possible factors include a reduced feed wastage with trimming, as well as better feather coverage, which decreases energy requirements for maintenance (Hughes & Michie, 1982). Feather cover, often indicative of level of feather pecking, is important for maintaining body heat and protecting the skin of the bird from damage. There is a substantial amount of research showing that beak trimming improves feather condition (reviewed in Hester, 2005). The effects of beak trimming on egg weight remain unclear as it has been reported to either have no effect or decrease egg weight (reviewed in Hester, 2005). This may be a consequence of what happens to feed intake, which may again be related to the age at trimming and the severity of the trim. Feed wastage may occur when beaks are intact. Craig et al. (1992a) measured feed intake and wastage at 46- to 47-week-old White Leghorns, and found a reduction in overall feed usage with beak trimming. Prescott and Bonser (2004) investigated the ability of trimmed (5 days of age) and intact laying hens to feed at 8 months of age. Birds (5 HB trimmed and 5 untrimmed) were given either a deep layer of pellets or a single layer of pellets at which to peck. In the single layer treatment, mandible asymmetry was negatively associated with feeding success. The implication of the study was that depending on the degree of asymmetry caused by beak trimming, it could, under certain circumstances, result in inadvertent feed deprivation or difficulties in grasping feed. However, the birds that were trimmed in this experiment were only trimmed on the top beak where 30 to 50% of the tissue was removed. It is possible that leaving the bottom beak intact produced very different results than would have occurred if both beaks had been treated similarly. Lastly, it has also been proposed that flock performance of beak trimmed birds may improve as a consequence of reduced stress levels (Eskeland, 1981; Struwe et al., 1992).

The impact of beak treatment on egg production is not consistent in the literature. In some cases, egg production has not been impacted by trim (Kuo et al., 1991; Struwe et al., 1992b; Maizama & Adams, 1994), while in others, egg production has increased (Glatz, 1990; Bell & Kuney, 1991). Others have noted a reduction in egg production with treatment (Bell, 1996). These differences are likely attributable to variation in the age of trim, severity of trim and the methodology used.

The reduction in mortality that may occur with beak trimming has been described above and in the Housing chapter of this review. A reduction in mortality will also impact hen-housed egg production. For example, Guesdon et al.

(2006) found a significant reduction in mortality when birds housed in either conventional or furnished cages were beak trimmed as compared to untrimmed controls. Because of this reduction, hen-housed egg production was significantly higher in the trimmed birds. Similarly, Kuo et al. (1991) and Craig (1992) found an improvement in hen-housed production in trimmed birds because of a reduction in mortality.

Beak trimming does not appear to impact many aspects of egg quality, including egg weight (Struwe et al., 1992; Mertens et al., 2009), albumen height (Mertens et al., 2009), blood spot frequency (Yannakopoulos and Tserven-Gousi, 1986) or shell quality (Guesdon et al., 2006; Mertens et al., 2009).

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7. GLOSSARY OF TERMS

Access to Pasture	Availability of a grassed outside area.
Affective States	Subjective experiences of animals (e.g. pain, fear, frustration, comfort, contentment).
Ammonia	A noxious gas common in animal enclosures that forms during breakdown of nitrogenous wastes in animal excrement.
Aviary	A non-cage housing system with multiple tiers where nests, feed and water are located; often there is also litter on the floor for scratching and dust bathing.
Beak Neuroma	A mass of regenerating nerve tissue (nerve bundle) that can form following amputation of part of the beak.
Beak Trimming	Removal of a portion of the beak, usually with a specialized instrument that simultaneously cuts and cauterizes (e.g. hot blade)
Bone Mineralization	The biological process of incorporating minerals into bone tissue that function to provide structure and strength.
Brooder	A brooder house refers to a warm building for rearing young birds; the term "brooder" refers to a heating unit (e.g. brooder lamp, gas brooder) or an area of a barn to which chicks can go for warmth.
Brooding Cycle	The sequence of activity patterns of chicks with hens that are cyclical in nature; it generally involves active periods of feeding and exploration interspersed with periods of resting.
Bumblefoot	A condition whereby a local infection causes an abscess to form on the plantar surface of the foot.
Cannibalism	A behaviour problem in which a bird pecks and consumes the flesh of another bird.
Chick	A hatched young bird; usually refers only to the first few days of life when the bird is still covered in down.
Cloaca	The common anatomical opening for the intestinal, urinary and reproductive tracts in birds; also called the vent.
Coccidiosis	A parasitic disease in which the intestinal tract of the bird is infected by protozoal organisms called coccidian.
Contra Free-Loading	Behaviour that involves searching or working for food, even when other sources of food are freely available.
Conventional Cage	A wire mesh enclosure for housing laying hens; it typically houses up to 8 hens with equipment for provision of water, automated feeding, and egg collection.
Corneal Lesion	Abnormality of the tissue involving the cornea of the eye; can be caused by disease, trauma or chemical damage.
Cross-Wise Perches	Perches that run in the direction of the width, rather than the length, of the cage
Dark Brooder	Warm, dark, enclosed resting area for chicks that is clearly distinct from surrounding well-lit activity areas.
Dust Bathing	A special sequence of behaviour patterns that functions to clean the feathers and improve their insulative value. Depending on the substrate, it may also remove parasites from plumage.
Epidemiological	Refers to studies that involve collection of data from a large population (e.g. large number of commercial farms) followed by a set of statistical procedures that determine risk factors associated with disease or behaviour problems.
Euthanasia	Humane termination of an animal's life.
Feather Pecking	A common behaviour problem in hens that involves a bird pecking (or plucking) the feathers from flock mates.

