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Effects of a high oil and fibre diet and supplementary roughage on performance, injurious pecking and foraging activities in two layer hybrids

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Abstract 1. The study investigated the feeding of a high oil and fibre diet containing 260 g/kg organically produced cold pressed sunflower cake or supplemental roughage to aviary-housed Lohmann Selected Leghorn (LSL) and Lohmann Brown (LB) layers between 20 and 74 weeks of age with outdoor access during summer.

2. Feeding roughage was associated with reduced vent injuries, a tendency to improve plumage condition, and was accompanied by improved FCR compared with controls. Feeding the high oil and fibre diet tended to improve FCR compared with the control diet.

3. The dry matter of faeces was reduced in both treatments compared with controls. Foot pad cleanliness and the proportion of dirty eggs were negatively affected by the high oil and fibre diet. Foot health was superior in LB compared to LSL.

4. LB used the outdoor hen-runs more than LSL, but LSL consumed more litter indoors. Fewer LB hens fed on the control feed were recorded in the outdoor hen-runs. Supplemental roughage tended to decrease litter consumption.

5. In conclusion, supplemental roughage reduced vent injuries and was correlated with foraging activities. Feeding 260 g/kg sunflower cake negatively affected hygiene in aviary hens. Sunflower cake is nevertheless a promising alternative feedstuff to fulfil the protein requirement in organic layers.

INTRODUCTION

Following a growing frequency of upward price shifts in the feed market, it is increasingly important to evaluate less conventional feed ingredients. This issue is especially urgent in alternative production systems such as organic egg production, which face future obstacles in the supply of high-quality protein feedstuffs. The Commission Regulation (EC) No. 889/2008 stipulates a ban on the use of synthetic amino acids, and limitations on the use of conventional feedstuffs in organic feed. As an alternative ingredient, organically produced cold-pressed sunflower cake is of interest because of its favourable amino acid profile. To the feed manufacturer, however, feed formulation using large amounts of cold-pressed sunflower cake may result in unconventionally high levels of dietary fibre and fat. This needs attention because, firstly, the fibre content in sunflower derived products may vary widely (Senkoylu and Dale, 1999). Soluble fibres may decrease the dry matter of faeces and negatively affect hygiene, i.e. plumage cleanliness and proportion of eggs contaminated with faeces, and foot health of the flock (Francesch and Brufau, 2004). Secondly, both oil and fibre obtained from the diet will likely influence digestion and metabolism, and eventually performance. In poultry, the liver is the main organ of lipid synthesis, and high oil and fibre diets may affect lipid deposition due to their capacity to reduce liver fat (Butler, 1979; Akiba and Matsumoto, 1980). Fibrous feedstuffs may also have an impact on the behaviour of poultry. Bearse *et al*. (1940) identified some

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cannibalism preventing properties of dietary fibre, which was confirmed more recently by Hartini *et al*. (2002). There have also been positive experiences, from feeding layers fibrous feedstuffs, on feather pecking (van Krimpen *et al*., 2009). In the present article, damaging feather pecking, and injuries following pecking in the vent region, are hereafter referred to as injurious pecking. In countries and production systems where beak trimming is not permitted, injurious pecking constitutes, ethically and economically, one of the most important aspects of egg production (Blokhuis *et al*., 2007). There is much evidence to suggest that feather pecking should be considered a redirected foraging behaviour (e.g. Blokhuis, 1986; Huber-Eicher and Wechsler, 1997; Aerni *et al*., 2000). In support of this hypothesis, feather pecking was decreased in laying hens following the provision of roughage as a foraging substrate (Steenfeldt *et al*., 2007). This is worth consideration in the context of alternative system feeding strategies, as organic poultry must be provided with roughage in addition to their daily feed ration, as described in (EC) No. 834/2007 and the implementation thereof (EC No. 889/2008). The significance of well-kept plumage to the energy expenditure of layers was shown by Peguri and Coon (1993). Thus, fibrous feeds and supplemental roughage may both reduce injurious pecking, but these effects should also be studied in a wider context, i.e. taking performance and different foraging activities into account.

