Feather-pecking response of laying hens to feather and cellulose-based rations fed during rearing

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ABSTRACT Recent studies in laying hens have shown that feather peckers eat more feathers than nonpeckers. We hypothesized that food pellets containing feathers would decrease the birds' appetite for feathers and thereby also decrease feather pecking. To separate the effect of feathers from that of insoluble fiber per se, additional control groups were fed pellets containing similar amounts of cellulose. Sixty (experiment 1) and 180 (experiment 2) 1-d-old Lohmann-Selected Leghorn birds were divided into 12 groups of 5 (experiment 1) and 15 (experiment 2) birds, respectively, and kept on slatted floors. During the rearing period, 4 groups each had ad libitum access to either a commercial pelleted diet, a pelleted diet containing 5% (experiment 1) or 10% (experiment 2) of chopped feathers, respectively, or a pelleted diet containing 5% (experiment 1) or 10% (experiment 2) of cellulose, respectively. In the consecutive laying period, all groups received a commercial pelleted diet. In experiment 1, feather pecking was recorded weekly from wk 5 to wk 16. In the laying period, observations were made in wk 18, 20, 22, 23, 24, 25, 26, 27, 28, and 30. In experiment 2, feather pecking was recorded weekly from wk 5 to 11, in wk 16 to wk 18, and in wk 20 and 21. At the end of the rearing period, plumage condition per individual hen was scored. Scores from 1 (denuded) to 4 (intact) were given for each of 6 body parts. The addition of 10% of feathers to the diet reduced the number of severe feather-pecking bouts ($P < 0.0129$) and improved plumage condition of the back area ($P < 0.001$) significantly compared with control diets. The relationship between feather pecking/eating and the gastrointestinal consequences thereof, which alter feather pecking-behavior, are unclear. Understanding this relationship might be crucial for understanding the causation of feather pecking in laying hens.

Key words: laying hen, feather pecking, feather eating, fiber, diet

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INTRODUCTION

Variable amounts of vegetation, seeds, stones, insects, and worms were found in the crop contents of chickens under free-range conditions (Wood et al., 1963). Moreover, Wood (1956) showed that birds prefer some food items over others. Given a choice, chickens prefer food components depending on their nutritional needs (Kutlu and Forbes, 1993; Forbes and Shariatmadari, 1994). In ruminants, Provenza (1995) showed that food preference is a result of the positive and negative consequences of foraging. Thus, animals consume a particular food, experience positive (nutrient award) or negative (malaise) effects, and adjust their preference for the ingested food on the basis of their postingestive experience (Provenza and Balph, 1990). Because birds swallow their food whole or with little oral manipulation, learning about the metabolic consequences of ingesting specific food substrates may contribute substantially to diet selection in chickens.

A British study recently showed that severe feather pecking remains an important unsolved problem in both organic and commercial laying hens in the UK, with a prevalence of 60 to 80% (Lambton et al., 2010). Similar prevalences can be assumed in other countries. Feather pecking is characterized as nonaggressive pecking and can be divided into 2 categories, mediated by different motivational systems (Kjaer and Vestergaard, 1999; McAdie and Keeling, 2002; Newberry et al., 2007; Dixon et al., 2008). In its mildest form, it has been observed as gentle repeated pecks at the tips and edges of feathers without removal of the feather. These pecks are considered similar to allo-preening in other birds (Dixon et al., 2008). In its severe form, feather pecking consists of forceful pecking with pulling and removal of feathers, causing feather damage, feather loss, and

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often resulting in cannibalism (Savory, 1995). Feather peckers pluck and eat feathers (McKeegan and Savory 1999, 2001). Although eaten feathers are high in CP, the main protein—keratin—is almost resistant to digestion by gastric and pancreatic proteolytic enzymes (Newell and Elvehejem, 1947). Therefore, feathers could be considered as an animal protein fiber, such as hair, fur, or cocoons of other animals. Diet composition in laying hens influences feather-pecking behavior and, for example, fiber content or source in laying hen diets play an important role in the development of feather pecking (Van Krimpen et al., 2005). Plant fiber sources, such as structural carbohydrates composed of cellulose, hemicelluloses, or other indigestible material, such as lignin, are usually added to the diet. A comprehensive review by Van Krimpen et al. (2005) underlines, however, that results from such experiments are inconclusive. In a preference test in which loose feathers and wood-shavings (cellulose) were offered in a food context simultaneously, the availability of wood-shavings did not substitute the specific appetite for eating feathers in feather peckers (Harlander-Matauschek et al., 2007). Feather-pecking laying hens therefore have a specific appetite or preference for a highly palatable food, which is not met in their diet (even if the diet meets nutritional needs). Birds seem to substitute this deficit with feather eating.

For the present work, it was hypothesized that birds provided feed containing feathers would exhibit reduced appetite for feathers and thus show reduced feather-pecking activity compared with both birds provided with normal food and birds provided with food containing insoluble cellulose instead of feathers.

