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Risk Factors for the Occurrence of Feather Pecking in Non-Beak-Trimmed Pullets and Laying Hens on Commercial Farms

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Abstract: Severe feather pecking (SFP) is a behavioral disorder, for which there are multifactorial reasons. Various aspects of pullet and laying-hen husbandry—including housing conditions, management, feeding, and genetics—must be considered, to prevent negative outcomes, such as severe plumage damage, skin injuries, and high mortality rates due to SFP. The aim of this study was to identify housing and management factors in the occurrence of feather pecking, so as to reduce the risk of this behavioral disorder in non-beak-trimmed laying hens on commercial farms with aviaries. Beak trimming may reduce the extent of plumage damage, but it does not prevent feather pecking and cannibalism. Thirty non-beak-trimmed flocks (16 in the first, and 14 in the second laying period) were investigated on 16 commercial farms in Germany. Each flock was visited twice during rearing, and three times during the laying period. During each visit, individual plumage and integument scoring were performed, and data were collected, regarding the housing and management conditions of the flocks. To analyze the influence of management and housing on the plumage condition of the rearing and laying flocks, models were calculated, using univariate multifactorial analysis. In the rearing period, high stocking density and poor litter quality were significant risk factors in plumage damage due to SFP. In the laying period, a lack of free range, poor litter quality, insufficient enrichment, and plumage damage during rearing were significant risk factors for the development of SFP. An individual risk analysis of pullet and layer farms is therefore strongly recommended, to prevent outbreaks of SFP and cannibalism, especially in non-beak-trimmed birds.

Keywords: severe feather pecking; animal welfare; behavior; poultry

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1. Introduction

Severe feather pecking (SFP) is defined as pecking, pulling, and removing of feathers [1]. It seems to be enhanced in conditions where birds have difficulty in coping with environmental stressors [2,3]. Feather pecking in laying hens may be considered a behavioral disorder, similar to human psychopathological disorders, and is triggered by low 5-hydroxytryptamine neurotransmission. It has a repetitive and compulsive character. The postsynaptic serotonin receptors involved in feather pecking are different to those in aggressive pecking [4]. There is some evidence that feather pecking is redirected ground pecking, deriving either from a foraging or a dust bathing background [2,5–7]. Frustration can be caused by the hindrance of performing foraging and ground pecking. This may lead to misdirected pecking behavior on the plumage of other birds in the barn, especially in an insufficiently enriched environment [5,7–15]. Flocks with high litter-pecking rates show less SFP, and vice versa. Pullets that are active during rearing, and spend more time foraging and less time resting and dust bathing, tend to become feather peckers later in life [16]. The occurrences of SFP, but not characteristics such as anxiety or social behavior, are very specific for different hybrid lines, owing to genetic differences. Several authors have supported genetic selection as a method to reduce SFP, and to promote desirable characteristics in laying hens [17–23]. Another study, however, found SFP to be related to low fearfulness, and the authors concluded that this might indicate a complex interplay between fearfulness, activity, and coping style that could play a role in the development of SFP [24]. Housing and management in the rearing period may affect the occurrence of SFP later in life [25–31]. There is some evidence that feather-pecking hens that are already feather pecking as pullets show more SFP during the laying period [1]. The plumage condition of laying hens in the 35th week of life is significantly better if there is no feather pecking during rearing [27]. Similarly, laying hens have a 90% probability of beginning SFP if there has been plumage damage during rearing [26]. However, Newberry et al. [16] did not find a significant correlation between SFP during the rearing period and the laying period. A high rate of SFP in the rearing period may be predictive of plumage damage later in life, but the same study did not find an effect of enrichment on plumage damage [25]. Behavior observations of pullets on a commercial farm revealed the positive effect of lower stocking density and the provision of enrichment on reducing the prevalence of feather pecking [32]. Lower stocking densities reduce the probability of SFP [26,33,34]. A study in 50 rearing units in Germany and Austria found several risk factors of SFP: high stocking density (mean: 15 pullets per square meter of useable area); access to litter only after the second week of life; and access to raised perches only after the fourth week of life [35]. Variation of stocking densities at a high level (all flocks >17 pullets per square meter of usable area) did not influence plumage condition, but the provision of enrichment (pecking stones, hay bales) had a positive influence at the end of the rearing period [36]. Von Eugen et al. [37] investigated behavioral and physiological parameters in relation to conventional crowded, undercrowded, and overcrowded stocking densities, and concluded that conventional stocking densities (500 cm^2 per pullet = 20 pullets per square meter of usable area) did not seem to impair the state of welfare in pullets. However, a threefold increase in stocking density did result in a slower rate of adaptation, and the authors concluded that there could be long-term consequences from both the different stocking densities and the increased costs of adaptation [37]. Provision of litter and sufficiently high perches were found to be preventative for SFP in a review [30]. Housing and management factors play an important role during the laying period as well [28,30,38]. A field study on 107 laying-hen flocks in Europe found that lower dietary protein content, and no daily access to free range, had an influence on feather damage in brown hens [39]. This finding is in line with other studies [1,30,33,40–42]: laying hens in free-range housing had less plumage damage than birds kept in aviaries [30,43], especially if the extra space was used extensively by the laying hens [1,44]. In a French field study of 80 free-range flocks, feather cover was associated with use of the outdoor run, lighting program, genotype, farm location, and date of housing construction [45]. In a Bavarian survey, the prevalence for SFP was 18.5% (293 flocks on 147 farms), and was related to the farming system, the presence of roosters, the locking of laying hens into the aviary, not allowing access to the entire litter space after housing, and the nervous or chasing behavior of laying hens [46].