An experiment was set up to investigate the effects of supplemental roughage and a high oil and fibre diet, containing 260 g/kg cold-pressed sunflower cake, on performance, injurious pecking and foraging activities in two layer hybrids, known to differ in production performance (Tauson *et al.,* 1999) and feather pecking activity (Kjaer, 2000).

MATERIALS AND METHODS

Birds and housing

A total of 600 Lohmann Selected Leghorn (LSL) and 680 Lohmann Brown (LB) layers were obtained from a commercial breeder at 16 weeks of age. Among these birds, 600 LSL and 600 LB were housed in groups/pens ($n = 12$) of 100 in a three-tier aviary system, described by Abrahamsson and Tauson (1998). Each group was considered a statistical unit, allowing for two replications per hybrid and treatment: see description below. The remaining 80 LB were kept in an adjacent room in groups of 8 in furnished cages, described by Wall and Tauson (2007), to study liver characteristics. All pullets in the experiment were raised in a three dimensional housing system, or in cages, depending on their final housing system. No birds were beak trimmed. Birds displaying open wounds following pecking were sprayed with an odour-repellent spray, an action which was effective at most times. However, in cases when the injurious pecking would not stop, the recipient bird was euthanised for welfare reasons. In the aviary, feed and water were supplied *ad libitum* in the two bottom tiers. Water and perches were provided at the top resting tier, and single nests lined the wall opposite the tiers. Light regimen was gradually increased from 9 h light at 16 weeks of age, to 16 h light at 25 weeks of age and onwards. Wood shavings were used as floor litter and were replenished *ad hoc* when depleted, and the amount used was recorded. Stocking density was 3·1 hens/available m^2, calculated over all three tiers and the ground floor. During summer, i.e. between 26 and 49 weeks of age, birds had daily access (900–1500 h) to separate outdoor hen runs ($26{\cdot}5 \times 3{\cdot}0$ m). To facilitate inspection it was necessary to trim overgrown hen-runs two to three times during the summer.

Feed and supplemental roughage

From 20 to 74 weeks of age, aviary housed birds were fed one of three experimental diets: control feed (C), C + supplemental roughage (C + R), or a high oil and fibre diet (HOF) containing 260 g/kg partly dehulled cold-pressed sunflower cake. Feed C was formulated using potato protein and maize gluten meal; two non-organic ingredients commonly used during the progression towards fully organically approved layer diets in Sweden. The HOF was formulated to conform to regulation (EC) No. 889/2008, which stipulates that no conventional feedstuffs should be used in organic feed from the year 2012. Both feeds included fish meal, which at the time of writing, was excluded from the criterion of organically produced feedstuffs.

Each diet was fed to two groups (replicates) of either LSL or LB. The apparent metabolisable energy value (AME) of diets was calculated using the European prediction equation (Rose, 1997), and diets were formulated to contain comparable amounts of all essential nutrients. No exogenous enzymes were used. Diets were pelleted and crumbled and the nutritional compositions are shown in Table 1. A commercial product of dried (880 g/kg DM) whole-crop lucerne hay supplemented with 150 g/kg molasses (Lantmännen KRAFFT AB, Falkenberg, Sweden) was used as a source of roughage, and was fed *ad libitum* from cylindrical metal pan feeders hanging above the littered floor area. Most lucerne hay particles measured ~30–50 mm in length and were normally not larger than ~100 mm. Molasses

Table 1. *Nutritional characteristics of experimental feeds*

Feed ingredients[1] (g/kg)	C and C + R	HOF
Wheat	508·5	433·0
Cold-pressed sunflower cake[4]		260·0
Oats	130·0	120·0
Wheat middlings	60·0	
Wheat bran	50·3	
Maize gluten meal	50·0	
Fish meal	50·0	52·3
Potato protein	39·8	
Calcium bicarbonate	100·5	96·8
Monocalciumphosphate	5·4	4·7
Salt	2·3	2·4
Soya oil	0·3	24·5
Premix[3]	3·0	6·4
Calculated AME (MJ/kg)	11·3	11·4
Chemical analysis[2] (g/kg DM)		
Crude protein	194·3	184·0
Methionine	4·0	3·8
Cysteine	3·7	3·5
Lysine	9·6	8·1
Threonine	7·5	6·6
Crude fat	33·0	69·0
Starch	429·0	370·7
Ash	147·3	129·0
Crude fibre	34·0	68·3
Neutral detergent fibre	100·5	139·5
Lignin	16·0	27·5
Total nonstarch polysaccharides (NSP)	11·8	14·3
Soluble NSP	2·2	3·0
Insoluble NSP	9·6	11·3