MATERIALS AND METHODS

Birds and Housing

In total, 60 (experiment 1) and 180 (experiment 2) non-beak-trimmed 1-d-old Lohmann-Selected Leghorn (**LSL**) chicks were reared and housed in a climate-controlled room under conventional management conditions at the experimental farm of the University of Hohenheim (Germany). In experiment 1, birds were divided into 12 groups of 5 birds allocated to identical pens measuring 89 × 73 cm (length × width). Each pen contained a perch along one of the shorter sides, a 50-cm food trough along one of the longer sides, and a bell drinker (diameter 26 cm). In experiment 2, 12 groups of 15 birds each were kept in identical compartments measuring 119 × 70 cm (length × width) from wk 1 to 10 and in compartments of 140 × 122 cm (length × width) between wk 11 and 21. Along 2 orthogonal sides of the compartment, a cross-wise perch was provided. Three food troughs, 50 cm each, and a bell drinker (diameter 26 cm) were provided. The floor of the pens was made of plastic-coated wire. The pens were separated by opaque boards to prevent physical and visual contact with neighboring birds. The recommended light and temperature scheme for LSL pullets was provided from 0 to 16 wk of age. Light was on for 24 h per day for the first 2 d, followed by 16 h per day until d 6, and followed by a gradual reduction to 9 h per day in wk 7, down to 8 h per day in wk 16. Temperature was decreased during the first week of life from 33°C to 30°C, followed by a gradual reduction to a constant value of 20°C in wk 6 and onwards.

The light schedule was gradually extended by one hour per week to 16L:8D. Food and water were provided ad libitum. Birds' health status was monitored twice daily.

Experimental Design

The following study comprises 2 experiments. In experiment 1, 5% of chopped feathers or 5% of cellulose, respectively, and in experiment 2, 10% of chopped feathers or 10% of cellulose, respectively, were added to the rearing diets of laying hens and the effects on behavior compared with birds reared with commercial pelleted diets. The experiments were conducted in 2 consecutive years.

On d 0, 60 chicks (experiment 1) and 180 chicks (experiment 2) were allocated to one of 3 diet treatments. Four groups of 5 birds (experiment 1) or 15 birds (experiment 2), respectively, each received a commercial pelleted diet (control group), a pelleted diet with 5% (experiment 1) or 10% (experiment 2) of chopped feathers, respectively, or a pelleted diet with 5% (experiment 1) or 10% (experiment 2) of cellulose (Typ Arbocel B 3000, Rettenmaier & Söhne, Germany), respectively. The rearing diets were divided in phase 1 (wk 1–8) and phase 2 (wk 9–16; Table 1) in experiment 1, and in phase 1 (wk 1–4), phase 2 (wk 5–10), and phase 3 (wk 11–17; Table 2) in experiment 2. Experimental diets were formulated to contain similar levels of calculated energy and crude protein, to be isocaloric, and equivalent in as many nutrients as possible.

The Hohenheim University pelleted layer ration (17.2% CP, 11.1 MJ/kg) without feathers or cellulose was provided ad libitum to all groups during the laying period (wk 17–30 in experiment 1; wk 18–21 in experiment 2).

Preparation of Chopped Feathers

Feathers used in experiment 1 were obtained from white-feathered laying hens that were slaughtered at 84 wk of age at the end of lay. Approximately 800 donor birds were euthanized with CO_2 before being plucked. Clean feathers of all body parts, excluding the wing and tail feathers, were plucked manually. Twenty-three kilograms of feathers was collected and stored in a climate-controlled room at a temperature of −10°C for hygienic reasons. Thereafter, feathers were coarsely chopped into smaller pieces using a meat cutter (Typ K64 DC8, Seydelmann KG, Aalen, Germany) with 2 vertical knife pairs at 4,000 rotations per minute for

Table 1. Percentage diet composition and calculated nutrient content in phase 1 (1–8 wk) and 2 (9–16 wk) during rearing in experiment 1

Item	1 to 8 wk starter control	1 to 8 wk starter feather	1 to 8 wk starter cellulose	9 to 16 wk grower control	9 to 16 wk grower feather	9 to 16 wk grower cellulose
Ingredient						
Soybean extracted HP	23.19	22.00	24.79	9.99	8.75	10.97
Wheat	67.98	62.00	58.25	83.63	77.52	73.79
Feather coarse	—	4.99	—	—	4.97	—
Cellulose coarse	—	—	4.93	—	—	4.97
Maize gluten	0.65	1.20	1.20	0.32	0.99	1.40
Limestone	1.65	1.53	1.60	1.69	1.69	1.70
Monocalcium phosphate	1.40	1.60	1.60	0.80	0.89	0.95
Sodium bicarbonate	0.33	0.33	0.33	0.32	0.36	0.36
Soybean oil	1.60	3.06	4.13	0.24	1.79	2.89
NaCl	0.10	0.10	0.10	0.10	0.10	0.10
DL-Methionine	0.17	0.19	0.17	0.14	0.14	0.13
L-Lysine-HCl	0.30	0.36	0.27	0.14	0.19	0.12
Choline chloride	0.15	0.15	0.15	0.15	0.15	0.15
Mineral Premix Vor SG1	0.08	0.08	0.08	0.08	0.08	0.08
Vitamin Premix Vit-Vorm. 6/1.5	0.18	0.19	0.19	0.18	0.18	0.17
Loxidan TD100	0.02	0.01	0.01	0.02	0.02	0.02
Luprosil	0.20	0.20	0.20	0.2	0.20	0.2
Molasses	2.00	2.00	2.00	2.00	2.00	2.00
Calculated nutrient content						
MJ/kg	11.82	11.79	11.79	11.86	11.85	11.87
CP, %	19.54	19.54	19.51	14.81	14.83	14.80
Crude fiber, %	3.07	2.86	5.82	3.12	2.91	5.88
Calcium, %	0.99	0.99	1.00	0.89	0.91	0.91
Available phosphorus, %	0.75	0.77	0.77	0.59	0.58	0.59
Methionine, %	0.44	0.44	0.44	0.35	0.34	0.34
Lysine, %	1.10	1.11	1.10	0.65	0.65	0.65

