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Impact of feeding management on feather pecking in laying hens

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In the near future EU-legislation will ban the use of conventional battery cages, while national legislation in some countries in Western Europe will ban beak trimming as well. The ban on battery cages and beak trimming causes an increased risk of feather pecking and cannibalism in laying hens. Many factors influence feather pecking behaviour, but this paper focuses on nutritional factors. Nutritional factors can have positive and negative effects on feather pecking behaviour in laying hens. Severe feather pecking has been demonstrated in birds that were fed a too low mineral level in the diet, a too low protein level or a too low amino acid level (methionine, arginine). Sometimes somewhat more feather pecking was found when layers were fed diets with mainly vegetable protein sources as compared with diets with protein from animal origin. Also more feather pecking may occur when the diets were fed restrictedly, fed coarsely ground, or fed as pellets. Feeding high-fibre diets, low energy diets, or roughages reduced feather pecking. Providing additional grain or straw in the litter during rearing could result in lower levels of feather pecking behaviour in adult stages. Some of these positive effects on feather pecking seem to be related to the time birds spend on feed intake and foraging. This paper gives an overview of the relationships between the occurrence of feather pecking behaviour and nutritional factors, such as diet composition and feeding strategies in laying hens.

Keywords: nutrition; feather pecking; pullets; laying hens; diet composition; feeding management

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Introduction

In 2012, changes in EU-legislation with regard to animal welfare and husbandry will be implemented that might increase the level of feather pecking in layers. These changes include a ban on traditional battery cages as the current housing system for layers in Western Europe. This ban is the result of a societal debate from which the conclusion was drawn that battery cages could not fulfil the birds' need to express their natural behaviour. This stressed the need to develop alternative housing systems for layers, such as furnished cages, free range systems, or aviary systems. These systems, however, show much higher incidences of feather pecking and cannibalism compared to cage systems (Morgenstern, 1995). In organic farming, mortalities of even up to 30%, as a result of cannibalism, have been reported (Van der Wouw, 1995). The most effective tool to prevent feather pecking and subsequent cannibalism is beak trimming, but in some West-European countries (*e.g.* Great Britain and The Netherlands) a general ban on beak trimming can be expected in the near future too. The bans on battery cages and beak trimming increase the risk of feather pecking and cannibalism.

Feather pecking in layers is a multi-factorial problem, which can be caused by environmental, genetic or nutritional factors (Blokhuis, 1989). In this paper, the focus will be on nutritional factors. The objective of the current study is to provide an overview of the relationship between feather pecking behaviour and nutritional factors, such as diet composition and feeding strategies in laying hens. It has been demonstrated many times that dietary deficiencies stimulate explorative behaviour (Bessei, 1983) and may increase feather pecking (*e.g.* Ambrosen and Petersen, 1997). Some authors have shown that the addition of fibre to the diet or feeding roughages could decrease feather pecking and cannibalism (*e.g.* Steenfeldt *et al.*, 2001). The relative importance of specific deficiencies in layer diets, as well as the effectiveness and possible modes of action of certain nutritional factors, will be examined and discussed in this review.

Definitions

Feather pecking in laying hens can be characterised as pecking at and pulling out of feathers of conspecifics. Five different types of bird-to-bird pecking can be distinguished, based on both cause and its effect (Savory, 1995). These are:

1. aggressive pecking,
2. gentle feather pecking without removal of feathers,
3. severe feather pecking leading to feather loss,
4. tissue pecking in denuded areas and
5. vent pecking.

Aggressive pecking among chickens is used to establish a stable dominance hierarchy. It may lead to some damage to the neck and neck region, but should not be confused with feather pecking behaviour. Gentle feather pecking without the removal of feathers sometimes appears to be directed at litter particles on the plumage. However, it can also develop into stereotypic pecking with a high frequency at the same spot on another bird (McAdie and Keeling, 2002), which can cause damage. Gentle feather pecking is often ignored by the recipient. Severe feather pecking, or feather pulling, is characterised by forceful pecking at or pulling out of feathers, to which the victim usually reacts. Feather removal has been shown to be painful (Gentle and Hunter, 1990), cause feather damage and can lead to bald patches. These bald patches may attract tissue pecking, which can result in wounding of the victim and eventually to cannibalism. Vent pecking may start as investigative pecking, but it can also lead to cannibalism when the oviduct is damaged or the internal organs are pulled out. The distinction between gentle feather pecking, severe feather pecking and tissue pecking is not always clear and the different pecking forms may transform into each other (Savory, 1995).

Feather pecking, especially the severe type, negatively affects the welfare of laying hens (Blokhuis and Wiepkema, 1998). Moreover, feather pecking causes feather loss of pecked birds resulting in higher feed intake, worse feed conversion ratio, and as a consequence higher feed costs (Tauson and Svensson, 1980; Herremans *et al.*, 1989; Peguri and Coon, 1993).

Factors affecting feather pecking behaviour

Many factors that affect feather pecking behaviour are related either to internal factors like the genetic nature or the physiological status of the birds, or to external factors like housing conditions of the birds or nutritional factors or to a combination of these factors. The interaction between internal and external factors also can increase feather pecking behaviour. It appears that feather pecking is initially performed by frustrated birds (Lindberg and Nicol, 1994). An overview of factors that affect feather pecking behaviour is given in *Figure 1*. This paper is mainly focused on the circled external factors 'diet composition' and 'feeding strategy'.

INTERNAL FACTORS

A large variation in the level of feather pecking behaviour exists between strains of laying hens. Some studies indicate the possibility for breeding programmes and behaviour-genetic experiments to reduce the feather pecking problem (Sørensen, 1997; Craig and Muir, 1998). Often the results of such programmes are inconsistent, with heritability estimates ranging from 0.04 – 0.56 (Bessei, 1984; Rodenburg *et al.*, 2003) depending on age and method of recording.

The role of fear in relation to feather pecking behaviour is unclear. Some authors have suggested that feather pecking is more likely to be initiated by fearful birds (Vestergaard *et al.*, 1993; Johnsen *et al.*, 1998). Observations in an open-field test show that laying hens that were more fearful and less social as young pullet showed higher levels of feather pecking as adult hens (Rodenburg *et al.*, 2004). Based on the same data a quantitative trait loci study (QTL) was performed, which indicated that there may be a common gene or a set of genes that affect both open-field behaviour and feather pecking behaviour (Buitenhuis *et al.*, 2003; Buitenhuis *et al.*, 2004). Most studies indicate that fearfulness is a consequence of feather pecking, induced by feather damage and pain, rather than the other way around (Lee and Craig, 1991; Hansen and Braastad, 1994; Jones and Hocking, 1999).

It appears that feather pecking is initially performed by a restricted number of birds in a flock. Such behaviour (and in particular cannibalism) can escalate into a great number of birds in a flock showing feather pecking (Zeltner *et al.*, 2000). McAdie and Keeling (2002) found some evidence that gentle feather pecking was transmitted in laying hens housed in cages. However, they found no evidence for the spreading of severe feather pecking. Social learning has been found to facilitate and accelerate outbreaks of feather pecking (Cloutier *et al.*, 2000; Zeltner *et al.*, 2000; McAdie and Keeling, 2002). Severe feather pecking should never be confused with normal gentle feather pecking, which plays an important functional role in the building and maintenance of social relationships between birds (Riedstra and Groothuis, 2002).

