Friedrich-Loeffler-Institut
- Bibliothek -
Dörnbergstr. 25/27
29223 Celle
Tel./Fax: (05141) 3846-110 / -117

Arch.Geflügelk., 77 (1). S. 1–9, 2013, ISSN 0003-9098. © Verlag Eugen Ulmer, Stuttgart

The interrelationships of nutrition and feather pecking in the domestic fowl – A review

Ernährung und Federpicken beim Geflügel – Eine Literaturstudie

J. B. Kjaer[1] and W. Bessei[2]

Invited Review Paper

Introduction

Feather pecking and cannibalism are generally considered to be caused by a complex of genetical and environmental factors. Among the environmental factors nutrition and feeding behaviour play a prominent role. Nutritionists and ethologists approach the problem of feather pecking in different ways. While nutritionists assume that feather pecking is caused by nutrient deficiencies or imbalances, ethologists search the primary causes of feather pecking in fundamental drives related to feed intake. There are numerous studies which showed the influence of raw materials, crude protein or single nutrients, such as amino acids and minerals on feather pecking. The first nutritional experiments have been reported as of the 1930th. During the last years there was an increasing interest in the effect of fibre and feathers on feather pecking and feed-related behaviours. While most experiments have been carried out with layer-type chickens, the problem of cannibalism exists in meat-type chickens, turkeys and other domestic poultry species, such as quail, muscovy ducks and ostriches. This paper reviews the main publications on nutrition and behavioural aspects related to nutritional aspects and feeding behaviour in fowls.

The effect of feedstuffs

The main ingredients of poultry diets have been investigated with regard to their risk of stimulating damaging pecking behaviour.

Grain types

Oats seem to be the grain type that reduce feather pecking relative to barley and wheat (Bearse et al., 1940; Scott et al., 1954a; Seemann, 1982; Wahlström et al., 1998). In pheasants, known to be severe feather peckers in suboptimal conditions, it was possible to avoid cannibalism in two flocks of breeder birds by adding oats to the ration (Pulliainen, 1965). In chickens, the positive effect interacts with genotype. Some strains respond positively to oats, others do not (Seemann, 1982; Wahlström et al., 1998). Karlson (1996) found LSL to have better plumage on rations with high levels of oats while the Swedish breed, Svenskhönan, a cross between White Leghorn and Rhode Island Red, maintained a high quality plumage regardless of oat content. Also suboptimal environmental conditions increase the positive effect of oats. For example the detrimental effects of potassium deficiency (Wahlström et al., 1998) or restricted feeder space (Seemann, 1982) were less pronounced in flocks given supplements of oats.

Comparing barley and wheat, Abrahamsson et al. (1996) found a better plumage condition in layers fed a diet high in barley (25% barley/39% wheat) compared to a diet high in wheat (50% wheat/14% barley).

Protein-rich feedstuffs

There is little information on the effect of protein-rich feedstuffs on feather pecking and cannibalism. Hydrolysed feather meal, fishmeal, bloodmeal and meat and bone meal have been excluded from poultry feed for various reasons, and soybean meal has become the main source of protein. The lack of protein of animal origin has been considered one of the causes of feather pecking and cannibalism. Atteh and Ajakaie (1993, loc. cit. McKeegan et al., 2001) offered laying hens in a cafeteria-system three protein sources, bloodmeal, fishmeal or soybean meal additional to their feed. The highest levels of cannibalism were observed in the choice feeding system with bloodmeal and soybean meal. Savory et al. (1999) fed bantam pullets either a vegetarian diet on the basis of soybean meal, or a diet based on animal protein (bloodmeal, fishmeal and hydrolysed feather meal) or semi-purified casein. There was no significant difference in feather scores at 3 and 6 weeks of age. There was a tendency of higher damages in the animal protein group. Similar results were reported by McKeegan et al. (2001). Commercial brown layers were fed either plant or animal-based diets during rearing and laying. The main protein source of the animal protein diet was fishmeal and that of the plant protein diet soybean meal. The numbers of vigorous pecking and pulling were higher in the plant protein groups throughout the experiment. There was, however, no significant difference between the treatments for the pecking damage scores. In two experiments Richter and Hartung (2003) compared layer diets containing 4% of meat and bone meal and 4 different diets based on protein of plant origin. There was a tendency of higher mortality in some of the vegetarian diets, the differences, however were not significant. Hadorn et al. (1998) found no difference in mortality of layers fed diets either based on meat and bone meal, fishmeal or on soybean meal. The plumage

[1] Inst. of Animal Welfare, Friedrich-Loeffler Institute, Celle, Germany
[2] Dept. of Farm Animal Behavior and Poultry Science, University Hohenheim, Stuttgart, Germany

of layers fed 4% of meat and bone meal was better than that of hens fed a vegetarian diet and diets of other animal protein sources (PFIRTER and WALSER, 1998). VAN KRIMPEN et al. (2010) fed 4 different types of processed pork meal to layers. There were no significant effects of the diets on feather damages at the end of the experiment, but two of the porc meals (meat and bone meals) delayed the development of feather pecking. There was more walking, ground pecking and less time spent food eating in these groups as compared to the other types of pork meal (meat meals). The higher level of walking and ground pecking in the meat and bone meals could be related to the lower intake of certain amino acids. However, the litter in the meat and bone meal groups contained less water than in the meat meal groups and this might have stimulated walking and ground pecking.

In summary, there exist effects of particular feedstuffs on feather pecking and pecking-related damages in poultry. With regard to the effect of different types of cereals it seems that grains which contain high amounts of fibre show a positive effect on feather pecking and cannibalism. The effect is, however highly variable and subject to interactions with genotype and various environmental influences.

Protein, amino acids and energy

Detrimental effects of low protein diets on feather pecking and cannibalism have been reported by SCHAIBLE et al. (1947). A basal corn/wheat diet low in protein (13.5%) and fibre (2.6%) produced feather pecking in chicks. GERUM and KIRCHGESSNER (1978) fed broilers 3 levels of energy ranging from 2850, 3350 to 3650 kcal ME/kg and 3 levels of protein (19, 23 and 27%). Feather eating increased with increasing energy levels in the diet. Less feather eating was recorded when the protein level increased. Similar results have been found by DONALDSON et al. (1955) and LEONG et al. (1955). The effect of low protein levels in the diet was obviously compensated by the increased feed and protein intake in the low energy diet. Contrasting results have been reported by CAIN et al. (1984). The authors fed growing pheasants diets containing 16, 19 and 22% of crude protein. The lowest level of protein produced high damages through feather pecking. The situation could be improved by raising the energy level from 2530 to 2970 kcal ME/kg.

AMBROSEN and PETERSEN (1997) found an improvement in plumage condition of caged layers with increasing levels of protein from 11.1% to 19.3% in isocaloric diets. Regression analysis showed that the feather score on a scale from 5 (very poor) to 20 (very good) increased by 0.4 to 0.5 points for each percent increase in protein in the feed. The same picture was seen with respect to mortality due to cannibalism. The mortality caused by cannibalism increased from 5.1 to 8.3 and 17.6% when the protein level was lowered from 13.8 to 12.5 and 11.1% respectively. These authors also found a strain × protein level interaction in plumage condition of 4 Leghorn strains, but not in 3 strains of layers of medium body size.

CONSON and PETERSEN (1986) fed 8 to 20 weeks old pullets of two layer strains on a diet low in lysine (max. 0.4%) and arginine (max. 0.56%). This gave rise to more feather pecking in the laying period (15th laying month) in one strain, but not in another. A surplus of arginine was found to stop feather pecking and cannibalism in groups of chickens and pheasants (SIRÈN, 1963). When adding arginine to a basal diet holding 3.9% arginine of crude protein (normal) to 6.9%, cannibalistic pecking at first rose, then declined, and after 2 days stopped. This could not be verified by MADSEN (1966). He used the same levels of arginine as suggested by Sirèn, but found a high level of feather pecking but no consistent pattern in relation to treatment, in three experiments with pheasants and partridges. NEAL (1956) reported on 'pick-outs' in relation to methionine supplementation in two flocks of layers. The basal diet had a calculated content of 0.20% methionine. The experimental diet was supplemented to about 1%. It was concluded: 'results indicate that methionine supplementation at a sufficient level can suppress cannibalism and pick-outs'. CREEK and DENDY (1957) (loc. cit. in MARSHBOON and SIERENS, 1962) failed to find any effect of methionine level on incidence of cannibalism. HUGHES and DUNCAN (1972) found higher pecking damage from 10 to 20 week old pullets of two Leghorn strains fed a growers' ration low in methionine. These authors also showed a strain × diet interaction for pecking damage from 6 to 18 weeks. One strain was pecked less on diet 1 and the other strain was pecked less on diet 2, when the diets differed in their methionine content. A diet × brooding temperature interaction was intermittently evident from weeks 6 to 17 in this study. Chickens fed a diet low in methionine and brooded at a 29°C temperature had less pecking damage than those brooded at 32°C. The opposite was true for birds fed a diet higher in methionine. High levels of cannibalism (20%) have been found in hens fed an organic diet containing 0.34% of methionine. The mortality, which was mainly caused by cannibalism, was reduced to 10.3% when the same diet was supplemented up to 0.41% of methionine (ANONYMOUS, 1997). KJAER and SØRENSEN (2002) fed medium heavy free range hens diets containing 0.5% or 0.9% methionine + cystine. No feather pecking or cannibalism was recorded in any treatment. DÄNNER and BESSEI (2000) fed white layer hybrids (LSL) increasing levels of methionine (0.22, 0.26, 0.31 and 0.36%). There was clear response to increasing methionine supplementation with reduced mortality and improved feather conditions. The main improvement could be observed when methionine level was raised from 0.22 to 0.26 which corresponded to a methionine + cystine level from 0.49 to 0.53.