[1]The mean of 4 feed deliveries.
[2]The mean of 2–3 feed deliveries.
[3]The premix contained yolk colouring agents and provided per kg: retinol 3 mg, cholecalciferol 75 μg, α-tocopherol 50 mg, CuSO4 6 mg and Na2SeO3 0·3 mg.
[4]Supplier's analysis (g/kg) of the sunflower cake was 197·0 crude fibre, 320·0 crude protein (7·0 methionine and 5·8 cysteine), 117·0 crude fat, 10·0 starch and 59·0 ash.

supplementation was used to increase palatability for species other than poultry, and was not associated with the present experiment. Roughage was supplied continuously, and refusals were weighed and discarded. Birds housed in furnished cages, and intended for analysis of liver characteristics, received diet C (5 cages) or HOF (5 cages) between 20 and 63 weeks of age.

Chemical analyses

Dry matter and ash respectively were determined at 105°C for 6 h and 550°C for 3 h. Protein (N × 6·25) was determined with the Kjeldahl method as described by Nordic Committee on Food Analysis (1976); fat as ether extract (Official Journal of European Communities, 1984); and starch as described by Sveinbjörnsson *et al.* (2007) with minor modifications. Amino acids were determined by HPLC (SS-EN ISO 13903:2005). Crude fibre was determined as described by Kalmendal *et al.* (2011). Total soluble and insoluble NSP and Klason lignin were determined according to Theander *et al.* (1995), previously described by Bach Knudsen (1997); and NDF was determined by the method of Chai and Udén (1998).

Recording of data

Injurious pecking was assessed by integument scoring according to the methods described in detail, including images, by Tauson *et al.* (2005). In short, 20 randomly selected birds from each aviary group were weighed and scored from 1 (worst) to 4 (best) with respect to plumage condition on the neck, breast, cloaca, back, wings and tail, and pecking wounds on the comb and in the vent region, at 40, 55 and 70 weeks of age. Plumage condition scores were summed (6–24 points) and presented as group means. The assessment also included scoring of plumage cleanliness, foot-pad cleanliness, bumble foot condition and foot lesions on a scale of 1 to 4 where 1 is worst and 4 is best, on an arbitrary scale. Bumble foot was defined as a prominent inflammation of the foot pad sole, and foot lesions included any physical damage caused by wear or dermatitis.

Feed intake was recorded on a four-week basis, and roughage consumption was monitored weekly. All eggs collected during one day, or a maximum of 90 eggs, were used for weekly egg weight recording. Mortality, rate of lay, and number of mislaid eggs, i.e. eggs laid outside the nests, were recorded on a daily basis. If present in dead birds, signs of cannibalism were recorded. At 74 weeks of age, total feed intake, rate of lay, egg weights and number of mislaid eggs were summed and used to calculate overall means for the entire period. Egg mass was defined as egg weight × rate of lay and feed conversion ratio (FCR) as feed intake divided by egg mass. Feed intake and rate of lay were corrected for mortality. The proportion of cracked eggs, and egg shells contaminated by faeces, were determined with an experimental candling unit in all eggs collected during three consecutive days at 25, 35, 40, 49, 56, 65 and 74 weeks of age. Fresh faeces were collected on a group basis at 55 and 73 weeks of age for dry matter determination (103°C, overnight).

The number of hens visiting the outdoor hen-run was recorded as $0 \leq 10$, $11 \leq 20$, $21 \leq 30$ or ≥ 31 hens/group at 10:00 AM, on a weekly basis. For statistical analyses, these results ($n = 24$) were scored (1–4) as: $0 \leq 10$ hens: 1; $11 \leq 20$ hens: 2; $21 \leq 30$ hens: 3; and ≥ 31 hens: 4.