The intensity and severity of feather pecking seems to depend on age (Rodenburg and Koene, 2003). Gentle feather pecking is mostly observed in young chickens (Kjaer and

Sørensen, 1997; Wechsler *et al.*, 1998) and severe feather pecking is more often seen at a later age (Huber Eicher and Sebo, 2001). In addition, the nature of environmental conditions given to young birds plays an important role in the development or occurrence of feather pecking later in life (Blokhuis and Van der Haar, 1992; Huber Eicher and Wechsler, 1998). McAdie and Keeling (2002) suggest that severe feather pecking and stereotyped gentle feather pecking can develop from gentle feather pecking, either by increased severity or increased intensity of pecks.

The increase in feather pecking around onset-of-lay is hormonally mediated, and can either be stimulated by administering a combination of oestrogen and progesterone or be blocked by giving testosterone (Hughes, 1973).

EXTERNAL FACTORS

Provision of litter at early ages substantially reduces feather pecking at later age (Blokhuis and Van der Haar, 1989). This is consistent with the theory that feather pecking is a form of redirected behaviour, developing either from ground pecking (Blokhuis, 1986) or pecking during dust-bathing (Vestergaard *et al.*, 1993). According to these theories, exposing chickens to litter early in life would prevent them from perceiving feathers as a substrate for either foraging or dust-bathing.

Increasing group size (Keeling, 1994; Bilcik and Keeling, 1999) or increasing stocking density (Appleby *et al.*, 1988; Savory and Mann, 1999) have been linked to an increase in feather pecking behaviour. Because group size and stocking density are confounded, the role of each individual factor can not be distinguished (Nicol *et al.*, 1999; Savory and Mann, 1999).

Increasing light intensity seems to increase the level of severe feather pecking (Allen and Perry, 1975; Kjaer and Vestergaard, 1999). Laying hens that were reared in 3 lux developed stereotypic gentle feather pecking, showing about 20 times more gentle pecking than hens that were reared at 30 lux. Severe pecks were 2 - 3 times more frequent in laying hens that were reared at 30 than at 3 lux. During the laying period, the immediate effects of the two light intensities on pecking behaviour were less pronounced than during rearing (Kjaer and Vestergaard, 1999). Possibly, low light levels during rearing impairs the bird's ability to identify environmental cues and consequently increases exploratory pecking in order to compensate. Light colour may also play a role in social recognition in laying hens (D' Eath and Stone, 1999).

Numerous other housing conditions can also influence feather pecking behaviour. An appropriate housing design, resulting in no competition or increased activity at feeders, drinkers and nest boxes, and the availability of perches may prevent feather pecking (Savory, 1995). Feather damage, caused by abrasion against other birds at high density or against equipment in the system or the side of cages, has also been found to facilitate and accelerate outbreaks of feather pecking (Savory and Mann, 1997; McAdie and Keeling, 2000). Also the availability of short feathers on the floor can influence feather pecking behaviour. Based on an experiment with layer pullets McKeegan and Savory (1999) concluded that once feather eating has become established, a too low availability of short feathers on pen floors may cause feather eating and pecking to be redirected to other birds.

In the above section genetic, physiological and some management factors related to feather pecking were briefly discussed. In the following paragraphs an overview is given of the impact of nutritional factors, such as diet composition and feeding strategies, on feather pecking behaviour in laying hens. Furthermore, the possible modes of action of these nutritional factors related to feather pecking behaviour are discussed.

Diet composition

PROTEIN AND AMINO ACID CONTENT

Crude protein: For decades, it has been known that protein-deficient diets may increase feather pecking and cannibalism in birds (Schaible *et al.*, 1947). A protein deficiency, especially a methionine deficiency (Elwinger *et al.*, 2002), might play a significant role in organic poultry production, because of the ban on particular protein sources and synthetic amino acids in organic layer diets (European Commission 1139/98, 1988). The addition of protein supplements, such as casein, gelatin, liver meal, blood meal, soybean oil meal, cotton seed meal and other protein sources to basal diets low in crude protein (CP) (135 g/kg), as well as in phosphorus (5.3 g/kg) and in fibre (26 g/kg) reduced the incidence of feather pecking and cannibalism in pullets from 0 to 8 weeks of age (Schaible *et al.*, 1947). A low protein diet (111 g/kg CP) without the addition of synthetic amino acids, that was tested in 7 layer strains, resulted in 17.6% cannibalism mortality compared to 2.5% cannibalism mortality in layers that were fed a diet of 193 g/kg crude protein (Ambrosen and Petersen, 1997). Mortality, however, was not significantly affected by dietary protein contents in two experiments of Al Bustany and Elwinger (1987a). The crude protein content in Experiment 1 ranged from 124 g/kg to 176 g/kg (total lysine intake 487 to 919 mg/hen/day) and in Experiment 2 from 134 g/kg to 177 g/kg (total lysine intake 703 to 1024 mg/hen/day) respectively. The results of Ambrosen and Petersen (1997) and Al Bustany and Elwinger (1987a) seem to contradict. However, in the experiment of Ambrosen and Petersen (1997) only significant effects of CP on mortality were found at CP levels of 126 g/kg or lower, while Al Bustany and Elwinger (1987a) did their experiments at CP levels above 124 g/kg. Furthermore, in Experiment 2 of Al Bustany and Elwinger (1987a) a treatment with 120 g/kg crude protein was excluded because of a high rate of cannibalism and mortality. Increasing the dietary protein and amino acid contents in these experiments resulted in improved plumage condition (3 points on a scale that ranged from 5 to 20) (Al Bustany and Elwinger, 1987a). In an earlier experiment of Al Bustany and Elwinger (1986) experimental diets were fed with crude protein contents of 124 g/kg, 150 g/kg and 176 g/kg and lysine contents of 4.6 g/kg, 6.6 g/kg and 8.7 g/kg, resulting in a total lysine intake of 461, 709, and 919 mg/hen/day. In that experiment no effect of protein and lysine content on plumage condition and mortality was found, but the strains of layers used in that experiment had been selected for several generations to perform well on a low protein and low energy diet.

Methionine and cysteine: Since feathers are 89-97% protein, dietary amino acids play a critical role in feather development. Feather development is related to the incidence of feather pecking (McAdie and Keeling, 2000). Ruffled or trimmed feathers encourage feather pecking behaviour, and even cannibalism, and this stresses the need of good feather development. The major amino acids involved in the synthesis of feather keratin are the sulphur-containing amino acids, methionine and cysteine. Marginal deficiencies of these amino acids will often be initially manifested in abnormal feathering (Robel, 1977; Deschutter and Leeson, 1986). Feeding an organic diet low in protein and amino acids (135 g/kg crude protein, 5.9 g/kg lysine and 5.1 g/kg methionine + cysteine) to laying hens resulted in an inferior plumage condition and a higher incidence of peck injuries of the comb and the rear body parts compared to feeding a standard organic diet with 169 g/kg CP, 8.7 g/kg lysine and 6.7 g/kg methionine + cysteine (Elwinger *et al.*, 2002). Hens fed the organic diet had a daily intake of 649 mg lysine and 561 mg methionine + cysteine, compared to 940 mg and 724 mg respectively in hens fed the standard diet. In contrast with these results, no effect was found of a low (4.2 g/kg) versus a high (8.2 g/kg) level of methionine + cysteine in organic diets on the plumage condition of laying hens (Kjaer and Sørensen, 2002). However, in the experiment of Elwinger *et al.* (2002), CP and lysine content changed in addition to methionine + cysteine content, so these experiments are not fully comparable.