Tryptophan is a precursor of serotonin, which acts as a neurotransmitter. The dietary level of tryptophan influence the level of serotonin in the brain (FERNSTROM, 1981), which in turn modulates aggressive behaviour in broiler breeder males (SHEA et al., 1990), fear (tonic immobility response) in broilers (NEWBERRY and BLAIR, 1993) as well as self pecking in parrots (IGLAUER and RASIM, 1993) and most likely feather pecking in laying hens (VAN HIERDEN et al., 2004; VAN HIERDEN et al., 2002). Less feather damage was observed in bantam chickens fed tryptophan levels considerably higher than recommended (22.6 versus 2.6 g/kg feed) (SAVORY et al., 1999).

Minerals including trace elements

Inadequate sodium supply in the diet has been reported to be a possible cause of cannibalism in poultry (COOKE, 1992). SWARBRICK and PARSONS (1992) have alleviated outbreaks of cannibalism by the addition of sodium bicarbonate to drinking water at a level of 2.5 g/l. HUGHES and WHITEHEAD (1974) did not find more feather pecking or pecking activity in caged layers fed a sodium deficient (0.038%) diet. This is explained by the fact that egg production ceased almost completely reducing the sodium requirement to a minimum. When adequate sodium levels were fed, egg production increased and plumage condition decreased, indicating that feather pecking increased. HUGHES and WOOD-GUSH (1973) deprived hens of calcium and found increasing general pecking activity, termed 'exploratory' behaviour, and locomotion. Feather pecking was not recorded. NESTLER et al. (1945) reported a range of observations concerning the control of cannibalism in Bobwhite quail using different

of layers fed 4% of meat and bone meal was better than that of hens fed a vegetarian diet and diets of other animal protein sources (PFIRTER and WALSER, 1998). VAN KRIMPEN et al. (2010) fed 4 different types of processed pork meal to layers. There were no significant effects of the diets on feather damages at the end of the experiment, but two of the porc meals (meat and bone meals) delayed the development of feather pecking. There was more walking, ground pecking and less time spent food eating in these groups as compared to the other types of pork meal (meat meals). The higher level of walking and ground pecking in the meat and bone meals could be related to the lower intake of certain amino acids. However, the litter in the meat and bone meal groups contained less water than in the meat meal groups and this might have stimulated walking and ground pecking.

In summary, there exist effects of particular feedstuffs on feather pecking and pecking-related damages in poultry. With regard to the effect of different types of cereals it seems that grains which contain high amounts of fibre show a positive effect on feather pecking and cannibalism. The effect is, however highly variable and subject to interactions with genotype and various environmental influences.

Protein, amino acids and energy

Detrimental effects of low protein diets on feather pecking and cannibalism have been reported by SCHAIBLE et al. (1947). A basal corn/wheat diet low in protein (13.5%) and fibre (2.6%) produced feather pecking in chicks. GERUM and KIRCHGESSNER (1978) fed broilers 3 levels of energy ranging from 2850, 3350 to 3650 kcal ME/kg and 3 levels of protein (19, 23 and 27%). Feather eating increased with increasing energy levels in the diet. Less feather eating was recorded when the protein level increased. Similar results have been found by DONALDSON et al. (1955) and LEONG et al. (1955). The effect of low protein levels in the diet was obviously compensated by the increased feed and protein intake in the low energy diet. Contrasting results have been reported by CAIN et al. (1984). The authors fed growing pheasants diets containing 16, 19 and 22% of crude protein. The lowest level of protein produced high damages through feather pecking. The situation could be improved by raising the energy level from 2530 to 2970 kcal ME/kg.

AMBROSEN and PETERSEN (1997) found an improvement in plumage condition of caged layers with increasing levels of protein from 11.1% to 19.3% in isocaloric diets. Regression analysis showed that the feather score on a scale from 5 (very poor) to 20 (very good) increased by 0.4 to 0.5 points for each percent increase in protein in the feed. The same picture was seen with respect to mortality due to cannibalism. The mortality caused by cannibalism increased from 5.1 to 8.3 and 17.6% when the protein level was lowered from 13.8 to 12.5 and 11.1% respectively. These authors also found a strain × protein level interaction in plumage condition of 4 Leghorn strains, but not in 3 strains of layers of medium body size.

CONSON and PETERSEN (1986) fed 8 to 20 weeks old pullets of two layer strains on a diet low in lysine (max. 0.4%) and arginine (max. 0.56%). This gave rise to more feather pecking in the laying period (15th laying month) in one strain, but not in another. A surplus of arginine was found to stop feather pecking and cannibalism in groups of chickens and pheasants (SIRÈN, 1963). When adding arginine to a basal diet holding 3.9% arginine of crude protein (normal) to 6.9%, cannibalistic pecking at first rose, then declined, and after 2 days stopped. This could not be verified by MADSEN (1966). He used the same levels of arginine as suggested by Sirèn, but found a high level of feather pecking but no consistent pattern in relation to treatment, in three experiments with pheasants and partridges. NEAL (1956) reported on 'pick-outs' in relation to methionine supplementation in two flocks of layers. The basal diet had a calculated content of 0.20% methionine. The experimental diet was supplemented to about 1%. It was concluded: 'results indicate that methionine supplementation at a sufficient level can suppress cannibalism and pick-outs'. CREEK and DENDY (1957) (loc. cit. in MARSHBOON and SIERENS, 1962) failed to find any effect of methionine level on incidence of cannibalism. HUGHES and DUNCAN (1972) found higher pecking damage from 10 to 20 week old pullets of two Leghorn strains fed a growers' ration low in methionine. These authors also showed a strain × diet interaction for pecking damage from 6 to 18 weeks. One strain was pecked less on diet 1 and the other strain was pecked less on diet 2, when the diets differed in their methionine content. A diet × brooding temperature interaction was intermittently evident from weeks 6 to 17 in this study. Chickens fed a diet low in methionine and brooded at a 29°C temperature had less pecking damage than those brooded at 32°C. The opposite was true for birds fed a diet higher in methionine. High levels of cannibalism (20%) have been found in hens fed an organic diet containing 0.34% of methionine. The mortality, which was mainly caused by cannibalism, was reduced to 10.3% when the same diet was supplemented up to 0.41% of methionine (ANONYMOUS, 1997). KJAER and SØRENSEN (2002) fed medium heavy free range hens diets containing 0.5% or 0.9% methionine + cystine. No feather pecking or cannibalism was recorded in any treatment. DÄNNER and BESSEI (2000) fed white layer hybrids (LSL) increasing levels of methionine (0.22, 0.26, 0.31 and 0.36%). There was clear response to increasing methionine supplementation with reduced mortality and improved feather conditions. The main improvement could be observed when methionine level was raised from 0.22 to 0.26 which corresponded to a methionine + cystine level from 0.49 to 0.53.

Tryptophan is a precursor of serotonin, which acts as a neurotransmitter. The dietary level of tryptophan influence the level of serotonin in the brain (FERNSTROM, 1981), which in turn modulates aggressive behaviour in broiler breeder males (SHEA et al., 1990), fear (tonic immobility response) in broilers (NEWBERRY and BLAIR, 1993) as well as self pecking in parrots (IGLAUER and RASIM, 1993) and most likely feather pecking in laying hens (VAN HIERDEN et al., 2004; VAN HIERDEN et al., 2002). Less feather damage was observed in bantam chickens fed tryptophan levels considerably higher than recommended (22.6 versus 2.6 g/kg feed) (SAVORY et al., 1999).