30 s and continuing at 64,000 rotations per minute for 60 s. Minimal wetting of the feathers took place before cutting to build a bulk of feathers in the cutter. The maximum length of chopped feathers was 1 cm in the stiff rachis. Chopped feathers were dried at 26°C on plastic blankets for 72 h and turned manually 3 times a day to allow a balanced drying.

Chopped feathers, as described above, used in experiment 2 were provided by AL Tierfrischmehl Produktions GmbH, Diepholz, Germany. They were irradiated (20 kGy) to improve microbiological safety while maintaining nutritional quality at the Department of Food Technology and Bioprocess Engineering, Max Rubner-Institut, Karlsruhe, Germany.

Preparation of Pellets

Chopped feathers and cellulose were added to the diets before pelleting. The pelleting press (Typ 14, Amandus Kahl GmbH, Reinbek, Germany) was manually fed by way of a feed hopper producing pellets 3 mm in diameter. Pellets were provided to the birds to ensure that cut feathers and cellulose were ingested.

Particle Size Distribution

In experiment 1, particle size distribution was analyzed by wet sieve analysis. A 30-g sample was sieved (Fritsch analysette 3) using 6 sieves with a mesh size of 2.5, 1.25, 0.63, 0.315, 0.16, and 0.071 mm, respectively, by using the method of Goelema et al. (1999). To reach complete disintegration of the pelleted food, all samples were soaked in 500 mL of distilled water for 45 min at room temperature. Average particle size of the 5% feather diet was 3.3 mm, of the 5% cellulose diet, 3.9 mm, and of the control diet, 2.9 mm. The layer diet showed an average particle size of 1.8 mm.

Observations

In experiment 1, severe feather-pecking bouts were recorded for 10 min per week and pen from wk 5 to wk 16. In the laying period, observations were made in wk 18, 20, 22, 23, 24, 25, 26, 27, 28, and 30. In experiment 2, severe feather-pecking bouts were recorded for 20 min per week and pen from wk 5 to 11, in wk 16 to 18, and in wk 20 and 21. Severe feather-pecking bouts were recorded when successive, forceful pecking or removal of the feather of the same pen mate were observed (Savory, 1995). A bout ended when there were no pecks for 5 s. All pens were observed in a randomized order as described in Anderson and Adams (1991). To exclude involuntary bias, the observer was blind to the dietary treatment of the hens.

Feather Condition Scores

After rearing, in wk 16 in experiment 1 and wk 17 in experiment 2, plumage condition per individual hen was scored using the system described by Tauson et al. (2005). This system comprises 6 body parts (neck, breast, cloaca/vent, back, wings, and tail) using a 1 to

Table 2. Percentage diet composition and calculated nutrient content in phase 1 (1–8 wk), 2 (9–16 wk), and 3 (11–17) during rearing in experiment 2

Item	1 to 4 wk starter control	1 to 4 wk starter feather	1 to 4 wk starter cellulose	5 to 10 wk grower control	5 to 10 wk grower feather	5 to 10 wk grower cellulose	11 to 17 wk developer control	11 to 17 wk developer feather	11 to 17 wk developer cellulose
Ingredient									
Soybean extracted HP	23.28	20.65	23.97	17.82	16.13	17.55	9.98	8.57	12.10
Wheat	65.52	53,28	46.61	74.15	61.8	55.64	84.15	71.40	64.78
Feather coarse	—	9.99	—	—	9.99	—	—	—	—
Cellulose coarse	—	—	9.99	—	—	9.99	—	9.99	9.97
Maize gluten	1.83	3.33	4.99	1.28	2.14	5.14	0.71	1.43	2.85
Limestone	1.33	1.23	1.23	1.14	1.07	1.07	1.28	1.14	1.21
Monocalcium phosphate	2.00	2.16	2.16	1.71	1.86	2.00	1.57	1.76	1.78
Sodium bicarbonate	0.33	0.33	0.33	0.36	0.36	0.36	0.36	0.36	0.36
Soybean oil	3.99	7.16	4.13	2.00	5.00	6.70	0.64	3.93	2.89
NaCl	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
DL-Methionine	0.27	0.28	0.25	0.20	0.21	0.20	0.13	0.14	0.12
L-Lysine-HCl	0.42	0.53	0.43	0.33	0.43	0.36	0.26	0.34	0.23
Choline chloride	0.15	0.15	0.15	0.15	0.15	0.15	0.10	0.10	0.10
Mineral Premix Vor SG1	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Vitamin Premix Vit-Vorm. 6/1.5	0.17	0.17	0.17	0.17	0.18	0.17	0.17	0.17	0.17
Loxidan TD100	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01
Ca-Propionate	0.4	0.4	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Threonine	0.08	0.08	0.08	0.05	0.05	0.05	—		—
Elancoban 200	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Calculated nutrient content									
MJ/kg	12.29	12.25	12.18	12.03	11.94	11.82	11.91	11.89	11.79
CP, %	20.18	20.19	20.15	18.00	18.02	17.97	15.03	15.01	15.00
Crude fiber, %	3.05	2.68	8.65	3.13	2.74	8.74	3.16	2.77	8.74
Calcium, %	1.01	1.00	1.00	0.88	0.90	0.90	0.90	0.90	0.90
Available phosphorus, %	0.85	0.84	0.85	0.77	0.77	0.80	0.71	0.72	0.72
Methionine, %	0.55	0.55	0.55	0.45	0.46	0.45	0.34	0.34	0.34
Lysine, %	1.20	1.20	1.22	1.01	1.02	1.04	0.75	0.76	0.76