Lysine: Adding lysine to a diet low in CP, such that the consumption of lysine increased from 485 to 587 mg per hen per day, improved plumage condition of laying hens considerably (Al Bustany and Elwinger, 1987b). In a dose – response trial, in which the total lysine content varied from 5.6 to 9.4 g/kg (resulting in increased crude protein contents), no further improvement of plumage condition was found from a lysine level of 8.2 g/kg onwards. Based on three experiments of Al Bustany and Elwinger (1987a,b), a total lysine content of about 8,0 g/kg, corresponding with in a total lysine intake of 850 to 950 mg/hen/day, seems to be sufficient for an optimal plumage condition. The effect of the different protein, lysine and/or methionine levels on feather pecking behaviour is summarised in *Table 1*.

Arginine: Reducing the dietary level of arginine from 6.9% to 3.9% of the total protein in diets of 4-week old cockerels increased the level of cannibalism from 0 to 21% (Sirén, 1963). Cannibalism in 8-week old cockerels, fed a diet with 3.9% arginine, could subsequently be cured by feeding a diet with 6.9% (of the total protein) arginine. Madsen (1966) completed similar experiments with pheasants and partridges. He found no evidence that arginine influenced pecking at the back and wings, tail feathers, or vent of pen mates.

Tryptophan: Dietary supplementation with tryptophan in growing bantams, ranging from 2.6 to 22.6 g/kg, resulted in a suppression of pecking damage with the higher doses compared to the control dose (2.6 g/kg), at 4 and 6 weeks of age (Savory, 1998; Savory *et al.*, 1999). This lower level of pecking damage is probably caused by a lower level of severe feather pecking behaviour. In line with this observation Van Hierden et al. (2003) reported reduced frequencies of gentle feather pecking in young chickens that were fed a diet with a very high tryptophan level (21 g/kg) compared to a diet with a standard tryptophan level (1.6 g/kg). Tryptophan is a precursor for serotonin synthesis (5-HT) and chickens from a high feather pecking line were found to display lower 5-HT turnover levels in response to acute stress than chickens from a low feather pecking line (Van Hierden et al., 2002). Increased dietary tryptophan stimulates serotonergic neurotransmission, resulting in a higher turnover of tryptophan to 5-HT in the brains (Van Hierden *et al.*, 2004). Thus feather pecking behaviour seems to be triggered by low serotonergic neurotransmission, because increasing serotonergic tone (higher levels of dietary tryptophan) decreases feather pecking behaviour. The effect of dietary tryptophan content on feather pecking behaviour is summarised in *Table 2*.

It can be concluded that marginal levels of CP and amino acids can result in feather pecking behaviour, whereas high levels of dietary tryptophan might decrease feather pecking behaviour. In most of the above mentioned cases of increased feather pecking the CP and amino acid levels of the control groups were below NRC requirements for laying hens. NRC requirements for layer diets are 150 g/kg CP, 5.8 g/kg methionine + cysteine, 6.9 g/kg lysine, 7.0 g/kg arginine and 1.6 g/kg tryptophan, and based on daily intake per hen daily 15 g CP, 580 mg/kg methionine + cysteine, 609 mg lysine, 700 mg arginine and 160 mg tryptophan (NRC, 1994).

ANIMAL VERSUS VEGETABLE PROTEIN

To prevent feather pecking behaviour, feed producers often add some animal protein (*e.g.* fish meal, meat and bone meal or milk protein sources) to the diet (Hadorn *et al.*, 1998). It has been suggested that any suppressive effect on feather pecking induced by animal protein is due to something beneficial found only in these protein sources, for instance vitamin B_{12} (McKeegan *et al.*, 2001). However, it is also conceivable that a detrimental compound in plant protein sources could increase feather pecking behaviour.

As an example, phytoestrogens could elevate plasma oestradiol concentrations and affect bird behaviour (McKeegan *et al.*, 2001). Since the ban on meat and bone meal in Europe, the diets of laying hens contain mainly vegetable proteins. In practice, farmers expect a higher occurrence of cannibalism as a result of using vegetable diets; some examples were given by Curtis and Marsh (1992). Diets based on animal (fish meal) or plant (soyabean meal) protein, were fed to layer pullets up to 24 weeks of age (McKeegan *et al.*, 2001). Greater numbers of vigorous pecks/pulls were observed in the plant protein groups throughout the experiment, although they were only significantly higher from week 13 to 16. Pecking damage scores, plasma oestradiol and progesterone, and egg production, however, were unaffected by diet. Laying hens that were fed diets with exclusively vegetable protein sources, such as extracted soybean meal, peas, faba beans and extracted sunflower seed tended to a higher mortality rate due to feather pecking compared with laying hens fed a diet with 4% meat and bone meal (Richter and Hartung, 2003). In contrast with these results, no differences in plumage condition were found in laying hens that were fed diets with either a mixture of vegetable and animal protein or only vegetable protein sources, while the plumage condition of laying hens that were fed exclusively animal protein sources was markedly worse (Pfirter and Walser, 1998). Performance and mortality (including cannibalism) were unaffected by feeding diets with either animal (herring and meat meal) or vegetable (soybean meal extracted) protein sources (Hadorn *et al.*, 1998; Hadorn *et al.*, 1999). Also feeding diets based on either plant (soyabean meal), animal (blood meal, fish meal and hydrolysed feather meal) or semi-purified (casein) protein to growing bantams did not result in differences in pecking damage scores between treatments (Savory, 1998; Savory *et al.*, 1999).

The effect of different protein sources on feather pecking behaviour is summarised in *Table 3*. Although practical evidence suggests a higher incidence of feather pecking in laying hens fed vegetable protein diets, no conformation of this hypothesis can be found in literature.

MINERALS

Magnesium: High magnesium content in layer diets is suggested to reduce feather pecking and cannibalism. Supplementation of 7 g/kg $MgSO_4$ (1.4 g/kg Mg) to a diet low in protein (135 g/kg), as well as in phosphorus (5.3 g/kg) and fibre (26 g/kg) reduced pecking behaviour and mortality due to cannibalism (Schaible *et al.*, 1947). A doubling of the magnesium content (from 1.35 to 2.70 g/kg), however, did not affect mortality due to cannibalism and feather quality (Hadorn *et al.*, 2001). The NRC requirement (NRC, 1994) for magnesium in diets of laying hens is 0.5 g/kg.

Zinc: Supplementation of micro elements, such as aluminium, barium, chromium, copper had no effect on plumage condition and cannibalism of laying hens (0-44 weeks of age) (Willimon and Morgan, 1953). Zinc, however had an effect: adding 0.1 g/kg $ZnCl_2$ (48 ppm zinc) to a zinc-deficient pullet diet (9.5 ppm zinc) improved the feather score from poor to good (Supplee *et al.*, 1958). Supplementing a zinc-deficient diet, containing about 40 ppm zinc, with 52 ppm extra zinc during the first week age reduced the incidence of feather abnormalities of pullets from 5-20 percent to very low levels (Sunde, 1972). Adding 200 ppm $ZnCO_3$ (104 ppm zinc) to a high rice bran (81.5%) layer diet that contained no specific zinc source markedly improved the feather score of the progeny of the layers at 2 weeks of age (Piliang *et al.*, 1984). Thus, in view of today's fast developing pullets, the NRC requirement (NRC, 1994) for zinc in pullet diets of about 40 ppm seems to be marginal for optimal feather development and to avoid feather pecking behaviour.