Minerals including trace elements

Inadequate sodium supply in the diet has been reported to be a possible cause of cannibalism in poultry (COOKE, 1992). SWARBRICK and PARSONS (1992) have alleviated outbreaks of cannibalism by the addition of sodium bicarbonate to drinking water at a level of 2.5 g/l. HUGHES and WHITEHEAD (1974) did not find more feather pecking or pecking activity in caged layers fed a sodium deficient (0.038%) diet. This is explained by the fact that egg production ceased almost completely reducing the sodium requirement to a minimum. When adequate sodium levels were fed, egg production increased and plumage condition decreased, indicating that feather pecking increased. HUGHES and WOOD-GUSH (1973) deprived hens of calcium and found increasing general pecking activity, termed 'exploratory' behaviour, and locomotion. Feather pecking was not recorded. NESTLER et al. (1945) reported a range of observations concerning the control of cannibalism in Bobwhite quail using different

levels and types of salt (NaCl). They concluded that the addition of 1 to 2% salt for a few days should be efficacious in controlling cannibalism in 2 out of 3 cases, but that: 'increasing the salt content cannot be considered as a certain cure for all cases of the habit'. They also discovered that pecking could be controlled just as effectively by placing a hopper full of feed concentrate such as fish meal, soybean meal, liver meal, or chopped fresh greens in the troublesome pen for a day or two. WILLIMON and MORGAN (1953) were not able to find any consistent effect on feather pecking and cannibalism in layers by adding trace elements such as Al, Ba, Cr, Pb, Ag, Sn, Zn and others. Adding sodium silicate did not prevent pecking damage in layers fed a corn based diet of low (3%) fibre (BEARSE et al., 1940).

Other feed ingredients and drugs

Haloanisone, a neuroleptic drug structurally related to chlorpromazine, stopped cannibalism in 20 flocks of chickens of various strains after 2 days of administration in the drinking water (MARSHBOON and SIERENS, 1962). Cannibalism resumed 10 to 20 days after the end of treatment. The drug exerts a sedative action. There were no adverse effects on growth rate when administering the drug in the feed at a dose level of 20–40 mg/kg feed. A saponin, Isosarsapogenine, used for treatment of syngamosis (Gapes) in two pens of pheasant chickens, had no effect on feather pecking or cannibalism (MADSEN, 1966).

Feeding pheasants diets supplemented with a range of antibiotics such as penicillin, zinc bacitracin, terramycin or aureomycin, had a substantially positive effect on growth, health and mortality, some positive effect on feathering, but did not prevent feather pecking (SCOTT et al., 1954a).

Diets supplemented with arsenic acid, protamon (a thyroid extract) or a combination had some positive effect on feathering of pheasant chicks at 2 weeks, but did not prevent outbreaks of cannibalism at 4 weeks (SCOTT et al., 1954b). Only one group of pheasants per treatment was used.

NESTLER et al. (1945) used a range of protein concentrates (soyabean oil meal, dried buttermilk meat and bone scrap etc.), but failed to prevent cannibalism in Bobwhite quail.

Adding various supplements rarely had any effect (minerals, fibre, lactose, phytin, wheat germ oil, sucrose, cystine-HCl, corn gluten meal, dried yeast and dried egg white). Calcium-dichloride ($CaCl_2$) substituting calcium-carbonate ($CaCO_3$) and sodium-chloride (NaCl) had some effect as had dried egg yolk, blood meal, cottonseed meal, liver meal, casein and gelatine.

Feed structure

Feeding White Leghorn pullets and 'crossbred fryers' a higher (18 versus 13 and 8%) fibre diet, prevented 'cannibalism/feather picking' when fed as mash, but not when fed as pellets (BEARSE et al., 1949). LONSDALE et al. (1957) found more feather pecking in 10 weeks old 'white cross bred chicks' fed pellets than in those fed mash. Pellet feeding caused feather pecking when the birds were kept at high density and under barren environmental conditions. When broilers were fed pellets (versus mash) they developed feather pecking at a stocking density of 683 cm^2 per bird but not at 1024 cm^2/bird (SKOGLUND and PALMER, 1961). Similar observations have been reported by HEYWANG and MORGAN (1944) in White Leghorn chickens and SAVORY et al. (1999) in bantams. NORGAARD-NIELSEN (1989) observed increasing feather pecking in layers when mash was replaced by pellets. The effect was more pronounced when the birds had no access to a straw basket. Similar results have been reported by HUBER-EICHER and WECHSLER (1997). The authors kept chicks either on slatted floor or on litter. Significantly higher feather pecking on slatted floor versus litter occurred when the birds were fed pellets, but not when they were fed mash. LINDBERG and NICOL (1994) found significantly more outbreaks of feather pecking when feeding pellets versus mash. SAVORY and HETHERINGTON (1997) also found more feather pecking, especially severe feather pecking (feather pulling), in pellet fed layers, and they observed outbreaks of cannibalism only in pellet fed birds, not in mash fed. In contrast, BILSING et al. (1992) found more feather pecking and cannibalism in muscovy ducks fed mash than pellets. Mash was stuck to the feathers during eating thereby inviting to increased preening and allopreening, and thus obviously facilitating feather pecking and cannibalism. Similar effects in chickens and turkeys have been reported by FELTWELL (1953) and HALE and SCHEIN (1962). Feeding pellets reduced time spent feeding and increased particularly vigorous pulling of a bunch of feathers (BESSEI et al., 1999). In two experiments HARTINI et al. (2002) fed caged layers pelleted and fine mash diets with high and low fibre contents. The pelleted low fibre diet produced the highest mortality and the high fibre mash the lowest mortality. SAVORY and MANN (1997) compared the effect of pelleted and mash diets on the feeding behaviour of layers. Pelleting reduced the time spent feeding and increased eating of cast feathers.

WALSER (1997) investigated the effect of different feed structures and treatments (mash; expanded, pelleted and crumbled feed; coarse and fine particle size) on feather pecking and cannibalism in two commercial hybrids. Expanded, pelleted and crumbled feed produced more feather pecking and more feather damage than untreated finely ground mash. When coarse and finely gounded crumbles were compared there was no significant difference between the treatments for feather pecking and feather scores. The structure and treatment did not influence the level of mortality, even though 12.5% of total mortality in one of the tested lines was due to cannibalism. NESTLER et al. (1945) recorded less cannibalism in Bobwhite quail fed corn, wheat, oats or barley ground on a 3/32" mesh screen compared to finer or coarser (2/32" or 4/32") mesh screens. When high level of coarsely ground fibre was fed to layers the development of feather damage caused by feather pecking was delayed, and the feather cover at the end of lay was better than in the control diet and in the high fibre diet based on finely ground fibre. Similar results have been reported by HETLAND et al. (2004) and VAN KRIMPEN et al. (2008). Coarsely grounded non-starch polysaccharides (NSP) in the diet reduced feather damages caused by feather pecking. This was explained by a reduced feed passage time in the foregut and an increase in the retention time in the crop and gizzard. The authors assumed that this effect may give the birds a feeling of satiation and, thus, reduce the motivation for feather pecking.

Crude fibre and feathers

The effect of high fibre diets on feed and energy consumption is not consistent throughout the different experiments. When high fibre is used to dilute the diet and to reduce ME, there is generally an increase of feed consumption and time spent eating (HARTINI et al., 2002; VAN KRIMPEN et al. 2008; WALSER, 1997). However, no full compensation of energy intake was achieved in growing birds and layers by LEESON et al. (1997). Other authors reported no negative effects of high fibre diets on production parameters (DEATON et al., 1977). VORECK and KIRCHGESSNER (1981) suggested 10% of fibre as acceptable in layer diets. Feeding White Leghorn pullets and 'crossbred fryers' a higher (18 versus 13 and 8%) fibre diet prevented damage to the integument

when fed as mash, but not when fed as pellets (BEARSE et al., 1949).

NESTLER et al. (1945) fed Bobwhite quail (*Colinus virginianus*) on diets ranging from 1 to 11% fibre (alfalfa meal or ground wood pulp) without any significant effect on the occurrence of cannibalistic pecking, primarily toe-pecking, and beak-pecking. CAIN et al. (1984) increased the energy content and decreased the fibre content at the same time (exact fibre contents were not given). This had a beneficial effect on cannibalism in pheasants. The opposite, increasing fibre content by adding oat hulls, was found to improve plumage condition in pheasant chickens (SCOTT et al., 1954a). BEARSE et al. (1940) fed layers a corn based diet of low (3%) or high (11–12%) fibre by adding oat hulls. Damages to the integument were higher in low fibre diets. Adding oat hull water extract, oat hull ash or sodium silicate could not prevent pecking indicating that the effect did come from other fractions of oat hulls.