4 point scale (1 = severe damage; 2 = moderate damage; 3 = slight damage; 4 = no damage).

Statistical Analysis

Data of experiments 1 and 2 were analyzed separately. PROC GLIMMIX (SAS 9.1, SAS Institute Inc., Cary, NC) was used in experiments 1 and 2 to analyze the number of severe feather-pecking bouts (number of pecks were divided by the number of birds per group) as a repeated measurement. The factors diet treatment (control, feathers, cellulose) and feeding period (rearing, laying) and their 2-way interactions were included as fixed effects. A random effect was modeled by combining the repeated factor 'week' with the random effect 'compartment'. Due to the repeated measurements taken on the same group of animals (compartment) at different time points (week), an autoregressive covariance structure of order 1 [AR (1)] was fitted to the compartment-by-week effect (Piepho et al., 2004). The repeated measures analysis using GLM models was used on log (x + 1) transformed data with an assumed Gaussian distribution and an identity link. Differences between least squares means were tested using t-tests. The results are presented as back-transformed means ± SE of severe feather-pecking bouts per 10 min.

The ordered categories of plumage scores of experiments 1 and 2 were analyzed as multinomial data with PROC GLIMMIX (SAS 9.1) with the fixed effect diet treatment (control, feathers, cellulose) and the random effect animal. The GLIMMIX statement fitted a model with probit link for the cumulative probabilities by maximum likelihood where the marginal log-likelihood was approximated by using an adaptive Gauss-Hermite quadrature (Diggle et al., 2002).

RESULTS AND DISCUSSION

Studies have shown that feather peckers consume more indigestible feathers than nonpeckers (Mc Keegan and Savory, 1999, 2001; Harlander-Matauschek et al., 2007), indicating that conventional diets may lack components for which the feathers may serve as a substitute for some birds. Therefore, this study was designed to evaluate whether laying hens' preference for feathers obtained through feather pecking would be decreased when feathers are added to their diets. In the present study, chopped feathers or cellulose were added to isocaloric rearing diets at a rate of 5% (experiment 1) and 10% (experiment 2), respectively, before pelleting to assess their effect on severe feather-pecking behavior and plumage condition in hens. Particle size of the pelleted diets fed during rearing (analyzed in experiment 1, see Materials and Methods) was quite similar.

In experiment 1, there were no significant main effects of feed treatment ($F_{2,258} = 0.56$; $P < 0.577$; Figure 1) or feeding period ($F_{1,258} = 1.81$; $P < 0.179$; Figure 2) on the number of severe feather-pecking bouts, and no significant interaction ($F_{2,258} = 1.97$; $P < 0.1416$) was detected. Similarly, hens of the different feed treatments did not differ significantly in plumage score for any of the body areas (Figure 3). Hens had an average feather score of 3, indicating slight feather damage in each of the body areas (Figure 3).

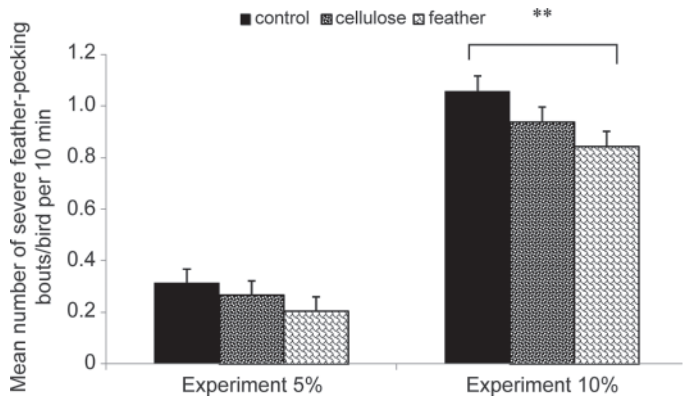

Figure 1. Backtransformed mean number + SE of severe feather-pecking bouts/bird per 10 min in experiment 1 (control, 5% cellulose, 5% feather) and experiment 2 (control, 10% cellulose, 10% feather. $^{**}P < 0.01$.