Sodium: Feeding a low sodium diet (0.4 g/kg) to 2 year old laying hens for only a period of four weeks showed no increase in feather pecking, toe pecking, pecking activity or general activity, compared to a control group fed a diet with 2.3 g/kg sodium, although egg production of the low sodium group almost completely ceased (Hughes and Whitehead, 1974). These authors investigated the effect of different dietary sodium (0.03 g/kg, 0.3 g/kg and 1.3 g/kg) and calcium (29 g/kg, 33 g/kg and 39 g/kg) levels on behaviour and plumage condition of 90-week old laying hens (Hughes and Whitehead, 1979). While the increased calcium levels did not affect cannibalism or feather pecking, cannibalism was seen in birds receiving low (0.03 g/kg) or intermediate (0.3 g/kg) levels of sodium. Cannibalism was not seen in birds receiving the control diet (1.3 g/kg Na). Plumage condition was unaffected by sodium content in the diet, but the birds showed an increased awareness of the environment, resulting in more general pecking. The NRC requirement (NRC, 1994) for sodium in diets of laying hens (1.5 g/kg) seems to give no reason for increased feather pecking behaviour.

The effect of dietary mineral contents on feather pecking behaviour is summarised in *Table 4*. Unfortunately, only a few investigations have been reported on the relationship between mineral contents in diets of laying hens and their feather pecking behaviour. The scarcely available literature, however, shows that deficiencies of dietary minerals can increase feather pecking behaviour and feather abnormalities.

ENERGY CONTENT

The energy content of the diet may also affect feather pecking behaviour. Increasing the dietary energy content of layer diets (10.7, 11.2, 11.7 and 12.2 MJ/kg) resulted in increased energy consumption, a tendency to higher mortality and a significant decrease in feather condition (Elwinger, 1981). Feeding non-beak trimmed laying hens a low density diet (11.05 MJ ME/kg, 51 g/kg crude fat), in which all nutrients were decreased by 5%, improved plumage condition compared to hens that were fed a standard diet (11.55 MJ ME/kg, 65 g/kg crude fat) (Lee *et al.*, 2001). Laying performance was not adversely affected by the lower density diet. Feed intake of the low density diet was higher, resulting in an almost equal energy intake in both diets. This suggests that laying hens fed diets with a lower energy density spent more time on feed intake, and so less time is remaining for feather pecking behaviour. This is in accordance with the results of Savory (1980) who fed male Japanese quail diluted (with 40% cellulose) and undiluted diets. Those receiving the diluted mash consumed about 40% more feed (14.9 vs 10.8 g/d), spent a higher proportion of total time (24 h) on feed intake (23.8 vs 9.1%), had a longer meal length (1.54 vs 0.87 min), a shorter inter-meal interval length (4.98 vs 8.92 min) and more meals per day (128 vs 86). Despite meal length being longer with diluted mash, the weight eaten per meal (av. 0.116 g) was equal to the amount with undiluted mash. However, the two diets had different densities and a much greater volume per meal was consumed with diluted mash than with undiluted mash (0.409 cm^3 vs 0.182 cm^3); this suggests that the difference in meal length was related to dietary bulk. The passage rate through the digestive tract and the emptying of the crop were both about 1.5 times faster with diluted compared to undiluted mash. The undiluted mash was 1.5 times better digestible than the diluted mash (Savory, 1980). The length of the inter-meal interval was closely associated with the difference in rate of feed passage. Savory (1980) suggested that gut-emptying, and particularly filling and emptying of the gizzard or duodenum, could be the main activating mechanism in meal initiation and termination.

The effect of dietary energy content on feather pecking behaviour is summarised in *Table 5*. A low energy content of the diet seems to reduce feather pecking behaviour and to improve plumage condition. However, the different energy levels are confounded with changes in other ingredients, protein and fibre levels, and with differences in meal length and frequency, as well as in passage rate and emptying of gut segments. The optimal dietary energy level for reducing feather pecking while maintaining laying performance remains unknown. However, we expect that a reduction of the dietary energy content of about 10%, compared to a standard level of about 10.6 MJ/kg will markedly reduce the incidence of feather pecking, without negatively affecting the egg production of the hen. Research should be initiated to measure the interaction between the pure effect of energy dilution of a diet and eating time on feather pecking behaviour in laying hens.

FIBRE CONTENT

Fibre helps to maintain normal structure and function of the gastrointestinal tract and prevents cannibalism, and should therefore be included in poultry rations (Esmail, 1997). For decades it is known that an increase in crude fibre content in diets for growing and laying pullets can markedly reduce feather pecking and cannibalism. Increasing the crude fibre content from 29 to 123 g/kg (by substituting corn with oat hulls) decreased feather pecking and cannibalism (Bearse *et al.*, 1940). The oat hull fibre fraction (obtained by dilute acid digestion of the hulls) was as effective as the oat hulls themselves in preventing feather pecking and cannibalism, while the ash of the dilute acid extract and the water extract of oat hulls were of little value in preventing cannibalism. Increasing the crude fibre content in diets of chickens up to 180 g/kg, by substituting oat mill feed by corn, reduced feather pecking rate and mortality, and also improved plumage condition. At a crude fibre content of over 130 g/kg a low incidence of feather pecking and cannibalism was recorded, whereas a high incidence of feather pecking and cannibalism was shown at a crude fibre content of below 80 g/kg (Esmail, 1997).

A number of studies have confirmed that the insoluble fibre fraction in the diets of laying hens is beneficial in preventing pecking behaviour (Aerni *et al.*, 2000; El Lethey *et al.*, 2000; Hartini *et al.*, 2002; Hetland and Choct, 2003b). One experiment showed that both insoluble (mill run) and soluble (barley) fibre were effective in reducing and controlling cannibalism in laying hens (Hartini *et al.*, 2002).

No effects of substitution of corn by wheat in diets for growing and laying pullets on feather pecking and cannibalism were found (Miller and Bearse, 1937). Feather pecking and cannibalism were reduced slightly by substituting barley for corn, and markedly when substituting oats for corn (Miller and Bearse, 1937; Al Bustany and Elwinger, 1988; Abrahamsson *et al.*, 1996; Wahlstrom *et al.*, 1998). The crude fibre content of barley (46 g/kg) and oat (105 g/kg) is substantially higher than corn (22 g/kg) and wheat (24 g/kg) (CVB, 2003).

Birds fed diets high in insoluble fibre spent more time eating and appear calmer than those fed low-fibre diets (Hetland and Choct, 2003b). Insoluble fibre plays an important role in modulating gut development and digestive function. Feeding a supplement of wood shavings (an insoluble fibre-rich raw material) to laying hens fed wheat-based diets increased starch digestibility (Hetland and Choct, 2003b). The improvement of starch digestibility may, in part, be due to enhanced emulsification of lipids as a result of a higher content of bile acids in the gizzard. The total content of bile acids in the gizzard increased in proportion to the amount of wood shavings retained in the gizzard. Consumption of 4% of feed as wood shavings resulted in a 50% percent heavier gizzard of broiler chickens, whereas including 40% whole wheat in a wheat-based mash diet increased the gizzard weight by only 10% (Hetland *et al.*, 2002), indicating that wood shavings has a higher impact on gizzard weight than whole wheat. The insoluble fibre content in the gizzard of chickens fed food shavings was twice as much as the content in the feed (Hetland and Choct, 2003a). This suggests that insoluble fibre accumulates in the gizzard and is retained longer than other nutrients, probably because it has to be ground to a critical particle size before entering the small intestine (Hetland *et al.*, 2002; Hetland and Choct, 2003a). The fact that feeding a mash diet that was diluted with 10% powdered cellulose (an insoluble fibre source) to growing bantams did not affect pecking damage scores compared with an undiluted mash (Savory *et al.*, 1999) could possibly be explained by the small particle size of the powder. Coarse fibre also decreases the passage time of fine particles when it is fed to broiler chickens (Hetland and Svihus, 2001; Svihus *et al.*, 2002). The fact that insoluble fibre accumulates in the gizzard may also indicate a slower feed passage rate when the level of coarse fibre is increased in the diet. This confirms that the gizzard is almost like a point of regulation for digestion, selectively retaining different feed particles and letting nutrients pass for further digestion. It is thought that accumulation of insoluble fibre in the gizzard triggers a temporary satiety, but once passed the gizzard, it passes through the gut quickly. This could make the bird feel more satisfied between feeding bouts, but more hungry after gizzard emptying (Hetland and Choct, 2003b). It can be hypothesized that chickens prefer not just fibre, but coarse fibre. The attractiveness for coarse fibre, such as wood shavings and paper seems to be considerably higher for birds fed a wheat-based diets than for those fed an oat-based diet (Hetland and Svihus, 2003). Since oats contain considerably more coarse fibre than wheat, the data indicate that the birds needed some coarse fibre in their diets, perhaps for gizzard activity (Hetland and Choct, 2003b). In line with this, birds fed an oat-based diet had a significantly heavier gizzard and a larger content of the gizzard compared with those fed a wheat-based diet when housed in cages. The reverse was true for the gizzard weight when the birds were reared under a free range system (Hetland and Svihus, 2003). These results support the hypothesis that, given the opportunity, birds fed low fibre diets will search for coarse materials to satisfy their fibre need. The amount of feathers in the gizzard of individual housed laying hens was higher in laying hens fed a low-structure diet based on rice and casein than in hens fed a diet based on wheat or enriched with coarse fibres. The gizzard content of the birds fed the rice-based diet, however, was markedly less than in hens fed the wheat-based or coarse fibre diets. Until now no causal factors for feather eating are known (McKeegan and Savory, 1999; McKeegan and Savory, 2001), but these results indicate that feather eating and pecking behaviour may be partly related to feed structure, which play a major role in the volume of gizzard contents (Hetland and Choct, 2003a).