VAN KRIMPEN et al. (2009) fed ISA Brown layers high or normal NSP levels (19.5 or 13.3%) combined with normal and low energy diets (2825 or 2540 kcal ME/kg). There was no significant effect of NSP or the energy level on the final feather scores or on the culling rate due to cannibalism. The development of feather deterioration, however, was delayed to some extend, when the NSP were offered in a coarsely ground form. ESMAIL (1997) fed increasing levels of fibre to chickens. Feather score improved dramatically at the level of 8% of fibre and mortality due to cannibalism was reduced when 13% of fibre was included.

KRIEGSEIS et al. (2012) fed hens isonitrogenous and isocaloric diets containing 10% of cellulose or with 10% of chopped, raw, feathers from day-old to 17 weeks of age. Feather pecking behaviour was consistently lower in the groups fed feathers or crude fibre as compared to the control birds. The effect was however not significant. From 18 weeks onwards all experimental groups were given a conventional low fibre layer diet. Feather pecking continued to increase in all groups with the birds raised on the high-feather diet maintaining the lower level. In the high-fibre diet, however, there was a sharp increase of feather pecking and an outbreak of cannibalism after the change to the low fibre diet. When the hens of the same experiment were given a free choice between the high-fibre, the high-feather and control diets the hens fed the high-fibre and high-feather diets preferred both diets against the control diet (BENDA, 2008). The high-feather diet was avoided by the hens raised on control and high-fibre diets, but not by the hens raised on the high-feather diet. This shows a clear effect of early experience on the preference of fibre and feathers in the diet of chickens. Hens of a Rhode Island Red line which have been divergently selected for high and low pecking to a bundle of feathers showed different reactions towards diets supplemented with 10% of ground oat hulls and 10% of sand (BESSEI, 1997). The diets were isocaloric and isonitrogenous. The hens of the high feather pecking line increased their pecking activity towards the feather bundle when fed the high fibre and high sand diets as compared to a control diet. The effect was significant in the high sand diet. The response of the low feather pecking line to both diets was small and not significant. White Leghorn lines selected for high and low feather pecking at other hens in the group differed in their choice of low digestible materials. The high feather pecking hens showed a clear preference of feathers versus wood shavings (BESSEI, 2011). KALMENDAL and BESSEI (2012) offered adult high and low feather pecking hens a high and low fibre diet in a simultaneous choice test. Hens from the high feather pecking line ate significantly more of the high fibre diet as compared to hens from the low feather pecking line. The cause for this particular preference has not been elucidated so far.

The high feather pecking lines, whether selected for pecking of a bunch of feathers or for severe pecking at the feathers of pen mates differed significantly in the number of feathers eaten from a transparent sheet of plastic (HARLANDER-MATAUSCHEK et al., 2007a) and in an operant conditioning situation (HARLANDER-MATAUSCHEK et al., 2006b; HÄUSLER, 2007). This confirms findings of MCKEEGAN and SAVORY (1999a) and MCKEEGAN et al. (2001) who reported that hens which had been identified as feather peckers ate significantly more loose feathers than non-feather pecking hens. Similar results have been found by RAMADAN and VON BORELL (2008). They raised Lohmann Silver pullets from day-old to 16 weeks of age in one of two conditions. In one treatment the cast feathers were systematically removed from the floor, while in the control all feathers were left. There was no significant difference in the behaviour, including feather pecking, between the treatment and the control during rearing. But in the laying period the hens raised in the feather-removed conditions showed less severe feather pecking and a better plumage than the control.

Discussion and Conclusions

The level of metabolisable energy in the diet seems to have little direct effect on feather pecking and cannibalism. The level of metabolic energy obviously acts through the regulation of feed intake and, thus, may increase or decrease the severity of the deficiency in particular nutrients. It is generally acknowledged that deficiency in crude protein, amino acids, and minerals are being detected by the birds within a short delay and elicit increased exploration behaviour. This behaviour can redirect their attention to the plumage of their pen mates, and thus, initiate feather pecking. Exploratory behaviour related to feeding or foraging in chickens is usually expressed by increased locomotor activity, ground scratching and ground pecking (BLOKHUIS, 1986). Increased locomotor activity of chickens in response to nutritional deficiencies has been reported by HUGHES and WOODGUSH (1973) for calcium deficiency and BESSEI (1978) for sodium deficiency in laying hens. VAN KRIMPEN et al. (2011) found increased locomotor activity in pullets with a low intake of various amino acids. This confirms the general stimulating effect of nutritional deficiencies on activity.

According to own experience and unpublished reports severe feather pecking and cannibalism develop within a few days and affects a large number of birds when nutrient deficient diets are fed. It usually disappears rapidly after restoring adequate nutrient levels. Nevertheless, it is interesting that feather pecking has been found to be genetically linked to high locomotor activity (KJAER, 2009). Further, birds found to be physically more active as pullets have a higher risk of developing feather pecking as adults (NEWBERRY et al., 2007). How activity and feather pecking is exactly connected and influenced by one another physiologically is still to be elucidated.

Feather pecking, however, also occurs when the feed contains adequate levels of all nutrients and a surplus of certain specific nutrients does not reliably prevent it. In order to ensure the supply of nutrients most poultry diets are highly concentrated with regard to the level of energy and protein. In addition the volume of poultry feed is often reduced by pelleting and crumbling. This allows the ingestion of high amounts of feed within a short time. The short time required for feed intake is considered a major cause of behavioural problems in farm animals in general and in poultry in particular. Chickens and turkeys under natural conditions spend about 40 to 60% of the day with feed-related activities, searching and eating (HUGHES and BLACK,

when fed as mash, but not when fed as pellets (Bearse et al., 1949).

Nestler et al. (1945) fed Bobwhite quail (*Colinus virginianus*) on diets ranging from 1 to 11% fibre (alfalfa meal or ground wood pulp) without any significant effect on the occurrence of cannibalistic pecking, primarily toe-pecking, and beak-pecking. Cain et al. (1984) increased the energy content and decreased the fibre content at the same time (exact fibre contents were not given). This had a beneficial effect on cannibalism in pheasants. The opposite, increasing fibre content by adding oat hulls, was found to improve plumage condition in pheasant chickens (Scott et al., 1954a). Bearse et al. (1940) fed layers a corn based diet of low (3%) or high (11–12%) fibre by adding oat hulls. Damages to the integument were higher in low fibre diets. Adding oat hull water extract, oat hull ash or sodium silicate could not prevent pecking indicating that the effect did come from other fractions of oat hulls.

Van Krimpen et al. (2009) fed ISA Brown layers high or normal NSP levels (19.5 or 13.3%) combined with normal and low energy diets (2825 or 2540 kcal ME/kg). There was no significant effect of NSP or the energy level on the final feather scores or on the culling rate due to cannibalism. The development of feather deterioration, however, was delayed to some extend, when the NSP were offered in a coarsely ground form. Esmail (1997) fed increasing levels of fibre to chickens. Feather score improved dramatically at the level of 8% of fibre and mortality due to cannibalism was reduced when 13% of fibre was included.

Kriegseis et al. (2012) fed hens isonitrogenous and isocaloric diets containing 10% of cellulose or with 10% of chopped, raw, feathers from day-old to 17 weeks of age. Feather pecking behaviour was consistently lower in the groups fed feathers or crude fibre as compared to the control birds. The effect was however not significant. From 18 weeks onwards all experimental groups were given a conventional low fibre layer diet. Feather pecking continued to increase in all groups with the birds raised on the high-feather diet maintaining the lower level. In the high-fibre diet, however, there was a sharp increase of feather pecking and an outbreak of cannibalism after the change to the low fibre diet. When the hens of the same experiment were given a free choice between the high-fibre, the high-feather and control diets the hens fed the high-fibre and high-feather diets preferred both diets against the control diet (Benda, 2008). The high-feather diet was avoided by the hens raised on control and high-fibre diets, but not by the hens raised on the high-feather diet. This shows a clear effect of early experience on the preference of fibre and feathers in the diet of chickens. Hens of a Rhode Island Red line which have been divergently selected for high and low pecking to a bundle of feathers showed different reactions towards diets supplemented with 10% of ground oat hulls and 10% of sand (Bessei, 1997). The diets were isocaloric and isonitrogenous. The hens of the high feather pecking line increased their pecking activity towards the feather bundle when fed the high fibre and high sand diets as compared to a control diet. The effect was significant in the high sand diet. The response of the low feather pecking line to both diets was small and not significant. White Leghorn lines selected for high and low feather pecking at other hens in the group differed in their choice of low digestible materials. The high feather pecking hens showed a clear preference of feathers versus wood shavings (Bessei, 2011). Kalmendal and Bessei (2012) offered adult high and low feather pecking hens a high and low fibre diet in a simultaneous choice test. Hens from the high feather pecking line ate significantly more of the high fibre diet as compared to hens from the low feather pecking line. The cause for this particular preference has not been elucidated so far.