In experiment 2, there was a significant main effect of feed treatment ($F_{2,150} = 3.18$; $P < 0.044$; Figure 1) on severe feather pecking, which could be attributed to a significantly lower number of severe feather-pecking bouts in the feather group compared with the control group ($t = -2.52$; $P < 0.0129$). There was neither a significant difference between the cellulose and control groups ($t = -1.41$; $P < 0.1592$), nor between the cellulose and feather groups ($t = -1.10$; $P < 0.2728$). Birds showed a significantly higher number of severe feather-pecking bouts in the laying period than in the rearing period ($F_{1,150} = 79.49$; $P < 0.0001$; Figure 2). In experiment 2, the neck, breast, and cloaca parts of the body showed no damage in all feeding treatments, whereas damage to the wings was slight and damage to the tails between moderate and slight. Plumage score

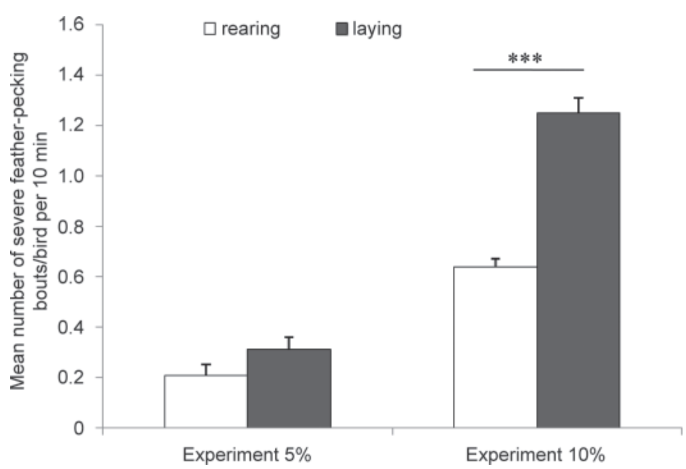

Figure 2. Backtransformed mean number + SE of severe feather-pecking bouts/bird per 10 min during rearing and laying in experiments 1 (control, 5% cellulose, 5% feathers) and 2 (control, 10% cellulose, 10% feathers). $^{***}P < 0.001$.

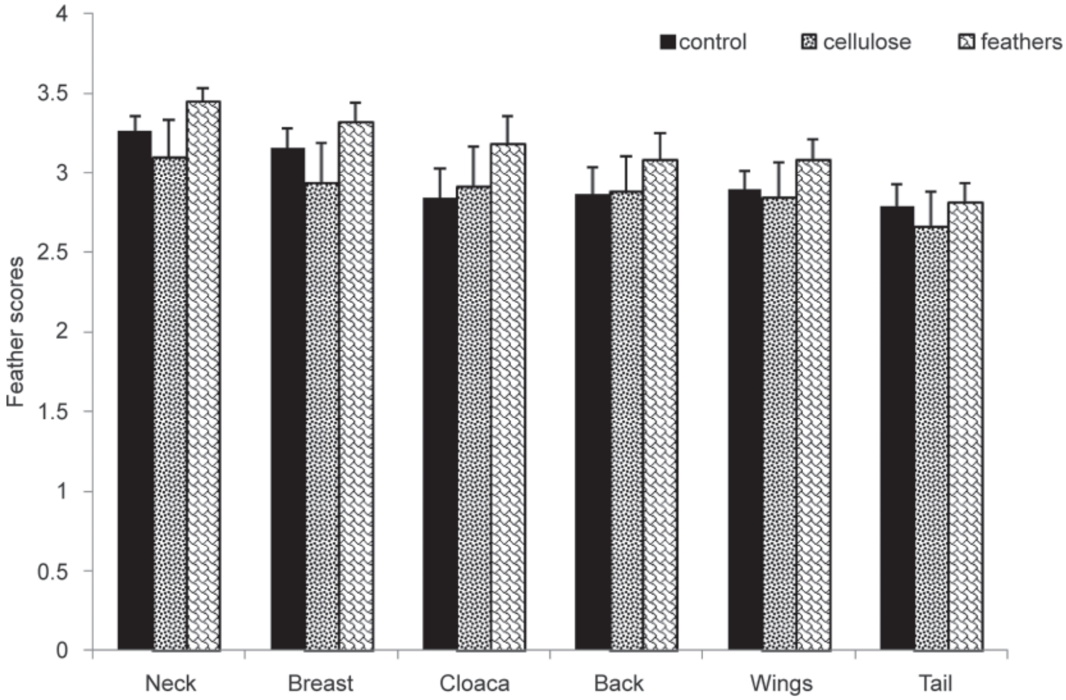

Figure 3. Mean feather scores of 6 body parts (neck, breast, cloaca, back, wings, tail) using a 1 to 4 point scale (1 = severe damage; 2 = moderate damage; 3 = slight damage; 4 = no damage) in experiment 1 (5% cellulose, control, 5% feather).

of the back area was significantly higher in the feather group compared with the cellulose ($t = -5.82$, $P < 0.0001$; Figure 4) and control groups ($t = -4.41$, $P < 0.0001$; Figure 4). Cellulose and control groups did not differ in their back area scores ($t = 1.91$, $P < 0.056$; Figure 4).