The effect of dietary fibre content on feather pecking behaviour is summarised in *Table 6*. Both soluble and insoluble fibre sources seem to affect feather pecking behaviour, although possibly other properties of the fibre-rich raw materials (mostly barley or oats) were determinative for the positive effects. The relationship between fibre content of the ration and prevention of feather pecking is only partially understood. Conceivably, it may be related to the increased consumption of feed resulting in a higher level of satiety, or the time occupied in eating. It was also postulated that ingestion of insoluble dietary fibre would increase gut viscosity and gut fill (Hartini *et al.*, 2002). However, the ideal dietary fibre content and fibre source for reducing feather pecking results while maintaining laying performance remains unknown. It is suggested here that an increase of at least 25% of the dietary insoluble fibre content, compared to a standard NSP (Non Starch Polysaccharides) level of about 140 g/kg, might markedly reduce the incidence of feather pecking due to a possible effect on satiety. This hypothesis should be tested in a trial, in which the effect of different NSP sources and levels on feather pecking behaviour will be measured.

Feeding strategy

FEEDING STRATEGY IN THE REARING PERIOD

The development of the digestive tract during the rearing period, resulting in an appropriate volume and digestive capacity of the gut at the beginning of lay, was suggested to be of great importance in the occurrence of feather pecking and cannibalism during the laying period (Hadorn and Wiedmer, 2001). The volume of the digestive tract (mainly the gizzard) can be increased by feeding coarse particles and/or fibre-rich diets. Similarly feeding whole wheat during the rearing period is thought to increase the digestive capacity of laying hens at the beginning of the lay. Supplementing extra straw or spreading 10% of the estimated feed intake as whole wheat into the litter had no effect on the development of body weight, plumage condition and mortality rate of the pullets (Hadorn and Wiedmer, 2001), but markedly reduced feather damage in the layer period (Blokhuis and Van de Haar, 1992). Distributing grain in the litter during rearing also directed foraging-related behaviours like ground scratching and ground pecking, suggesting that the incentive value of the ground, and the substrate covering it, might be increased with grain during the rearing period (Blokhuis and Van der Haar, 1992). Although feeding strategy during rearing seems to be of importance for feather pecking behaviour in the laying period, few investigations studied this kind of nutritional carry-over effect. In diets of pullets an energy dilution or an increase of (coarse) insoluble fibre may stimulate their feed related behaviour during the rearing period, resulting in less feather pecking behaviour of the laying hens.

FEED FORM

The physical form of the diet, *e.g.* mash, crumble or pellet, and also the distribution of particle size in mash diets, can affect feather pecking behaviour, possibly due to differences in time spending on feed intake. More feather pecking was found in laying hens fed a coarsely ground meal (33-55% of particles > 2mm) compared with laying hens fed a finely ground meal (0-13% of particles > 2mm) (Walser and Pfirter, 2001). Based on the results of this experiment an optimal mash structure should have a normal distribution pattern of fine particles between 0.25 and 2 mm. Addition of whole cereals to mash diets enlarges the average particle size of the diet, which may cause an increasing risk of feather pecking. The type of whole cereal seems to be of importance in affecting feather pecking behaviour: laying hens fed diets containing whole wheat or barley had poorer performance, inferior plumage condition and a higher mortality rate than laying hens fed mash diets, (Al Bustany and Elwinger, 1988). Whole oats or mixtures of whole oats, whole barley and whole wheat resulted in better plumage than did mash diets with ground barley or ground wheat. Possibly, the favourable effects of the high insoluble fibre content of whole oats compensate amply for the adverse effects of whole wheat and barley.

A number of studies have confirmed that laying hens fed pellets are more likely to develop feather pecking than birds fed on mash (Heywang and Morgan, 1944; Bearse *et al.*, 1949; Jensen *et al.*, 1962; Savory, 1974; Lindberg and Nicol, 1994; El Lethey *et al.*, 2000; Walser and Pfirter, 2001). Providing pellets may also decrease the age when feather pecking behaviour is initiated. Incorporating more coarse structure into pellets by adding whole wheat in the mixer before pelletising, however, positively affects plumage condition, gizzard weight and gizzard contents of laying hens, all indicators of better welfare (Hetland *et al.*, 2003). The coarse wheat particles seem to accumulate in the gizzard, which possibly trigger a temporary satiety. In contrast, when pullets were kept in pens with litter-covered floors, feed form (mash or pellet) exhibited no significant effect on feather pecking (Savory and Mann, 1997). In another study, feather pecking behaviour was equal in laying hens fed on crumbles or mash (Wahlstrom *et al.*, 2001). Since feeding pellets had dissimilar effects on feather pecking in different studies, interaction effects of pellets with other factors, *e.g.* housing conditions, is highly probable.

There may be an interaction between feed form and available floor space: in pullets, feather pecking was only observed in two of the six groups receiving a pelleted diet (Heywang and Morgan, 1944) and feather pecking stopped when these two groups were removed from the houses to yards where they had more floor space. According to the authors space explained the reduction of feather pecking. However, apparently other environmental factors, like changes in temperature and the availability of daylight were confounded with space. Also a significant interaction was shown between foraging material (with or without long straw) and food form (mash or pellet) (Aerni *et al.*, 2000). High rates of feather pecking and pronounced feather damage were only found in laying hens housed without straw and fed on pellets, indicating that laying hens (especially when fed pellets) should be provided with an adequate amount of foraging material. Laying hens with access to foraging material also had a lower heterophil-to-lymphocyte ratio and an increased immune response to immunisation than those without access to such materials, indicating lower stress in these birds (El Lethey *et al.*, 2000).