The high feather pecking lines, whether selected for pecking of a bunch of feathers or for severe pecking at the feathers of pen mates differed significantly in the number of feathers eaten from a transparent sheet of plastic (Harlander-Matauschek et al., 2007a) and in an operant conditioning situation (Harlander-Matauschek et al., 2006b; Häusler, 2007). This confirms findings of McKeegan and Savory (1999a) and McKeegan et al. (2001) who reported that hens which had been identified as feather peckers ate significantly more loose feathers than non-feather pecking hens. Similar results have been found by Ramadan and von Borell (2008). They raised Lohmann Silver pullets from day-old to 16 weeks of age in one of two conditions. In one treatment the cast feathers were systematically removed from the floor, while in the control all feathers were left. There was no significant difference in the behaviour, including feather pecking, between the treatment and the control during rearing. But in the laying period the hens raised in the feather-removed conditions showed less severe feather pecking and a better plumage than the control.

Discussion and Conclusions

The level of metabolisable energy in the diet seems to have little direct effect on feather pecking and cannibalism. The level of metabolic energy obviously acts through the regulation of feed intake and, thus, may increase or decrease the severity of the deficiency in particular nutrients. It is generally acknowledged that deficiency in crude protein, amino acids, and minerals are being detected by the birds within a short delay and elicit increased exploration behaviour. This behaviour can redirect their attention to the plumage of their pen mates, and thus, initiate feather pecking. Exploratory behaviour related to feeding or foraging in chickens is usually expressed by increased locomotor activity, ground scratching and ground pecking (Blokhuis, 1986). Increased locomotor activity of chickens in response to nutritional deficiencies has been reported by Hughes and Wood-Gush (1973) for calcium deficiency and Bessei (1978) for sodium deficiency in laying hens. Van Krimpen et al. (2011) found increased locomotor activity in pullets with a low intake of various amino acids. This confirms the general stimulating effect of nutritional deficiencies on activity.

According to own experience and unpublished reports severe feather pecking and cannibalism develop within a few days and affects a large number of birds when nutrient deficient diets are fed. It usually disappears rapidly after restoring adequate nutrient levels. Nevertheless, it is interesting that feather pecking has been found to be genetically linked to high locomotor activity (Kjaer, 2009). Further, birds found to be physically more active as pullets have a higher risk of developing feather pecking as adults (Newberry et al., 2007). How activity and feather pecking is exactly connected and influenced by one another physiologically is still to be elucidated.

Feather pecking, however, also occurs when the feed contains adequate levels of all nutrients and a surplus of certain specific nutrients does not reliably prevent it. In order to ensure the supply of nutrients most poultry diets are highly concentrated with regard to the level of energy and protein. In addition the volume of poultry feed is often reduced by pelleting and crumbling. This allows the ingestion of high amounts of feed within a short time. The short time required for feed intake is considered a major cause of behavioural problems in farm animals in general and in poultry in particular. Chickens and turkeys under natural conditions spend about 40 to 60% of the day with feed-related activities, searching and eating (Hughes and Black,

1976; Bessei, 1983). The time spent feeding highly concentrated pelleted feed of caged hens is reduced to approximately 2 hours (Bessei et al., 1999). It is assumed that birds have a genetically determined spontaneous motivation for feed related behaviours (pecking, scratching, locomotion), which is not related to the nutrition or other environmental factors. The mismatch between the spontaneous activity and the actual time required for feeding is considered a cause of feather pecking (Baum, 1995). Evidence for differences in spontaneous locomotor activity in two lines of White Leghorn laying hens has been proved by Jezierski and Bessei (1978). The same lines did not differ in their feather pecking activity (Bessei et al., 1984). In a recent study with a New Hampshire layer line in our own lab we found heritabilities of a moderate to high size for spontaneous locomotor activity in the home pen (Kjaer, 2012) and the high levels of activity correlated with high levels of feather pecking (Kjaer, 2009). Bulky feed, e.g. feed containing high amounts of fibre and presented as finely ground mash, may absorb a major part of the spontaneous activity and, thus, reduce the risk of feather pecking. This is supported by numerous experiments quoted above which showed a beneficial effect of factors which are known to increase the time required for feed intake. The availability of extra materials which attract food pecking or exploratory pecking, such as litter, hay baskets, strings etc., operate in the same direction. The presentation of high fibre diets as mash and the availability of supplementary material which is considered to attract the pecking activity of the birds reduce the incidence or, delay the development of feather pecking and cannibalism in an overwhelming number of studies. The effect of high fibre diets on feather pecking may not only act through increasing the time spent feeding. Insoluble fibre has been found to increase the mean retention time in the foregut and to reduce the retention time in the hind gut (Hartini et al., 2003). High relative weights of the gizzard and gizzard contents of hens have also been reported by Steenfeldt et al. (2007) and Hetland et al. (2005). Van Krimpen et al. (2011) confirmed the higher retention time of the digesta in the foregut of hens fed high fibre diets. Since the overall retention time was not influenced by the diet it was assumed that the retention time in the lower gut was accelerated. The authors suggested that the higher filling of the foregut in response to unsoluble dietary fibre „make the birds feel more satiated" (loc. cit. Van Krimpen et al., 2011), and thus reduce the motivation of feather pecking.

Nevertheless, unacceptable high levels of feather pecking and cannibalism persist even when fibre is available. This raises the question why some birds are pulling the feathers of group mates when the feed is not deficient in nutrients and the birds receive manifold other targets for foraging, such as grass, hay or straw. The findings that feather pecking birds are eating the feathers (Harlander-Matauschek et al., 2007b) indicate that feathers not only represent material for occupation and exploration but also might play a role in the digestive tract. The protein content of feathers is only marginally digestible (McCasland and Richardson, 1966). It is therefore not expected that feathers contribute to the protein supply of the birds, especially when the feed provides adequate levels of amino acids. Feathers are similar to dietary insoluble fibre insofar as they increase the filling of the crop (Harlander-Matauschek and Bessei, 2005) and accelerate the passage time of the ingesta of hens (Harlander-Matauschek et al., 2006b). Indeed, hens of a White Leghorn line selected for high feather pecking showed a faster feed passage than hens selected for low feather pecking, particularly when fed loose feathers on a plate of plastic (Benda, 2008).

Recent experiments have shown that feathers modify the bacterial diversity in the digestive tract (Meyer et al., 2012). This suggests that feathers may represent a substitute for unsoluble fibre. This is supported by the finding that hens of a line selected for high feather pecking (Kjaer et al., 2001) ate more fibre when given the choice of a high and a low fibre diet (Kalmendal and Bessei, 2012). Hetland and Choct (2003) assumed that chickens have a physiological need for insoluble fibre. The same may be true for feathers. Feathers cast during the moult of juvenile birds are eaten frequently (McKeegan and Savory, 1999b), and caged layers eat feathers offered on a sheet of plastic. The high feather pecking birds differentiate between feathers and fibre and prefer feathers over fibre in choice tests (Häusler, 2007). These birds will continue to pull and eat feathers from group mates even if sufficient fibre and alternative material is available. Even if the number of birds with a high initial preference for feathers is small in commercial poultry flocks, pecking can spread through the groups by social learning and an increasing number of feather pecking birds may cause considerable damages in these typical very large groups.

In order to solve the problem it will be necessary to identify birds, which show this particular preference for feathers under favourable nutritional and environmental conditions. The physiological and genetic characteristics of these birds will allow their identification and elimination from commercial breeding stocks. Automated systems for this kind of identification on a large scale should be developed in order to solve one of the most severe welfare problems of modern egg production.

Conclusions

There is a consistent interrelationship of nutrition and feather pecking insofar as deficiencies in protein, amino acids and minerals increase the risk of feather pecking in all poultry species investigated. Supply of nutrients beyond the known requirement for production does not clearly reduce feather pecking. High fibre diets reduce the risk of feather pecking. The effect of dietary fibre on feather pecking can be attributed to its effect on the time spent feeding and on its influence on the passage time of the ingesta in the different parts of the intestinal tract. Though the risk of feather pecking can be reduced through appropriate nutrition, it cannot be prevented. Experiments with layer lines selected for high feather pecking have shown that these birds have a special preference for eating feathers. This particular affinity to feathers is considered the cause of feather pecking under optimum feeding systems.