In experiment 2, raw feathers in the pellets proved to be effective in reducing feather pecking. On the one hand, the feather diet resulted in a significantly lower number of severe feather- pecking bouts compared with the control diet. On the other hand, it resulted in significantly better plumage condition in the back

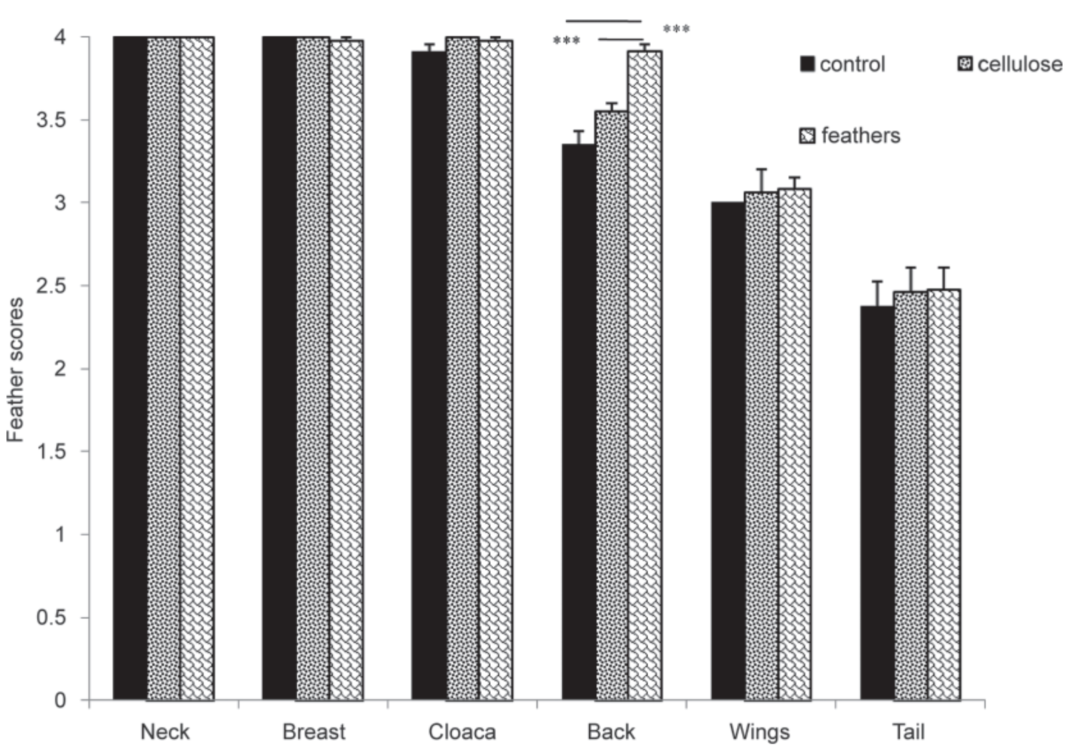

Figure 4. Mean feather scores of 6 body parts (neck, breast, cloaca, back, wings, tail) using a 1 to 4 point scale (1 = severe damage; 2 = moderate damage; 3 = slight damage; 4 = no damage) in experiment 2 (10% cellulose, control, 10% feather). ***$P < 0.001$.

area of the birds compared with control and cellulose diets. The mechanism, however, by which feathers added to the hens' diet affects the expression of severe feather pecking remains unknown. Feathers, an animal protein fiber, are considered as nonnutritive matter (McCasland and Richardson, 1966) similar to plant insoluble polysaccharide fiber, such as cellulose. Fiber consists of a diverse group of substances of chemical and morphological complexity, and the age and species of, for example, plant source, and the extraction method may influence the nature of the fiber and their physiological consequences (Kay, 1982). Physiological consequences of fiber ingestion are mediated by bacterial enzymes that degrade fiber components, the products of fermentation themselves (e.g., short-chain fatty acids) and the water-holding capacity or the adsorption of organic material such as various toxic compounds or bacteria (Kay, 1982). In a comprehensive literature review, Van Krimpen et al. (2005) concluded that high-fiber diets may affect feather pecking in laying hens, but that it is unclear which plant fiber content and fiber source may be ideal for reducing feather pecking. Harlander-Matauschek et al. (2006) showed that ingested feathers increase the speed of feed passage in high feather-pecking birds, which could be beneficial in minimizing harmful microorganisms or parasites. Interestingly, an epidemiological study by Green et al. (2000) showed that the occurrence of intestinal worms was associated significantly with feather pecking in laying hens. However, it remained unclear whether feather pecking served to increase feed passage to eliminate parasites or whether the parasites in the digestive tract caused some stress or discomfort that triggered feather pecking. Great Crested Grebes ingest feathers to enable the formation of pellets that can be ejected. This minimizes the chance that any serious population of gastric parasites can build up in the upper part of the alimentary tract (Piersma and van Eerden, 1989), despite the fact that other natural plant fiber resources were available. Benda et al. (2008) showed that wood shavings (plant fiber which includes polysaccharides such as lignin and cellulose) did not fasten feed passage time in high feather-pecking birds. However, their experiment indicated that a faster feed passage in high-feather pecking birds compared with low feather-pecking birds might be associated with genetic differences in digestive processes. Furthermore, Harlander-Matauschek et al. (2007) showed that the availability of wood shavings did not stop the appetite for eating feathers in high feather-pecking birds. Physical characteristics are important in the choice of feathers (Harlander-Matauschek and Feise, 2009), and the physical structure of fiber is the most important determinant of hydratability (Robertson and Eastwood, 1981). Water-holding capacity of the fiber may affect nutrient absorption, satiety, and intestinal motility, however, the effect of fiber is significantly influenced by bacterial fermentation (Stephen and Cummings, 1980). Bacterial fiber fermentation was significantly different between control and feather-treated birds in regard to products of fermentation, such as short-chain fatty acids (Meyer et al., 2012). So far it is unknown if, for example, bacterial fermentation or improved gastrointestinal motility has beneficial consequences for the hens, and if so, by what mechanisms.