Chickens engage in more feed directed behaviour when fed finely ground mash than when fed coarsely ground mash, crumbles or pellets (Savory, 1974; Savory, 1995; Aerni *et al.*, 2000; Walser and Pfirter, 2001). Similarly, laying hens in individual cages spent more time on feed intake as the particle size of the diet decreased (100 minutes per day for pellets, 154 for crumbles and 234 for mash) (Tanaka *et al.*, 1983). The frequency of feed pecking also increased with decreasing particle size: 9,723 times per day for pellets, 15,874 for crumbles and 22,845 for mash, with an average feed intake of 11.8, 7.4 and 5.2 gram per peck. Laying hens that were fed a high volume mash pecked feed more frequently and feathers less than birds fed a low volume mash (Bessei, 1983). Feeding pelletised diets resulted in two times more pecks directed to a bundle of feathers (Bessei *et al.*, 1999), or more time spent on perching, whereas more feeding directed behaviours (sum of time spent on feeding and foraging) were recorded in hens fed on mash (Aerni *et al.*, 2000). Spending more time eating will fulfil the need of the foraging behaviour of the laying hens, which may lead to a decrease in feather pecking (Blokhuis and Arkes, 1984).

The effect of feed form on feather pecking behaviour is summarised in *Table 7*. It seems that a too high amount of coarse particles or pellets in the diet may cause an increasing risk of feather pecking behaviour compared to mash diets, possibly due to spending less time on feed intake. Feeding strategies that result in laying hens spending more time on feed intake and foraging could decrease the risk of feather pecking behaviour.

FEED RESTRICTION

Freezing the feed consumption of cage-housed pullets at the *ad libitum* level of intake at six weeks of age until the age of sixteen weeks resulted in the same amount of time spending on pecking at food and non-food objects as pullets fed ad libitum (Savory and Fisher, 1992). There was no evidence that this 'freeze-feeding' was associated with increased bird-to-bird pecking, either aggressively or non-aggressively. Thus, the time freeze-fed birds spent pecking at non-food objects, appeared to substitute the time they would otherwise spent on feeding. However, laying hens housed as pairs in cages with no access to feed from 07:30 to 15:30 h each day, spent 23% of their time on stereotypic behaviour like cage-pecking, feather pecking and pacing when feed was unavailable, whereas ad libitum fed hens spent 7% of their time on these behaviours (Preston, 1987). Hens fed ad libitum showed a tendency for more feather- and cage pecking before 07:30 h than the hens with limited access to feed. Hens fed *ad libitum* and those fed 6% less feed showed no difference in plumage condition (Elwinger and Andersson, 1978). Feed intake was expected to affect feather pecking behaviour, with more feather pecking in birds that spent less time on feed intake. However, the changeable effects of feed restriction on feather pecking has been shown, in the literature, to vary.

SUPPLYING ROUGHAGES

Roughage supplements may reduce feather pecking in birds (Hoffmeyer, 1969; Köhler *et al.*, 2001; Steenfeldt *et al.*, 2001). Supplements of cut green clover and branches with green leaves as roughage sources, given to young pheasants (five and ten weeks old), led to significantly less feather pecking than in the controls (Hoffmeyer, 1969). Mutual comparison of the two roughage sources (branches with green leaves and cut green clover spread on the floor) in pheasants of ten weeks old showed markedly less feather pecking in the clover group. The amount of feather pecking was inversely correlated with the amount of pecking directed at the supplemented source. The pheasants treated the leaves and other roughages in the same way as feathers, indicating a great similarity between the behaviour shown in feather pecking and the normal feeding behaviour (Hoffmeyer, 1969). Roughages, which are a normal target for the pheasant food pecking activity in natural habitats, must provide a sign for stimulating feeding behaviour. Feathers may provide some of the sensory stimuli (optical, tactile) to which the (innate) feeding response mechanisms of pheasants are specially attuned (Hoffmeyer, 1969). Based on these experiments Hoffmeyer (1969) concluded that feather pecking is a substitute for normal feeding behaviour.

Carrots, maize-silage and barley-pea-silage were supplied to laying hens from 20-54 weeks of age to examine the effect of supplementing roughages on performance, gastro-intestinal health and feather pecking behaviour (Steenfeldt *et al.*, 2001). At 24 weeks of age, treatments differed significantly in the incidence of feather pecking, with less gentle and severe feather pecking in hens fed carrots or maize-silage compared to the control group. At 53 weeks of age, differences in feather pecking were non-significant but similar tendencies were still observed. Hens fed the silage had the best plumage condition at 53 weeks of age. In line with this, hens given ad libitum access to fresh grass had better plumage condition than those without (Köhler *et al.*, 2001). Roughage supplementation did not affect egg production (except for barley-pea-silage) and feed efficiency, but significantly decreased mortality rate (Steenfeldt *et al.*, 2001). Roughage supplementation significantly decreased pH in the caecum, probably caused by a higher fermentation rate in this part of the gastro-intestinal tract (Steenfeldt *et al.*, 2001). The positive effects of roughage supplementation could possibly be explained by a lower dietary density and/or an increased crude fibre content of the diet. Supplementing the diets with carrots (in the experiment of Steenfeldt et al., 2001) decreased the density of the diet by about 40%. This could be an explanatory factor, especially since the roughages increased the total consumption of the laying hens, which could be an indication of spending more time on feed intake. Regrettably, Steenfeldt et al. (2001) showed no data concerning distribution of time spent on different types of behaviour. Conceivably, the positive effects may be related to other nutrients than dietary density and/or crude fibre.

The effect of roughage supply on feather pecking behaviour is summarised in *Table 8*. Supplying roughages to laying hens seems to be a promising approach to reduce feather pecking behaviour (though there is scarce literature on this). The relationship of roughage intake and feather pecking, however, is only partially understood.

Summarising conclusion

Nutritional factors may positively or negatively affect feather pecking behaviour in laying hens. Indeed, some investigations show that feather pecking behaviour is a substitute for normal feeding behaviour. Until now, the mode of action of these nutritional factors is not fully understood. Dietary deficiencies, resulting in a marginal supply of nutrients, such as protein, amino acids, or minerals, may increase feather pecking behaviour and cannibalism. Nutritional factors seem to reduce feather pecking behaviour in laying hens if these factors increase the time spent on feeding behaviour, by affecting foraging and feed intake. Laying hens may spend more time on these feeding behaviours when they are fed 1) mash diets in stead of crumbles or pellets, 2) low energy diets, 3) high (in-)soluble fibre diets or 4) roughages. Further research, especially directed to the role of dietary density and (coarse) insoluble fibre, is needed to better understand the impact of nutritional factors on feather pecking behaviour and thus, welfare of layers. Future research should focus on the interaction effects between energy level, insoluble fibre and particle sizes of the insoluble fibre on foraging time and passage rate, as being assumed indicators for developing feather pecking behaviour.

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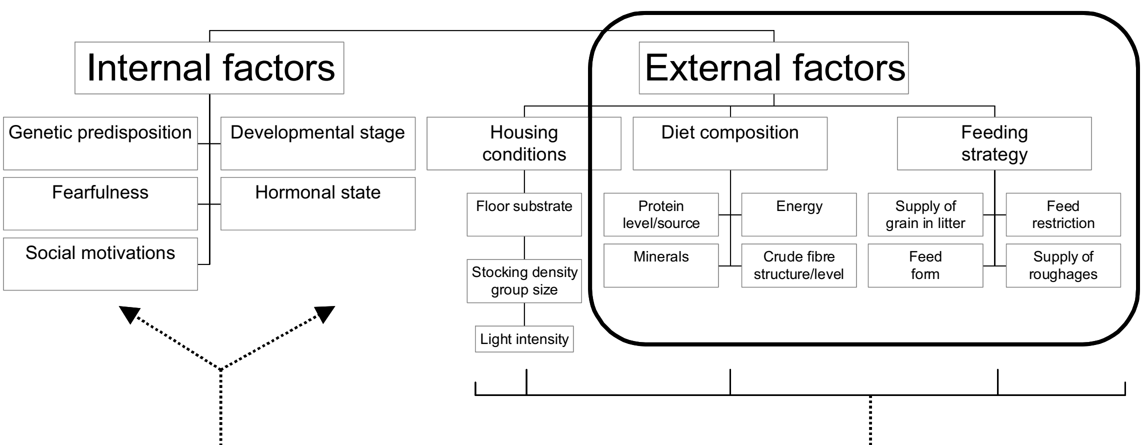

Figure 1 Factors affecting feather pecking behaviour.