Summary

It has been shown in numerous experiments that nutrition influences feather pecking and cannibalism in different poultry species. While nutritionists assume that nutritional deficiencies are the main causes of the problem, ethologists consider feather pecking and cannibalism as a result of a fundamental drive related to feeding behaviour. The present paper reviews the influence of nutrition on feather pecking behaviour in different species of domestic fowls on the basis of publications of the last 60 years. Inadequate supply of protein and amino acids, mainly methionine and lysine, stimulate feather pecking and in some cases cannibalism. The effect of dietary arginine on feather pecking is not clearly documented. The beneficiary effect of tryptophane on feather pecking in different species has been attributed

to its function as precursor of serotonin. Sodium deficient diets increased feather pecking in many cases. The effect of other minerals and trace elements did not show consistent results. It is generally acknowledged that nutrient deficiencies increase the exploratory behaviour, which can be directed towards the feather cover of group mates. Supplementation of nutrients beyond the requirement was found to reduce feather pecking in the case of arginine only. A wide range of other feed ingredients and antibiotics have been tested with regard to their effect on feather pecking in chickens, quail and pheasants. None of the ingredients did prevent feather pecking.

There was a consistent trend of the feed structure with coarse particles, especially pellets and crumbles, producing more feather pecking and cannibalism than finely ground feed. This effect was explained by the influence of feed structure on the time spent feeding. Pelleted or coarsely ground feed reduce the time required to ingest the feed, and thus, may not allow to fullfil the drive of food pecking and exploration. The remaining pecking activity may be directed on the pen mate`s feathers. Dilution of the diets with crude fibre, especially with finely ground fibre, reduced feather pecking and pecking-related feather damages in pullets, laying hens and pheasants. The positive effect of dietary fibre on feather pecking can – similarly to the fine feed structure – be attributed to the increase of time spent feeding. A part of the effect of dietary fibre is supposed to be caused by its influence on the passage of the ingesta through the gut. Although adequate levels of all nutrients and high fibre diets fed as fine mash reduce the risk of feather pecking it does not prevent it entirely. Feeding experiments with a chicken line selected for high feather pecking behaviour have shown that these birds show a special preference for feathers. They constantly eat feathers when offered on a sheet of plastic. Raw feathers in the diet show a similar effect on the passage of the digesta through the gut as indigestible fibre. However, the birds of the high feather pecking line prefer feathers over fibre when given the free choice. The cause for this specific preference for feathers remains to be investigated.

Key words

Laying hen, feather pecking, cannibalism, nutrition

Zusammenfassung

Ernährung und Federpicken beim Geflügel

In zahlreichen Experimenten wurde nachgewiesen, dass die Ernährung einen Einfluss auf Federpicken und Kannibalismus bei verschiedenen Geflügelarten hat. Während Geflügelernährer annehmen, dass Mangelerscheinungen die wichtigsten Ursachen für das Problem sind, neigen Ethologen dazu, Federpicken und Kannibalismus als das Ergebnis eines Triebes anzusehen, der mit dem Futteraufnahmeverhalten zusammenhängt. Die vorliegende Arbeit ist eine Übersicht über den Einfluss der Ernährung auf das Federpickverhalten bei verschiedenen Geflügelarten. Sie umfasst Publikationen der letzten 60 Jahre.

Mangel an Protein und Aminosäuren, hauptsächlich Methionin, Cystin und Lysin führt zu Federpicken und in manchen Fällen auch zu Kannibalismus. Der Effekt von Arginin auf Federpicken ist weniger untersucht und nicht gesichert. Tryptophan zeigte einen positiven Effekt auf Federpicken bei verschiedenen Geflügelarten. Dieser Effekt wurde in der Funktion von Tryptophan als Vorstufe von Serotonin diskutiert. Der Mangel an Natrium führte in vielen Fällen zu einem deutlichen Anstieg von Federpicken und Kannibalismus. Für andere Mineralstoffe und Spurenelemente im Futter wurde kein konsistenter Effekt gefunden. Es wird allgemein angenommen, dass Nährstoffmangel zu einer Erhöhung des Explorationsverhaltens führt, das dann auf die Federn der Gruppengenossen gerichtet wird. Das Angebot von Nährstoffen über den bekannten Bedarf hinaus hat bisher nur bei Arginin einen positiven Effekt auf Federpicken gezeigt. Neben den genannten Nährstoffen wurde eine große Anzahl von Futterzusatzstoffen und Antibiotika in ihrer Wirkung auf Federpicken überprüft. Keiner der geprüften Stoffe konnte Federpicken verhindern.

Von der Futterstruktur geht ein deutlicher Effekt auf Federpicken und Kannibalismus aus. Grobe Futterpartikel, Pellets und Krümel hatten einen fördernden Effekt auf Federpicken und Kannibalismus. Dieser Effekt wurde über die Dauer der Futteraufnahme erklärt. Bei pelletiertem und grob strukturiertem Futter ist die Futteraufnahmedauer deutlich reduziert. Es wird angenommen, dass unter dieser Situation die Motivation zum Futterpicken nicht befriedigt werden kann. Die persistierende Motivation zum Picken wird dann auf die Artgenossen gerichtet. Eine Verdünnung der Rationen mit Rohfaser verlängert ähnlich wie fein vermahlenes Futter die Dauer der Futteraufnahme und reduziert Federpicken. Ein weiterer Aspekt der Rohfaser in Bezug auf Federpicken wird ihrer Wirkung auf die Darmpassage zugeschrieben.

Mit Rationen, die ausreichend mit Nährstoffen ausgestattet sind, eine feine Struktur haben und einen hohen Rohfasergehalt aufweisen kann die Ausprägung von Federpicken verringert aber nicht verhindert werden. Fütterungsexperimente mit Hühnerlinien, die auf hohes Federpickverhalten selektiert worden waren, haben gezeigt, dass diese Tiere eine ausgeprägte Präferenz für Federn haben und Federn fressen, wenn diese ihnen auf Plastikdeckeln angeboten werden. Rohe Federn beeinflussen die Darmpassage in ähnlicher Weise wie Rohfaser. Die auf hohes Federpicken selektierten Tiere zeigten jedoch eine Präferenz für Federn gegenüber Rohfaser. Die Ursachen dieser speziellen Präferenz sind nicht bekannt.

Stichworte

Legehenne, Federpicken, Kannibalismus, Ernährung

References

Abrahamsson, P., R. Tauson, K. Elwinger, 1996: Effects on production, health and egg quality of varying proportions of wheat and barley in diets for two hybrids of laying hens kept in different housing systems. Acta Agric. Scand., Sec. A, Anim. Sci. **46**, 173-182.

Ambrosen, T.A., V.E. Petersen, 1997: The influence of protein level in the diet on cannibalism and quality of plumage of layers. Poult. Sci. **76**, 559-563.

Anonymus, 1997: Alternativ eggproduksjon oker. Gemensam nordisk fjäderfätidskrift, 16-17.

Baum, S., 1995: Zur Genese der Verhaltensstörung „Federpicken" beim Haushuhn. 23. Int. Arbeitstagung Angewandte Ethologie bei Haustieren, KTBL Schrift **351**, 60-68.

Bearse, G.E., V.L. Miller, C.F. McClary, 1940: The cannibalism preventing properties of the fiber fraction of oat hulls. Poult. Sci. **19**, 210-215.

Bearse, G.E., L.R. Berg, C.F. McClary, V.L. Miller, 1949: The effect of pelleting chicken rations on the incidence of cannibalism. Poult. Sci. **28**, 756.

Benda, I., 2008: Untersuchungen zu den Beziehungen von Federpicken, Exploration und Nahrungsaufnahme bei Legehennen. Universität Hohenheim, Institut für Tierhaltung und Tierzüchtung, FG Nutztierethologie und Kleintierzucht, Stuttgart.

Bessei, W., 1978: Der Einfluß einer Na-armen Ration auf die Laufaktivität von Legehennen. Arch. Geflügelk. **42**, 246-248.

Bessei, W., 1983: Verhaltensänderungen des Huhns bei Intensivierung des Haltungssystems. Arch. Geflügelk. **47**, 8-16.

Bessei, W., 1997: Ethologische Untersuchungen zum Pickverhalten von Legehennen. Lohmann Information **3/97**, 3-8.

Bessei, W., 2011: Le picage des plumes – Nouveaux aspects d'un vieux problème. 9èmes Journées de la Recherche Avicole – Tours, France, 29 et 30 mars 2011, 207-211.

Bessei, W., G. Klinger, B. Peitz, 1984: Das Verhalten von Legehennen unter dem Einfluß der Leistungsselektion in Boden- und Käfighaltung. Arch. Geflügelk. **48**, 29-35.

Bessei, W., K. Reiter, T. Bley, F. Zeeb, 1999: Measuring pecking of a bunch of feathers in individually housed hens: first results of genetic studies and feeding related rations. Lohmann Info. **22**, 27-31.