Feather Score	A method for quantifying quality of plumage in birds; usually involves a subjective scale ranging from no damage/feathers in perfect condition to severe damage/complete loss of feathers.
Feed Conversion	The amount of feed consumed for a given amount of weight gained or eggs produced; describes the efficiency of the animal in turning food energy into product.
Floor Eggs	Eggs that are laid outside of the nest boxes in non-cage systems.
Foraging	The behaviour patterns involved in searching for and consuming food.
Free Range	A system where laying hens are allowed access to an enclosed pasture or range area.
Free Run Barn	A system where hens are allowed to roam free inside a laying facility but do not have outdoor access. These systems are often equipped with slatted or wire floors, perches, and automated egg collection and manure removal.
Furnished Cage	A wire mesh enclosure outfitted with perches, nest area, scratch area and more head room compared to a conventional cage; group sizes in furnished cages can range from 10 to over 100 hens, depending on the model. Also referred to as "enriched cages" or "enriched colony" systems.
Hen	A female domestic fowl that has reached sexual maturity.
Heritable/Heritability	Refers to a trait that can be passed down from parent to offspring; when a trait has high heritability, genetic selection for that trait results in a rapid change in the population.
Hot Blade Beak Trimming	Beak trimming performed using the hot-blade (HB) method, either manually or with automated equipment.
Hyperkeratosis	Excessive growth of the skin on the toes and foot pads; similar to callus.
IR (Infrared) Beak Trimming	Beak trimming performed using an infrared (IR) energy light.
Keel Bone	A specialized extension of the breastbone of birds onto which the pectoral and flight muscles attach.
Litter (or Bedding)	Loose substrate, usually straw, wood shavings or a similar material, used to cover floors or for bedding in animal housing.
Lux	A standard measure of light intensity.
Mash	Feed that is delivered to the hens as particles of the components of the feed (oats, corn, etc). It may be ground, but not homogenized. Crumble feed is homogenized, and may be delivered in a variety of sizes.
Medullary Bone	One of three types of bone tissue in birds; medullary bone acts as a reserve for calcium for egg shells but provides little structural strength to bone.
Morphology	The structural features of an animal.
Necropsy	Post mortem examination of an animal.
Non-Cage Systems	Systems that house larger groups of hens (i.e. usually more than 1000 hens) than cage systems (e.g. conventional cages; furnished cages); large enough for caretakers to enter to perform duties. May or may not be combined with outdoor facilities.
Osteoporosis	A condition involving loss of bone mass leading to bone fragility and risk of fracture.
Oviposition	The process of laying an egg.
Plumage	Feather cover of a bird.
Pullet	A young female domestic fowl that has not yet reached sexual maturity (i.e. begun to lay eggs).
QTL	Quantitative Trait Locus; a section of DNA linked to a specific trait in an animal; QTL mapping allows scientists to better understand the specific genes involved in traits of interest.

Rearing Density	The number of birds in a given amount of cage or pen space during their growing period.
Red Mite	An external parasite that feeds on the blood of birds and lives most of its life in the barn, not on the bird itself.
Re-Epithelialisation	Regrowth of epithelial tissue.
Sensory Input	Information transmitted from sensory neurons to the brain.
Silage	Fermented, high-moisture feedstuff made from grasses or leafy parts of grain plants.
Space Envelope	The 3-dimensional amount of space needed to perform a movement pattern.
Thermoregulatory Behaviours	Behaviour patterns that function to maintain body temperature (e.g. panting or shivering and huddling together).
Tibial and Humeral Breaking Strength	The strength of the bones within the leg (tibia) and wing (humerus) of the bird; measured by the amount of force it takes to break the bone.
Trabecular Bone	One of three types of bone tissue in birds; trabecular bone provides structural strength in the long bones.
Vocalization	A sound produced by an animal that functions in communication.