Table 1 Effect of dietary crude protein, lysine and/or methionine levels (g/kg) on plumage condition, occurrence of feather pecking and mortality in birds.

Type of bird[1]	Period of age (weeks)	Beak-trimmed	Crude Protein	Total Lysine	Total Methionine + Cysteine	Plumage Condition[2]	Level of feather pecking[3]	Mortality (%)	Authors
Laying hens; LSL and SH	16 – 58	No	135 and 169	5.9 and 8.7	5.1 and 6.7	4.0 and 6.6	3.3 and 3.9[4]	2.3 and 3.9 (n.s.)	Elwinger *et al.*, 2002
Laying hens; ISA brown, NH, WL, NH x WL	16 - 43	No	154	8.1	4.2 and 8.2	9.0 and 9.3 (n.s.)	Not recorded	Not available	Kjaer and Sorensen, 2002
Laying hens; WL and Brown layer strain	20 - 60	No	111 - 193	4.2 - 9.5[4]	4.2 - 7.9[5]	4.5 - 7.0	Not recorded	17.6 - 2.5	Ambrosen and Petersen, 1997
Laying hens; 3 x WL (Hisex, LSL, Shaver), WL x RIR, WL x (WL x RIR)	20 - 80	Yes	124 - 176	4.6 - 8.7	Not recorded	4.1 - 6.1	Not recorded	12.4 - 10.0 (n.s.)	Al Bustany and Elwinger, 1987a Experiment 1
Laying hens: 2 x WL (LSL, Shaver), RIR, WL x RIR	20 - 80	Yes	134 - 177	5.8 - 8.8	Not recorded	4.1 - 6.3	Not recorded	8.4 - 6.9 (n.s.)	Al Bustany and Elwinger, 1987a Experiment 2
Laying hens: RIR, Shaver, WL x RIR	20 - 80	Yes	123 - 177	5.6 - 9.4	Not recorded	4.5 - 6.2	Not recorded	7.5 - 10.4 (n.s.)	Al Bustany and Elwinger, 1987b
Laying hens: WL and RIR	32 - 72	Yes	124 - 176	4.6 - 8.7	Not recorded	7.5 - 7.7 (n.s.)	Not recorded	Average 8.4 (n.s.)	Al Bustany and Elwinger, 1986

[1]Explanation of abbreviations: NH = New Hampshire, WL = White Leghorn, LSL = Lohmann Selected Brown, RIR = Rhode Island Red
[2]Original data recalculated to a scale of 0 to 10 where 0 indicates almost naked and 10 an intact plumage
[3]Original data recalculated to a scale of 0 to 10 where 10 indicates no observed injuries
[4]Peck injuries to cloacae/rear body parts at 58 weeks ranging from score 1 to 4 where 4 indicates no observed injuries
[5]Based on own recalculation of the diets

Table 2 Effect of dietary tryptophan levels (g/kg) on plumage condition, occurrence of feather pecking and mortality in birds.

Type of bird	Period of age (weeks)	Beak-trimmed	Tryptophan content	Plumage Condition[1]	Level of feather pecking	Mortality (%)	Authors
Pullets:	1 - 7	No	1.6	Not recorded	137.7/16[2]	Not recorded	Van Hierden *et al.*, 2003
White Leghorns (WL)			21.0		65.0/9.4[2]		
(Low and high feather pecking line)							
Bantams	1 - 6	Unknown	2.6	3.8	Not recorded	0	Savory *et al.*, 1999
			12.6	5.3		0	
			22.6	5.9		0	

[1]Original data recalculated to a scale of 0 to 10 where 0 indicates almost naked and 10 an intact plumage
[2]Respectively number of gentle and severe feather pecks in 30 minutes.

Table 3 Effect of protein source (animal versus vegetable protein) on plumage condition, occurrence of feather pecking and mortality in birds.

Type of bird	Period of age (weeks)	Beak-trimmed	Protein source	Plumage Condition[1]	Level of feather pecking	Mortality (%)	Authors
Laying hens:	21 - 72	Unknown	Soyabean meal	9.2	Not recorded	3.3	Hadorn *et al.*, 1998;
LSL White			Fish meal/meat meal	9.2		2.2	Hadorn *et al.*, 1999
Bantams	0 - 6	Unknown	Soyabean meal (30%)	6.1	Not recorded	Not recorded	Savory *et al.*, 1999
			Fish meal (6%), Blood meal (3.2%), Feather meal (5.2%)	4.7			
			Casein (8.4%)	5.7			
Laying hens:	Period of 40	Unknown	Soyabean meal (7.5%), potato protein (6%)	6.7	Not recorded	Not recorded	Pfirter and Walser,
ISA brown,	weeks		Soyabean meal (3%), potato protein (6%), Meat meal (4%)	7.7			1998
Lohmann brown			Potato protein (3%), meat meal (3%), blood meal (3%), fish meal (1.5%)	5.6			

[1]Original data recalculated to a scale of 0 to 10 where 0 indicates almost naked and 10 an intact plumage

Table 4 Effect of dietary mineral levels on plumage condition, occurrence of feather pecking and mortality in birds.

Type of bird	Period of age (weeks)	Beak-trimmed	Mineral	Plumage Condition[1]	Level of feather pecking	Mortality (%)	Authors
Laying hens: Isa brown	21 - 62	No	Magnesium / Crude fibre	n.s.	Not recorded	n.s.	Hadorn *et al.*, 2001
			1.35 g/kg/ 40 g/kg	5.7		17.3	
			2.7g/kg / 40 g/kg	5.5		15.7	
			1.35 g/kg/ 25 g/kg	4.9		18.6	
			2.7 g/kg / 25 g/kg	5.7		14.9	
Pullets; Leghorn	0 - 8	Unknown	0 and 7 g/kg $MgSO_4$	3.3 and 3.3	27 and 8% [2]	31 and 21% [3]	Schaible *et al.*, 1947
Breeder layers: feather development scored on progeny	2	Unknown	0 and 200 ppm $ZnCO_3$	4.1 and 9.2	Not recorded	Not recorded	Piliang *et al.*, 1984
Laying hens: (Babcock and Warren SSL)	93 - 98	Unknown	0.03 g/kg Sodium	9.0	9.2%		Hughes and Whitehead, 1979
			0.3 g/kg Sodium	8.7	9.5%		
			1.3 g/kg Sodium	8.7 n.s.	2.3% [4]		

[1]Original data recalculated to a scale of 0 to 10 where 0 indicates almost naked and 10 an intact plumage
[2]Percentage of chickens picked, but alive
[3]Percentage of chickens killed by picking
[4]Percentage of birds that had to be removed because of injurious pecking

Table 5 Effect of dietary energy levels (MJ/kg) on plumage condition, occurrence of feather pecking and mortality in birds.