Bilsing, A., I. Becker, M. Nichelmann, 1992: Verhaltensstörungen bei der Moschusente. KTBL Schrift **351**, 69-76.

Blokhuis, H.J., 1986: Feather pecking in poultry: its relation with ground pecking. Appl. Anim. Behav. Sci. **16**, 63-67.

Cain, J.R., J.M. Weber, T.A. Lockamy, C.R. Creger, 1984: Grower diets and bird density effects on growth and cannibalism in ring-necked pheasants. Poult. Sci. **63**, 450-457.

Conson, M., J. Petersen, 1986: Beurteilung der Gefiederbeschaffenheit unterschiedlich aufgezogener Legehybriden. Arch. Geflügelk. **50**, 159-169.

Cooke, B.C., 1992: Cannibalism in laying hens. Vet. Rec. **131**, 495.

Creek, R.D., M.Y. Dendy, 1957: The relationship of cannibalism and methioine. Poult. Sci **36**, 1093-1094.

Dänner, E., W. Bessei, 2000: Influence of sulphur amino acid content on performance and feathering of laying hybrids. Proc. 21th WPSA, Montreal, Canada CD.

Deaton, J.W., L.F. Kubena, F.N. Reece, B.D. Lott, 1977: Effect of dietary fibre on the performance of laying hens. Br. Poult. Sci. **18**, 711-714.

Donaldson, W.E., G.F. Combs, G.L. Romoser, W.C. Supplee, 1955: Body composition, energy intake, feed efficiency, growth rate, and feather condition of growing chickens as influenced by calorie-protein ratio of the ration. Poult. Sci. **34**, 1190.

Esmail, S.H.M., 1997: Fibre Nutrition. Poultry Intern., 31-34.

Feltwell, R., ed. 1953: Intensive methods of poultry management. 2nd ed. HMSO, London.

Fernstrom, J.D., 1981: Dietary precursors and brain neurotransmitter formation. Anu. Rev. Med. **32**, 413-425.

Gerum, J., M. Kirchgessner, 1978: Perosis and feather pecking of broilers with varying energy and protein supply. Arch. Geflügelk. **42**, 78-80.

Hadorn, R., H. Wiedmer, A. Gloor, 1998: Effect of the exclusion of animal proteins from layer diets. Agrarforschung **5**, 409-412.

Hale, E.B., M.W. Schein, 1962: The behaviour of turkeys. in The Behaviour of Domestic Animals. E. S. E. Hafez, ed. Balliere, Tindall & Cox, London.

Harlander-Matauschek, A., W. Bessei, 2005: Feather eating and crop filling in laying hens. Arch. Geflügelk. **69**, 241-244.

Harlander-Matauschek, A., C. Baes, W. Bessei, 2006a: The demand of laying hens for feathers and wood shavings. Appl. Anim. Behav. Sci. **101**, 102-110.

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

Harlander-Matauschek, A., I. Benda, C. Lavetti, M. Djukic, W. Bessei, 2007a: The relative preferences for wood shavings or feathers in high and low feather pecking birds. Appl. Anim. Behav. Sci. **107**, 78-87. doi:10.1016/j.applanim.2006.09.022.

Harlander-Matauschek, A., K. Häusler, W. Bessei, 2007b: A note on the relative preferences of laying hens for feathers from different body parts. Appl. Anim. Behav. Sci. **108**, 186-190.

Hartini, S., M. Choct, G. Hinch, A. Kocher, J.W. Nolan, 2002: Effects of light intensity during rearing and beak trimming and dietary fiber sources on mortality, egg production, and performance of ISA Brown laying hens. J. Appl. Poult. Res. **11**, 104-110.

Hartini, S., M. Choct, G. Hinch, J.V. Nolan, 2003: Effect of diet composition, gut microbial status and fibre forms on cannibalism in layers. AECL **03/03**, 1-111.

Häusler, K., 2007: Untersuchungen zur Motivation zum Federfressen bei Legehennen. Dissertation, Universität Hohenheim, Institut für Tierhaltung und Tierzüchtung, Fachgebiet Nutztierethologie und Kleintierzucht, Stuttgart.

Hetland, H., M. Choct, 2003: Role of insoluble non-starch polysaccarides in poultry nutrition. Proc. 14th European Symposium of Poultry Nutrition, Lillehammer, Norway, 64-69.

Hetland, H., R.O. Moe, R. Tauson, S. Lervik, B. Svihus, 2004: Effect of including whole oats into pellets on performance and plumage condition in laying hens housed in conventional and furnished cages. Acta Agric. Scand. Sect. A, Anim. Sci. **54**, 206-212.

Hetland, H., B. Svihus, M. Choct, 2005: Role of insoluble fiber on gizzard activity in layers. J. Appl. Poult. Res. **14**, 38-46.

Heywang, B.W., R.B. Morgan, 1944: A comparison of a pelleted and unpelleted all-mesh diet for growing chickens. Poult. Sci. **23**, 16-20.

Huber-Eicher, B., B. Wechsler, 1997: Feather pecking in domestic chicks: its relation to dustbathing and foraging. Anim. Behav. **54**, 757-768.

Hughes, B.O., I.J.H. Duncan, 1972: The influence of strain and environmental factors upon feather picking and cannibalism in fowls. Br. Poult. Sci. **13**, 525-547.

Hughes, B.O., D.G.M. Wood-Gush, 1973: An increase in activity of domestic fowls produced by nutritional deficiency. Anim. Behav. **21**, 10-17.

Hughes, B.O., C.C. Whitehead, 1974: Sodium deprivation, feather pecking and activity in laying hens. Br. Poult. Sci. **15**, 435-439.

Hughes, B.O., A.J. Black, 1976: Battery cage shape: its effect on diurnal feeding pattern, egg shell cracking and feather pecking. Br. Poult. Sci. **17**, 327-336.

Iglauer, F., R. Rasim, 1993: Treatment of psychogenic feather pecking in psittacine birds with a dopamine antagonist. J. Small Anim. Pract. **34**, 564-566.

Jezierski, T., W. Bessei, 1978: Der Einfluß von Genotyp und Umwelt auf die lokomotorische Aktivität von Legehennen in Käfigen. Arch. Geflügelk. **42**, 159-166.

Kalmendal, R., W. Bessei, 2012: The preference for high-fiber feed in laying hens divergently selected on feather pecking. Poult. Sci. **91**, 1785-1789.

Karlson, A., 1996: Effekt av olika spannmålsslag på fjäderplockning och kannibalism hos värphöns i olika inhysninssystem. Examensarbete **74**, Swedish University of Agric. Sci, Uppsala.

Kjaer, J.B., 2009: Feather pecking in domestic fowl is genetically related to locomotor activity levels: Implica-

tions for a hyperactivity disorder model of feather pecking. Behav. Genetics **39**, 564-570. doi:10.1007/s10519-009-9280-1.

KJAER, J.B., in prep. : Divergent selection on spontaneous locomotor acitivity in chickens: Selection program and phenotypic response.

KJAER, J.B., P. SØRENSEN, G. SU, 2001: Divergent selection on feather pecking behavior in laying hens (Gallus gallus domesticus). Appl. Anim. Beh. Sci. **71**, 229-239.

KJAER, J.B., P. SØRENSEN, 2002: Feather pecking and cannibalism in free-range laying hens as affected by genotype, dietary level of methionine + cystine, light intensity during rearing and age at first access to the range area. Appl. Anim. Behav. Sci. **76**, 21-39.

KRIEGSEIS, I., W. BESSEI, B. MEYER, J. ZENTEK, H. WUERBEL, A. HARLANDER-MATAUSCHEK, 2012: Feather-pecking response of laying hens to feather and cellulose-based rations fed during rearing. Poult. Sci. **91**, 1514-1521.

LEESON, S., L. CASTON, J.D. SUMMERS, 1997: Layer performance of four strains of Leghorn pullets subjected to various rearing programs. Poult. Sci. **76**, 1-5.

LEONG, K.C., M.L. SUNDE, H.R. BIRD, C.A. ELVEHJEM, 1955: Effect of energy: protein ratio on growth rate, efficiency, feathering and fat deposition in chickens. Poult. Sci. **34**, 1206.

LINDBERG, A.C., C.J. NICOL, 1994: An evaluation of the effect of operant feeders on welfare of hens maintained on litter. Appl. Anim. Behav. Sci. **41**, 211-227.

LONSDALE, M.B., R.M. VONDELL, R.C. RINGROSE, 1957: Debeaking at one day of age and the feeding of pellets to broiler chickens. Poult. Sci. **57**, 565-571.

MADSEN, H., 1966: on feather pecking and cannibalism in pheasant and partridge chicks, particularly in relation to the amino acid arginine. Acta Vet. Scand. **7**, 272-287.