The trial conducted in the aviary housing system was terminated at 74 weeks of age. At this

Table 2. *Production parameters (20–74 weeks of age) of Lohmann Selected Leghorn (LSL) and Lohmann Brown (LB) layers, fed on a wheat-based control diet (C), C + supplemental roughage (C + R), or a high oil and fibre diet (HOF). Means within a column lacking a common superscript differ (P < 0·05). Estimated standard error of mean (SEM) and P-values are presented*

Treatment	Mortality (%)	Feed intake (g/d)	Rate of lay (%)	Egg weight (g)	Egg mass (g/d)	FCR (g/g)
C	6·1	117·7	88·9	64·0	56·9	2·07^{a}
C + R	2·7	113·7	90·5	64·0	57·9	1·96^{b}
HOF	3·9	114·7	89·5	63·9	57·1	2·01^{ab}
LB	6·5^{a}	117·4	87·4^{b}	65·0^{a}	56·8	2·07^{a}
LSL	2·0^{b}	113·4	91·8^{a}	63·0^{b}	57·8	1·96^{b}
SEM	0·84	0·85	0·47	0·15	0·37	0·011
P-values						
Diet	0·348	0·212	0·410	0·926	0·551	0·018
Hybrid	0·028	0·057	0·003	<0·001	0·210	0·002
Diet × Hybrid	0·649	0·217	0·174	0·119	0·100	0·219

time, 5 birds per group were randomly selected for dissection and recording of abdominal fat pad weight. At 63 weeks of age, two birds per furnished cage were randomly selected and liver weight, liver dry matter content, and liver fat content, determined as ether extract, were recorded. All dissected birds were killed by cervical dislocation following a stun blow to the head. The entire trial was approved by the Uppsala Local Ethics Committee.

Statistical analysis

In the aviary system, the feeds (C, C + R and HOF) and hybrids (LSL and LB) were used in a 3x2 factorial arrangement with two groups (replicates) per treatment. When analysing repeated measurements, age and age interactions were included, using autoregressive covariance structure (SAS 9·1). Aviary pens and individual furnished cages were considered statistical units/replicates and analyses were based on group means. Mortality figures and proportions of dirty eggs were subjected to arcsin transformation (Snedecor and Cochran, 1968), but figures are presented untransformed as least squares means, and with the estimated standard error of mean (SEM).

RESULTS

Feed analyses

As indicated in Table 1, the C feed contained more protein, methionine, cysteine, lysine, threonine, starch and ash than HOF, but less oil and dietary fibre. Differences in nitrogenous and ash contents were unintended. HOF contained 36% more soluble NSP than C, and exhibited a lower insoluble:soluble NSP ratio (3·8) than C (4·4). The lucerne hay used in the C + R treatment contained 33·4% crude fibre, 12·8% crude protein and 7·2% ash.

Performance

Production figures, including mortality, are given in Table 2. Mortality was higher in LB than in LSL, but unaffected by dietary treatment. Mortality was notably high in LB hens fed diet C (10·2%), and based on post-mortem recording of wounds it was estimated that two thirds of the mortality was due to cannibalistic pecking. Cannibalism was not observed in LSL.

FCR was superior in C + R groups compared to C, and a tendency ($P = 0·052$) for improved FCR was seen in HOF. Over the entire production period, the proportion of mislaid eggs was substantially higher in LB (20·1%) than in LSL (2·6%) (SEM = 1·84, $P < 0·001$) but was unaffected by diet (data not shown). The proportion of cracked eggs was higher in LB (2·43%) than in LSL (1·05%) (SEM = 0·15, $P = 0·001$) and increased with age ($P < 0·001$). The proportion of cracked eggs tended ($P = 0·061$) to be lower in birds fed on diets C + R (1·27%) than C (2·34%) whereas HOF (1·61%) was not significantly different from C or C + R.