Type of bird [1]	Period of age (weeks)	Beak-trimmed	Energy content Exp. 1	Energy content Exp. 2	Plumage Condition [2] Exp. 1	Plumage Condition [2] Exp. 2	Level of feather pecking	Mortality (%) Exp. 1	Mortality (%) Exp. 2	Authors
Laying hens: SCWL, Hisex, LSL	18 - 70	Unknown	10.7	10.7	4.4	3.7	Not recorded	8.8	7.4	Elwinger, 1981
			11.2	11.2	3.4	4.2		13.0	10.5	
			11.7	11.7	4.0	2.9		12.0	10.4	
			12.2	12.2	3.3	3.0		11.7	11.0	
Laying hens: (LSL and Bovans Goldline)	30 - 52	No	11.05		8.1		Not recorded	Not recorded		Lee *et al.*, 2001
			11.55		7.3					

[1]Explanation of abbreviations: SCWL = Single Comb White Leghorns, LSL = Lohmann Selected Leghorn
[2]Original data recalculated to a scale of 0 to 10 where 0 indicates almost naked and 10 an intact plumage

Table 6 Effect of dietary fibre levels (g/kg) on plumage condition, occurrence of feather pecking and mortality in birds.

Type of bird [1]	Period of age (weeks)	Beak-trimmed	Fibre Source	Fibre content (g/kg)	Plumage Condition [2]	Level of feather pecking [3]	Mortality (%)	Authors
Laying hens: ISA brown	17 – 20	50% yes 50% no	Control (73% wheat)	29.3	Not recorded	Not recorded	13.2	Hartini *et al.*, 2002
			Millrun [4] (32%) and Sorghum (48%)	43.4			3.9	
			Barley (76%)	51.6			5.8	
			Barley + enzyme (76%)	51.6			4.1	
Laying hens: ISA brown	21 – 24	50% yes 50% no	Control (73% wheat)	29.3	Not recorded	Not recorded	28.9	Hartini *et al.*, 2002
			Millrun [4] (32%) and Sorghum (48%)	43.4			14.3	
			Barley (76%)	51.6			15.9	
			Barley + enzyme (76%)	51.6			17.8	
Laying hens: LSL and Lohmann brown	20 – 80	No	Wheat diet (25% wheat, 10% oats)	44	Not recorded	Not recorded	18.4	Wahlstrom *et al.*, 1998a (exp. 1)
			Oats diet (0% wheat, 33% oats)	64			13.4	
Laying hens: LSL, Lohmann brown and SLU	20 – 80	No	Oats/wheat ratio:			Not recorded		Wahlstrom *et al.*, 1998b (exp. 2)
			0/60	21.8	7.8		8.9	
			12/48	38.3	8.1		10.8	
			24/36	48.6	8.3		8.4	
			36/24	58.8	8.9		10.9	
			48/12	68.9	9.0		10.8	
			60/0	79.2	9.1		12.8	
Laying hens: ISA brown and LSL	18 – 80	Unknown	Wheat/barley ratio			Not recorded	n.s.	Abrahamsson *et al.*, 1996
			50/13.7	36.0	3.6		15.8	
			25/38.7	40.0	5.1		16.5	
Laying hens: LSL and L324	20 – 73	Unknown	Wheat diet (72% wheat)	25.5	3.8	Not recorded	8.8	Al Bustany and Elwinger, 1988
			Barley diet (74% barley)	39.0	4.1		8.8	
			Oats diet (75% oats)	69.0	5.1		7.2	
Laying hens: SCWL)	2 – 40	Unknown	Corn (81% corn)	29.1	Not recorded	100 [5]	3.9 / 8.7 [6]	Bearse et al., 1940
			Corn /oat hull fibre (23% oat hull fibre)	110.7		5.8	4.0 / 13.4	
			Corn/oat hulls (34.5% oat hulls)	122.6		2.3	0.8 / 3.7	
Laying hens: SCWL	2 – 40	Unknown	Wheat (80%)	32.9 [7]	Not recorded	92.3 [5]	0.0	Miller and Bearse, 1937
			Corn (80%)	31.2		97.0	1.7	
			Barley (78%)	51.2		73.2	0.0	
			Oats (81%)	100.1		0.0	0.0	

[1]Explanation of abbreviations: LSL = Lohmann Selected Leghorn, SLU = cross-bred of Leghorn x Rhode Island Red, SCWL = Single Comb White Leghorn, L324 = cross-bred of White Leghorn x Rhode Island Red
[2]Original data recalculated to a scale of 0 to 10 where 0 indicates almost naked and 10 an intact plumage
[3]Number of pecking interactions per bird per hour
[4] (2/3 wheat bran, 1/3 wheat pollard)
[5]Percentage of birds pecked at 40 weeks of age
[6]Percentage mortality in growing period and after 16 weeks of laying period respectively
[7]Based on own recalculation of the diets

Table 7 Effect of feed structure on plumage condition, occurrence of feather pecking and mortality in birds.

Type of birds [1]	Period of age (weeks)	Beak-trimmed	Feed structure	Plumage Condition [2]	Level of feather pecking [3]	Mortality (%)	Authors
Laying hens:	16 - 68	No	Pellets	2.4	Not recorded	8.8	Hetland *et al.*, 2003a
LSL and Shaver			Pellets; whole wheat (40%) in mixer before pelleting	3.7		8.8	
Laying hens:	19 - 27	No	Pellets	7.8	3.9	Not recorded	Aerni *et al.*, 2000
LSL			Mash	9.4	0.7		
Bantams	1 - 6	Unknown	Pellets	6.5	Not recorded	Not recorded	Savory *et al.*, 1999
			Mash	9.4			
			Diluted Mash (40% cellulose powder)	9.6			
Laying hens:	20 - 73	Unknown	Mash and whole cereals	Mash/whole	Not recorded	Mash / whole	Al Bustany and Elwinger, 1988
LSL and L324			Barley	4.9 / 3.3		6.6 / 10.9	
			Wheat	4.6 / 3.1		8.1 / 9.4	
			oats	n.r./5.1		n.r. / 7.2	

[1]Explanation of abbreviations: LSL = Lohmann Selected Leghorn, L324 = cross-bred of White Leghorn x Rhode Island Red
[2]Original data recalculated to a scale of 0 to 10 where 0 indicates almost naked and 10 an intact plumage
[3]Number of pecking interactions per bird per hour

Table 8 Effect of roughage supply on plumage condition, occurrence of feather pecking and mortality in birds.

Type of bird	Period of age (weeks)	Beak-trimmed	Source of Roughage	Plumage Condition [1]	Level of feather pecking [2]	Mortality (%)	Authors
Laying hens:	20 - 54	Unknown	Control diet (pellet)	5.9	1.08	15.3	Steenfeldt *et al.*, 2001
ISA brown			Maize-silage	8.9	0.36	1.5	
			Barley-pea-silage	9.5	0.71	2.5	
			Carrots	7.5	0.69	0.5	
Laying hens:	20 - 33	Unknown	Control (all-mash)	6.6	Not recorded	Not recorded	Köhler *et al.*, 2001
Lohmann brown			Fresh grass	7.2			
Laying hens:	19 - 27	No	Without straw	7.8	4.2	Not recorded	Aerni *et al.*, 2000
LSL (Lohmann Selected Leghorns)			Long-cut straw (foraging material)	9.4	0.8		
Pheasant chickens	3	Unknown	Control vs. clover	6.5 vs.10.0	Not recorded	Not recorded	Hoffmeyer, 1969
	5		Control vs, clover	6.1 vs. 8.8			
	10		Branches with leaves vs. clover	5.5 vs. 1.8			
	5		Green plastic band	4.8			
			Branches with green leaves	6.8			
			Green clover	8.4			

[1]Original data recalculated to a scale of 0 to 10 where 0 indicates almost naked and 10 an intact plumage
[2]Pecks per bird per hour