MARSHBOON, R., G. SIERENS, 1962: Treatment and prophylaxis of cannibalism in poultry with haloanisone-R 2028. Poult Sci **41**, 776-780.

MCCASLAND, W.M.E., L.R. RICHARDSON, 1966: Methods for determining the nutritive value of feather meals. Poult. Sci. **45**, 1231-1236.

MCKEEGAN, D.E.F., C.J. SAVORY, 1999a: 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., C.J. SAVORY, 1999b: Feather pecking and dietary protein: Is development of pecking damage in layer pullets influenced by dietary protein source? Poult. Intern. **38**, 48-50.

MCKEEGAN, D.E.F., C.J. SAVORY, M.G. MACLEOD, M.A. MITCHELL, 2001: Development of pecking damage in layer pullets in relation to dietary protein source. Brit. Poult. Sci. **42**, 33-42.

MEYER, B., W. BESSEI, W. VAHJEN, J. ZENTEK, A. HARLANDER-MATAUSCHEK, 2012: Dietary inclusion of feathers affects intestinal microbiota and microbial metabolites in growing Leghorn-type chickens. Poult. Sci. **91**, 1506-1513. doi:10.3382/ps.2011-01786.

NEAL, W.M., 1956: Cannibalism, Pick-Outs and Methionine. Br. Poult. Sci. **35**, 10-13.

NESTLER, R.B., L.M. LLEWELLYN, M.J. RENSBERGER, 1945: Comparison of Animal and Plant Proteins For Young Penreared Bobwhite Quail. Journal of J. Wildlife Managem. **9**, 274-279.

NEWBERRY, R.C., L.J. KEELING, I. ESTEVEZ, 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.

NEWBERRY, R.C., R. BLAIR, 1993: Behavioral responses of broiler chickens to handling: effects of dietary tryptophan and two lighting regimens. Poult Sci **72**, 1237-1244.

NORGAARD-NIELSEN, G., 1989: Effekten af naebtrimming pa fjerpilning, fjerdragtens tilstand, dodelighed og produktion hos honer i Hans Kier systemet. Rapport til Hans Kiers Fond, Foreningen til Dyrenes Beskyttelse, 1-38.

PFIRTER, H.P., P. WALSER, 1998: Wieviel und welches Protein? UFA – Revue **11**, 26-28.

PULLIAINEN, E., 1965: Cannibalism in the pheasant (Phasianus cholchicus L.) during the egg-laying period. Annales Zoologica Fennia, 203-214.

RAMADAN, S.G.A., E. VON BORELL, 2008: Role of loose feathers on the development of feather pecking in laying hens. Br. Poult. Sci. **49**, 250-256.

RICHTER, G., H. HARTUNG, 2003: Pflanzliche Rationen im Vergleich. DGS Magazin 2003 **(1)**, 20-24.

SAVORY, C.J., J.D. HETHERINGTON, 1997: Effects of plastic anti-pecking devices on food intake and behaviour of laying hens fed on pellets or mash. Br. Poult. Sci. **38**, 125-131.

SAVORY, C.J., J.S. MANN, 1997: Behavioural development in groups of pen-housed pullets in relation to genetic strain, age and food form. Br. Poult. Sci. **38**, 38-47.

SAVORY, C.J., J.S. MANN, M.G. MACLEOD, 1999: Incidence of feather pecking damage in growing bantams in relation to food form, group size, stocking density, dietary tryptophan concentration and dietary protein source. Br. Poult. Sci. **40**, 579-584.

SCHAIBLE, P.J., J.A. DAVIDSON, S.L. BANDEMER, 1947: Cannibalism and feather pecking in chicks as influenced by certain changes in a specific rations. Br. Poult. Sci. **26**, 651-656.

SCOTT, M.L., E.L. HOLM, R.E. REYNOLDS, 1954a: Studies on pheasant nutrition. 3. Effects of antibiotics, arsenicals and thyroactive compounds upon growth and feathering. Poult. Sci. **33**, 1261-1265.

SCOTT, M.L., E.L. HOLM, R.E. REYNOLDS, 1954b: Studies on pheasant nutrition. 2. Protein and fiber levels in diets for young pheasants. Poult. Sci. **33**, 1237-1244.

SEEMANN, M., 1982: Die Reaktion von Legehybriden auf Wahlfütterung. Universität Hohenheim, Institut für Tierhaltung und Tierzüchtung, Fachgebiet Kleintierzucht, Stuttgart.

SHEA, M.M., S.A. MENCH, O.P. THOMAS, 1990: The effect of dietary tryptophan on aggressive behavior in developing and mature broiler breeder males. Poul. Sci. **90**, 1664-1669.

SIRÈN, M.J., 1963: A factor preventing cannibalism in cockerels. Life Sci. **2**, 120-124.

SKOGLUND, W.C., D.H. PALMER, 1961: Light intensity studies with broilers. Poult. Sci. **40**, 1458.

STEENFELDT, S., J.B. KJAER, R.M. ENGBERG, 2007: Effect of feeding silages or carrots as supplements to laying hens on production performance, nutrient, digestibility, gut structure, gut micorflora and feather pecking behaviour. Brit. Poult. Sci. **48**, 454-468.

SWARBRICK, O., D.G. PARSON, 1992: Cannibalism in laying hens. Vet. Rec. **131**, 543.

VAN HIERDEN, Y.M., S.M. KORTE, E.W. RUESINK, C.G. VAN REENEN, B. ENGEL, G.A.H. KORTE-BOUWS, H.J. BLOKHUIS, 2002: Adrenocortical reactivity and central serotonin and kopamine turnover in young chicks from a high and low feather-pecking line of laying hens. Phys. Behav. **75**, 653-659.

VAN HIERDEN, Y.M., S.F. DE BOER, J.M. KOOLHAAS, S.M. KORTE, 2004: The control of feather pecking by serotonin. Behav. Neurosci. **116**, 575-583.

VAN KRIMPEN, M., T. VELDKAMP, G.P. BINNENDIJK, R. DE VEERT, 2010: Effect of four prcessed animal proteins in the diet on digestibility and performance in laying hens. Poult. Sci. **89**, 2608-2616.

VAN KRIMPEN, M., R.P. KWAKKEL, C.M.C. VAN DER PEET-SCHWERING, L.A. DEN HARTOG, M.W.A. VERSTEGEN, 2008: Low

dietary energy concentration high nonstarch polysaccharide concentration, and coarse particle sizes of nonstarch polysaccharides affect the behavior of feather-pecking-prone laying hens. Poult. Sci. **87**, 485-496.

VAN KRIMPEN, M.M., R.P. KWAKKEL, C.M.C. VAN DER PEET-SCHWERING, L.A. DEN HARTOG, M.W.A. VERSTEGEN, 2009: Effects on nutrient dilution and nonstarch polysaccharide concentration in rearing and laying diets on eating behavior and feather damage of rearing and laying hens. Poult. Sci. **88**, 759-773.

VAN KRIMPEN, M.M., R.P. KWAKKEL, C.M.C. VAN DER PEET-SCHWEERING, L.A. DEN HARTOG, M.W.A. VERSTEGEN, 2011: Effects of dietary energy concentration, nonstarch polysaccharide concentration, and particle size of nonstarch polysaccharides on digesta mean retention time and gut development in laying hens. Br. Poult. Sci. **52**, 730-741.

VORECK, O., M. KIRCHGESSNER, 1981: Zum Einfluss unterschiedlicher rohfasergehalte bei verschiedenen Energiestufen auf Futterverzehr, Legeleistung und Lebendmassenentwicklung von Legehennen. Arch. Geflügelk. **45**, 33-41.

WAHLSTRÖM, A., R. TAUSON, K. ELWINGER, 1998: Effect on plumage condition, health and mortality of dietary oats/wheat ratios to three hybrids of laying hens in different housing systems. Acta Agri. Scand., Sect. A, Anim. Sci. **48**, 250-259.

WALSER, P., 1997: Einfluss unterschiedlicher Futterzusammensetzung und -aufbereitung auf das Auftreten von Federpicken, das Nahrungsaufnahmeverhalten, die Leistung und den Gesamtstoffwechsel bei verschiedenen Legehennenhybriden. Dissertation Nr. 12365, ETH Zürich, Switzerland.

WILLIMON, C.P., C.L. MORGAN, 1953: The effect of minor nutrient mineral elements in the diet of chickens on feather pulling and cannibalism. Poult. Sci. **32**, 309-313.

Correspondence: Prof. Dr. Dr.h.c. Werner Bessei, Dept. of Farm Animal Behavior and Poultry Science, Institute 470, University Hohenheim, Stuttgart, Germany; e-mail: werner.bessei@uni-hohenheim.de