Dry matter of faeces was higher in groups fed on the C diet (26·6%) than in groups fed on HOF (23·5%) and C + R (23·3%) (SEM = 0·450, $P = 0·044$). Faeces were drier at 73 weeks of age than at 55 weeks of age ($P = 0·019$), but breed had no effect. Plumage cleanliness scores were higher in LB than in LSL ($P < 0·001$) but were otherwise unaffected by treatment (Table 3). Larger proportions of egg shells were contaminated in LB (13·0%) than in LSL (10·0%) (SEM = 0·48, $P = 0·021$); and in groups fed on HOF (14·5%) than C (9·9%) and C + R (10·2%) ($P = 0·013$). Foot pad cleanliness (Table 3) improved in all treatment groups with time ($P < 0·001$) but less so in birds fed on the HOF

Table 3. *Integument scores in Lohmann Brown (LB) and Lohmann Selected Leghorn (LSL) fed on a wheat based control diet (C), C + supplemental roughage (C + R), or a high oil and fibre diet (HOF). Scores range from 1 (worst) to 4 (best) and 'plumage score' refers to the sum of scores from 6 body parts. Means within a column lacking a common superscript differ (P < 0·05). Estimated standard error of mean (SEM) and P-values are presented*

Treatment	Plumage score	Pecking wounds		Plumage cleanliness	Foot pad cleanliness	Bumble foot condition	Foot lesion score	Live weight (kg)
		Comb	Vent					
C	14·5	3·1	3·3[b]	3·7	2·8[a]	3·5	3·4	1·96
C + R	17·8	3·2	3·8[a]	3·6	2·8[a]	3·3	3·2	1·99
HOF	15·2	3·2	3·4[b]	3·4	2·3[b]	3·5	3·4	1·91
LB	16·3	3·2	3·4	4·0[a]	2·6	3·7[a]	3·6[a]	2·08[a]
LSL	15·3	3·2	3·6	3·2[b]	2·7	3·1[b]	3·0[b]	1·83[b]
40 weeks	19·0[a]	3·2	3·8[a]	3·6	2·1[b]	3·1[c]	3·0[b]	1·96
55 weeks	15·0[b]	3·1	3·3[b]	3·6	2·9[a]	3·5[b]	3·4[a]	1·95
70 weeks	13·4[c]	3·2	3·4[b]	3·5	3·0[a]	3·7[a]	3·5[a]	1·95
SEM	0·49	0·03	0·07	0·05	0·03	0·04	0·03	0·015
P-values								
Diet	0·075	0·431	0·044	0·202	0·002	0·085	0·096	0·138
Hybrid	0·341	0·491	0·143	<0·001	0·070	<0·001	<0·001	<0·001
Age	<0·001	0·423	0·001	0·401	<0·001	<0·001	<0·001	0·912
Diet × Hybrid	0·366	0·338	0·307	0·246	0·056	0·729	0·856	0·333
Diet × Age	0·671	0·108	0·038	0·658	0·022	0·835	0·663	0·580
Hybrid × Age	<0·001	<0·001	0·023	0·752	0·171	0·011	0·004	0·097

Table 4. *Liver characteristics in Lohmann Brown layers housed in furnished cages and fed on either a control (C) or a high oil and fibre diet (HOF) between 20 and 63 weeks of age. Means within a column lacking a common superscript differ (P < 0·05). Estimated standard error of mean (SEM) and P-values are presented*

	Bird live weight (kg)	Liver fresh weight (g)	Liver DM (%)	Liver fat (% of DM)	Total liver fat content (g)
C	2·25	52·3	33·5[a]	35·7[a]	6·86[a]
HOF	2·07	42·4	29·7[b]	24·5[b]	3·24[b]
SEM	0·121	2·73	0·73	1·93	0·818
P-value	0·0647	0·1085	0·0312	0·0202	0·0582

(diet × age: $P = 0{\cdot}022$). Overall, groups fed on HOF had worse foot pad cleanliness scores ($P = 0{\cdot}002$). Bumble foot scores were superior in LB ($P < 0{\cdot}001$) and improved with time in LB but not in LSL (hybrid × age: $P = 0{\cdot}011$). Foot lesions followed the same pattern. LB hens were heavier than LSL hens ($P < 0{\cdot}001$). In hens from the aviary, the weights of abdominal fat pads were unaffected by hybrid and diet, but in furnished cages HOF exerted pronounced effects on liver fat deposition (Table 4). Feeding HOF tended ($P = 0{\cdot}065$) to reduce live bird weight.