In experiment 1, 5% fiber treatment did not affect severe feather pecking or plumage condition. Although, we must be cautious in comparing the 2 feather contents directly because they were studied in 2 independent experiments, there is some evidence that 5% of feathers may be too little to affect feather pecking. For example, Esmail (1997) reported that a fiber content of over 130 g/kg of feed is needed to lower the incidence of feather pecking. Thus, irrespective of the fiber source, a fiber content of 50 g/kg may be too low to affect feather pecking. However, the large difference in the level of severe feather-pecking between the 2 experiments should not be overlooked. Birds in both experiments were kept at similar stocking densities; however, group size in experiment 2 was larger. Nicol et al. (1999) suggested that flock size rather than stocking density per se may be an important mediating factor of feather pecking. Similarly, Allen and Perry (1975) found in a cage environment that increased group size is associated with an increased risk of feather pecking.

In experiment 2, a higher number of severe feather-pecking bouts was observed in the laying compared with the rearing period. This difference was not detected in experiment 1. It is possible that differences in group size between the 2 experiments explain this difference. For example, Huber Eicher and Sebo (2001) found that feather pecking at lay was affected by the level of feather pecking during rearing.

In conclusion, the addition of 10% feathers to the diet reduced severe feather pecking significantly and improved plumage condition. Whereas animal fiber substituted the special appetite for feathers in feather-pecking birds, this was not the case with the plant fiber cellulose. However, feathers also contain components other than fiber, which may also have affected the results. The present study provides no practical solution to prevent feather pecking because concerns have been raised about the risk of intraspecies feed, which could be a health risk for both animals and consumers as well as an ethical concern. However, the question that arises from this study is what renders feathers so attractive for ingestion that birds show this abnormal behavior? Our findings may stimulate new avenues of research into the interaction between fiber sources and other dietary components within the gut in relation to the physical and chemical nature of feathers on intestinal physiology, including the indigenous microbiota and their metabolites.

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REFERENCES

Allen, J., and G. C. Perry. 1975. Feather pecking and cannibalism. Br. Poult. Sci. 16:441–451.

Anderson, K. E., and A. W. Adams. 1991. Effects of type of cage front and feed trough partitions on productivity and ingestive, agonistic, and fearful behaviors of egg-type hens. Poult. Sci. 70:770–775.

Benda, I., W. Bessei, and A. Harlander-Matauschek. 2008. The dietary effect of wood shavings on feed passage in high and low feather pecking birds. Page 39 in East and West European ISAE Meeting 2008. Bratislava, Slowakia.

Diggle, P. J., P. Heagerty, K. Y. Liang, and S. L. Zeger. 2002. The Analysis of Longitudinal Data. 2nd Edition. Oxford University Press, Oxford, UK.

Dixon, L. M., I. J. H. Duncan, and G. J. Mason. 2008. What's in a peck? Using fixed action pattern morphology to identify the motivational basis of abnormal feather-pecking behaviour. Anim. Behav. 76:1035–1042.

Esmail, S. H. M. 1997. Fibre Nutrition. Poult. Int. 36:31–34.

Forbes, H. J., and F. S. Shariatmadari. 1994. Diet selection for protein. World's Poult. Sci. J. 50:7–24.

Goelema, J. O., A. Smits, L. M. Vaessen, and A. Wemmers. 1999. Effects of pressure toasting, expander treatment and pelleting on in vitro and in situ parameters of protein and starch in a mixture of broken peas, lupins and faba beans. Anim. Feed Sci. Technol. 78:109–126.

Green, L. E., K. Lewis, A. Kimpton, and C. Nicol. 2000. Cross-sectional study of the prevalence of feather pecking in laying hens in alternative systems and its associations with management and disease. Vet. Rec. 147:233–238.

Harlander-Matauschek, A., I. Benda, C. Lavetti, M. Djukic, and W. Bessei. 2007. The relative preferences for wood shavings or feathers in high and low feather-pecking birds. Appl. Anim. Behav. Sci. 107:78–87.