Injurious pecking

Results from the plumage scoring are presented in Table 3. Plumage condition deteriorated in both hybrids over time ($P < 0{\cdot}001$), see Figure 1. Wounds from vent pecking increased with time in LB but not in LSL (hybrid × age: $P = 0{\cdot}023$). Feeding C + R reduced vent wounds (SEM = 0·072, $P = 0{\cdot}044$) and tended to improve plumage condition ($P = 0{\cdot}075$) in both hybrids.

Plumage scores were poorer in LSL (17·5) than LB (20·5) at 40 weeks of age ($P = 0{\cdot}012$), but subsequently were not different between hybrids.

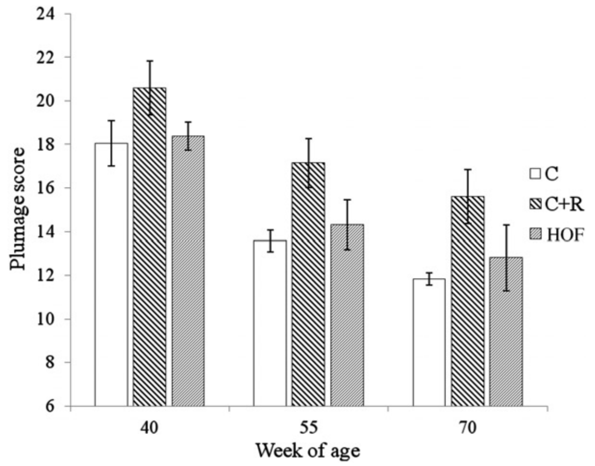

Figure 1. *Pooled mean plumage condition scores for Lohmann Brown (LB) and Lohmann Selected Leghorn (LSL) at 40, 55 and 70 weeks of age, fed on a wheat based control diet (C), C + supplemental roughage (C + R), or a high oil and fibre diet (HOF). Error bars indicate standard deviations. A score of 24 equals a fully feathered bird and a score of 6 a fully denuded bird.*

Table 5. *Percentage of times the given numbers of Lohmann Brown (LB) and Lohmann Selected Leghorn (LSL) hens were recorded in the outdoor hen-runs. Data were acquired weekly at 10:00 AM between 26–49 weeks of age. Birds were fed on a wheat based control diet (C), C + supplemental roughage (C + R), or a high oil and fibre diet (HOF)*

Number of birds recorded outdoors	Diet			Hybrid	
	C	C + R	HOF	LSL	LB
≥0 ≤ 10	72·9	58·3	54·2	97·9	25·7
>10 ≤ 20	21·9	24·0	25·0	2·1	45·1
>20 ≤ 30	5·2	13·5	18·8	0·0	25·0
>30 ≤ 100	0·0	4·2	2·1	0·0	4·2

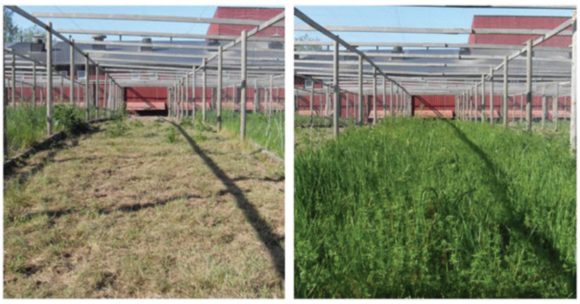

Figure 2. *Typical amounts of vegetation seen in two outdoor hen-runs after 5 weeks of access. Lohmann Brown (LB) hens had access to the left hen-run and Lohmann Selected Leghorn (LSL) hens to the right. Both groups were fed on a high oil and fibre diet (HOF).*

Wounds from comb pecking were unaffected by diet and hybrid, but increased in LB and decreased in LSL with time (hybrid × age: $P < 0{\cdot}001$).

Foraging activities

The numbers of hens recorded in the hen-runs are shown in Table 5. No general trend in number of hens outdoors was seen over the 24 week period. Overall, more hens were seen outdoors in groups of LB than in groups of LSL ($P < 0{\cdot}001$); the difference in foraging activity being obvious after only 5 weeks of outdoor access, see Figure 2. In LB, but not in LSL, fewer hens were recorded outdoors in groups fed on C than on C + R and HOF (hybrid × feed: $P = 0{\cdot}004$). As illustrated in Table 5, LSL hens were rarely seen in the hen-runs, irrespective of feed. After 15 weeks of access, all vegetation in hen-runs of the LB groups fed on C + R and HOF was virtually depleted, whereas some vegetation was still present in hen-runs of LB fed on C. These effects were further augmented with time.

Lucerne consumption averaged 2·9 g per hen per day, but was not statistically different between LB (3·9 g) and LSL (1·8 g) (SEM = 0·40, $P = 0{\cdot}119$). No trends in lucerne consumption were observed over time.

LSL birds continuously consumed their floor litter (wood shavings) and consequently, more litter was added (*ad hoc*) in LSL pens (79·8 kg) than in LB pens (44·7 kg) (SEM = 3·07, $P = 0{\cdot}001$). Supplemental roughage tended ($P = 0{\cdot}052$) to reduce litter consumption, which amounted to 69·4, 48·4 and 69·0 kg in total for diets C, C + R and HOF, respectively.

DISCUSSION

Hybrid differences

Scores of feather damage and vent wounds in this experiment were moderate, and the pattern of development in the two hybrids agree with Kjaer (2000). The hybrid × age interaction for comb wounds may be explained by the larger combs in LSL, which would be easier to peck at and thus attract more pecks *per se*. The hybrid difference at 40 weeks of age reflected this phenomenon, but with time, comb wounds increased in LB and comb scores of LSL, in contrast, slightly improved. Hybrid differences in plumage cleanliness scores can be ascribed to the fact that traces of dirt are easier to detect on white plumage than brown (Wall and Tauson, 2007). As expected, body weight, egg weight, feed consumption ($P = 0{\cdot}057$) and FCR were lower, and rate of lay was higher, in LSL than in LB. However, egg mass was equal in LSL and LB. This is in accordance with the reports of Tauson *et al.* (1999) and Singh *et al.* (2009). The proportions of cracked and dirty eggs were larger in LB than LSL, reflecting the higher frequency of misplaced eggs in the former hybrid. The propensity of LB to misplace their eggs has been described earlier (Tauson *et al.*, 1999). Hybrid differences in bumble foot condition are probably best explained by the general propensity of LSL to develop this condition (Tauson and Abrahamsson, 1994; Tauson *et al.*, 1999). Mortality was higher in LB than in LSL, which supports the findings of Tauson *et al.* (1999) where, as with the present study, beak-trimming was not performed on these hybrids. Interestingly, in the present trial cannibalism was only seen in LB.

The lower number of LB hens fed on diet C that were recorded in the outdoor area could reflect the higher level of injurious pecking in these groups, which most likely affects the stress level of the birds. Stress, fear and feather pecking may correlate with low frequencies of outdoor visits (Grigor *et al.*, 1995; Mahboub *et al.*, 2004). LSL birds did not use their hen-runs extensively, but rather seemed to perform their foraging activities indoors as they frequently depleted their floor litter. Since only marginal amounts of litter were spread outside the group pens due to activity such as dust bathing, it was assumed that the wood shavings were consumed. In support of this notion, Hetland and Svihus (2007) demonstrated that layers housed in furnished cages voluntarily consume between 4·0–11·0 g of litter per day, depending on the litter material. The findings of Hetland and Svihus (2007) were just recently confirmed at these experimental facilities (unpublished data).