Harlander-Matauschek, A., and U. Feise. 2009. Physical characteristics influence feather eating behavior. Poult. Sci. 88:1800–1804.

Harlander-Matauschek, A., H. P. Piepho, and W. Bessei. 2006. The effect of feather eating on feed passage in laying hens. Poult. Sci. 85:21–25.

Huber-Eicher, B., and F. Sebo. 2001. The prevalence of feather pecking and development in commercial flocks of laying hens. Appl. Anim. Behav. Sci. 74:223–231.

Kay, R. M. 1982. Dietary fiber. J. Lipid Res. 23:221–242.

Kjaer, J. B., and K. S. Vestergaard. 1999. Development in feather pecking in relation to light intensity. Appl. Anim. Behav. Sci. 62:243–254.

Kutlu, H. R., and J. M. Forbes. 1993. Self selection of ascorbic acid in coloured feeds by heat-stressed broiler chicks. Physiol. Behav. 53:103–110.

Lambton, S. L., T. G. Knowles, C. Yorke, and C. J. Nicol. 2010. The risk factors affecting the development of gentle and severe feather pecking in loose housed laying hens. Appl. Anim. Behav. Sci. 123:32–42.

McAdie, T. M., and L. J. Keeling. 2002. The social transmission of feather pecking in laying hens; effects of environment and age. Appl. Anim. Behav. Sci. 75:147–159.

McCasland, W. E., and L. R. Richardson. 1966. Methods for determining the nutritive value of feather meals. Poult. Sci. 45:1231–1236.

McKeegan, D. E. F., and C. J. Savory. 1999. Feather eating in layer pullets and its possible role in the aetiology of feather pecking damage. Appl. Anim. Behav. Sci. 65:73–85.

McKeegan, D. E. F., and C. J. Savory. 2001. Feather eating in individually caged hens which differ in their propensity to feather peck. Appl. Anim. Behav. Sci. 73:131–140.

Meyer, B., A. Harlander-Matauschek, W. Bessei, W. Vahjen, and J. Zentek. 2012. Dietary inclusion of feathers affects intestinal microbiota and microbial metabolites in growing Leghorn-type chickens. Poult. Sci. 91:1506–1513.

Newberry, R. C., L. J. Keeling, I. Estevez, and B. Bilcik. 2007. Behaviour when young as a predictor of severe feather pecking in adult laying hens: The redirected foraging hypothesis revisited. Appl. Anim. Behav. Sci. 107:262–274.

Newell, G. W., and C. A. Elvehejem. 1947. Nutritive value of keratin. III. Effect of source, particle size, and method of grinding. J. Nutr. 33:673–683.

Nicol, C. J., N. G. Gregory, T. G. Knowles, I. D. Parkman, and L. J. Wilkens. 1999. Differential effects of increased stocking density, mediated by increased flock size, on feather pecking and aggression in laying hens. Appl. Anim. Behav. Sci. 65:137–152.

Piepho, H. P., A. Büchse, and C. Richter. 2004. A mixed modeling approach to randomized experiments with repeated measures. J. Agron. Crop Sci. 190:230–247.

Piersma, T., and M. R. van Eerden. 1989. Feather eating in Great Crested Grebes *Podiceps cristatus*: A unique solution to the problems of debris and gastric parasites in fish-eating birds. Ibis 131:477–486.

Provenza, F. D. 1995. Postingestive feedback as an elementary determinant of food preferences and intake in ruminants. J. Range Manage. 48:2–17.

Provenza, F. D., and D. F. Balph. 1990. Applicability of five diet-selection models to various foraging challenger ruminants encounter. Pages 423–460 in Behavioural Mechanisms of Food Selection. R. N. Hughes, ed. NATO ASI Series, Vol. G20. Springer Verlag, Berlin, Germany.

Robertson, J. A., and M. A. Eastwood. 1981. An examination of factors which may affect the water-holding capacity of dietary fiber. Br. J. Nutr. 45:83–88.

Savory, C. J. 1995. Feather pecking and cannibalism. World's Poult. Sci. J. 51:215–219.

Stephen, A. M., and J. H. Cummings. 1980. Mechanism of action of dietary fiber in the human colon. Nature 284:283–284.

Tauson, R., J. Kjaer, G. Maria, R. Cepero, and K. E. Holm. 2005. Applied scoring of integument and health in laying hens. Pages 153–159 in Proc. 7th European Symposium on Poultry Welfare. A. Witkowski, ed. Lublin, Poland.

Van Krimpen, M. M., R. P. Kwakkel, B. F. J. Reuvekamp, C. M. C. van der Peet-Schwering, L. A. den Hartog, and M. W. A. Verstegen. 2005. Impact of feeding management on feather pecking in laying hens. World's Poult. Sci. J. 61:663–685.

Wood, G. M. 1956. Consumption of forage by chickens. Poult. Sci. 35:1083–1089.

Wood, G. M., R. T. Smith, and D. C. Henderson. 1963. A crop analysis technique for studying the food habits and preferences of chickens on range. Poult. Sci. 42:304–309.