Provision of roughage

Supplemental roughage significantly reduced beak-inflicted vent wounds and tended to improve plumage condition and was mirrored in superior FCR. The condition of the plumage is critical to the energy expenditure, i.e. heat loss from the body (Tauson and Svensson, 1980; Peguri and Coon, 1993); and since the low intake of roughage contributed negligible amounts of nutrients, the superior FCR most likely reflected increased energy efficiency. Hammershøj and Steenfeldt (2005) reported that mortality following cannibalistic pecking seemed to decrease by feeding roughage and in agreement with the present trial, Steenfeldt *et al.* (2007) found that supplemental roughage improved feather condition in ISA Brown layers. In the present trial, the supply of roughage was accompanied by a numerical reduction in consumption of wood shavings. This suggests that hens without access to suitable foraging substrates, such as roughage, may be more prone to consume the litter. The significance of foraging material to the development of feather pecking has been described by Aerni *et al.* (2000). Taken together, data from the present trial support the suggestion that feather pecking should be considered a redirected foraging behaviour, as proposed by Blokhuis (1986).

Effects of feeding the high oil and fibre diet

Feeding HOF failed to reduce feather pecking, and this might be explained by the quality of fibre in the feed. In the literature, positive effects from feeding fibrous feeds on feather pecking and cannibalism mainly derive from trials where insoluble fibre, such as oat hulls (van Krimpen *et al.*, 2009) or fibres extracted from oat hulls (Bearse *et al.*, 1940) were used. In the present experiment, the HOF diet was formulated using partly dehulled sunflower seeds. Although sunflower seeds are rich in insoluble fibre, the process of dehulling lowers the content of insoluble fibre, whereas the content of soluble fibre is less affected (Bach Knudsen, 1997). Hens fed on the HOF diet had an average daily insoluble NSP intake of 13·0 g, compared to 11·3 g in hens fed on diet C. These intakes are closer to the insoluble NSP intake of hens fed the standard diet (9·3 g/d) than a diet containing 10% oat hulls (17·7 g/d) that reduced feather pecking in the study of van Krimpen *et al.* (2009). Because the HOF in the present study contained 36% more soluble NSP than C, the negative effects on faecal dry matter, and consequently on foot pad cleanliness and the proportion of dirty eggs, were expected.

It is noteworthy that HOF tended to improve FCR, particularly as it contained less protein and amino acids than did C. Since the calculated AME values of the different feeds were similar, this effect may be due to the 'extra caloric value' of fat. HOF contained more than twice as much oil as did C. Additional oil has been shown to increase the dietary energy in a non-linear manner in laying hens, due to an increased utilisation of carbohydrates following a reduction in digesta transit (Mateos and Sell, 1981). However, the inclusion of sunflower cake in HOF necessitated several quantitative adjustments in the feed composition, which makes it difficult to exclude variations in digestibility of different ingredients.

Housing pre-requisites allowed for only one hybrid to be used to study the effect of HOF on liver characteristics and LB was chosen because of its anticipated larger feed intake. It was argued that if liver characteristics would respond in a dose-dependent manner to the actual intakes of certain nutrients, these effects would be more likely to be detected in LB than in LSL. Furthermore the choice of time of sampling was due to limitations in the procedure of analyses and not to the experimental design. In furnished cages, feeding HOF decreased the liver fat content, and was accompanied by a tendency to lower live weight in the LB birds. The effects of HOF on liver fat can be explained by the capacity of certain fibres to reduce hepatic lipids (Akiba and Matsumoto, 1980), in combination with the shift towards fat at the expense of starch (Hillard *et al.*, 1980). Dietary oil and fat is known to depress hepatic lipogenesis induced by starch feeding (Butler, 1979).

The liver is the main organ of lipogenesis in birds, but adipose tissue constitutes the major fat storage depot. Thus, we expected that fat metabolism in the liver would be mirrored by the weight of the abdominal fat pad from birds kept in aviaries. However, individual variations in abdominal fat pad weights at termination were too large to detect significant differences.

In conclusion, the present trial demonstrates that supplemental roughage may reduce injurious pecking in layers of two different genotypes, and that provision of roughage seems to correlate with foraging activities. Formulating diets with large amounts of soluble fibre may decrease the dry matter of faeces and this needs consideration in organic feed manufacturing, where the use of exogenous enzymes is restricted. Cold-pressed sunflower cake is a valuable feedstuff, particularly in organic nutrition, given the future limitations on conventional ingredients. Finally, the high oil and fibre diet substantially influenced liver fat metabolism on a long-term basis.

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