Larger flocks are associated with more SFP [1,5,16]. A lower drinking place per hen ratio might predict SFP during the laying period [47], but this finding may have been an indirect effect [30]. Another study found that a high percentage of SFP was observed on perches [48]. A lack of perches, in combination with plastic grids on the aviary tiers, increased the percentage of hens with missing feathers [47]. Perches installed well above head height of the birds helped to improve their plumage condition [30,47]. There is some evidence that litter [49] and environmental enrichment, such as pecking stones, reduce SFP, but this effect may also be due to other management factors [50]. Enrichment such as pecking stones and alfalfa bales may have diverging effects between strains, and future practical recommendations for laying-hen husbandry should be strain-specific [51]. A meta-analysis confirmed the modest effectiveness of environmental enrichment in reducing SFP and, subsequently, plumage damage, but suggested that other management strategies must be implemented to reduce SFP [52].

Feather pecking, however, is a multifactorial problem, and different studies often identify contradictory findings [52,53]. An individual risk analysis is therefore recommended [43,54,55], including feeding [54], which might help to forecast SFP during the laying period [55]. Management-based measures have the potential to improve hen welfare regarding injurious pecking [29,43], and good compliance with recommendations may prevent SFP [29,42,56]. This study was conducted to identify housing and management factors in the occurrence of feather pecking in non-beak-trimmed laying hens on commercial farms with aviaries. Although beak trimming may reduce the extent of plumage damage, it does not prevent feather pecking and cannibalism [35]. This practice has been banned or has ceased voluntarily in several European countries, including Austria, Denmark, Finland, Germany, and Norway [28,56,57]. Therefore, an important aim of this study was to investigate the possible risk factors of SFP in non-beak-trimmed pullets and laying hens.

2. Materials and Methods

2.1. Animals and Farms

In the first laying period, 16, and in the second laying period, 14 non-beak-trimmed flocks were investigated. They comprised hens of the hybrid lines Lohmann Brown, Lohmann Brown Extra (both abbreviated as LB), Lohmann Selected Leghorn (LSL), Bovans Brown (BB), and Dekalb White (DW), kept in either homogeneous (one hybrid line per flock) or mixed (one brown and one white hybrid line) flocks (Tables 1 and 2).

Table 1. Overview of the rearing flocks. Flock numbers were the same for rearing and laying periods. For flocks 11 and 16, only the first rearing period was studied; for flock 2, only pullets of the second rearing period were plumage-scored. Pullets for layer flocks 8, 9, 12, 13, and 14 were raised on different farms for the first and second laying period. Abbreviations: RV = rearing visit (week of life).

Flock No.	Housing for Rearing	Rearing Period	Hatch Date (dd.mm.yyyy)	RV1	RV2	Flock Size	Stocking Density (Pullets/m^2 Usable Area)
1	Aviary	1	26.03.2012	12	15	3670	19.0
		2	12.08.2013	10	17	3000	15.5
2	Ground floor	1	06.10.2011	-	-	-	21.9
		2	10.12.2012	11	17	9100	11.9
3	Aviary	1	14.03.2012	12	19	2940	23.1
		2	12./14.03.2013	9	16	3200	24.5
4	Aviary	1	27.12.2011	12	18	4200	14.1
		2	07.12.2012	9	16	4300	14.9
5	Aviary	1	27.12.2011	12	18	4200	14.1
		2	07.12.2012	9	16	4300	14.9
6	Aviary	1	27.01.2012	12	18	21,270	12.8
		2	01.02.2013	10	16	21,630	13.0
7	Ground floor	1	04.05.2012	11	17	4600	16.8
		2	15.04.2013	11	18	1670	12.3
8	Aviary	1	20.02.2012	13	18	2050	21.8
	Aviary	2	27.03.2013	11	20	1470	23.5

Table 1. *Cont.*

Flock No.	Housing for Rearing	Rearing Period	Hatch Date (dd.mm.yyyy)	RV1	RV2	Flock Size	Stocking Density (Pullets/m^2 Usable Area)
9	Aviary	1	31.12.2011	11	16	2000	19.5
	Aviary	2	28.12.2012	10	18	37,000	31.6
10	Aviary	1	31.12.2011	11	16	2000	19.5
		2	18.02.2013	10	17	5200	29.6
11	Aviary	1	03.03.2012	11	19	2200	24.9
		2	-	-	-	-	-
12	Aviary	1	10.04.2012	12	17	2700	17.7
	Ground floor	2	09.05.2013	11	17	13,390	16.5
13	Aviary	1	14.01.2012	9	17	1600	20.4
	Aviary	2	20.05.2013	12	17	1310	23.5
14	Aviary	1	15.04.2012	13	18	5220	21.8
	Aviary	2	25.02.2013	10	16	5150	24.9
15	Aviary	1	18.04.2012	12	16	900	13.4
		2	11./12.09.2013	10	18	1066	15.7
16	Ground floor	1	04.05.2012	11	19	4600	16.8

Table 2. Overview of the layer flocks. All flocks were housed in aviaries. Flocks 11 and 16 were only studied in the first laying period. Abbreviations: DW = Dekalb White; BB = Bovans Brown; LB = Lohmann Brown or Lohmann Brown Extra; LSL = Lohmann Selected Leghorn; HFN = high-frequency neon tube; LED = light-emitting diode; LV = laying visit (week of life).

Flock No.	Additional Space	Laying Period	LV1	LV2	LV3	Hybrid Line(s)	Flock Size	Daylight/Artificial Light Type/Color
1	None	1	31	46	66	BB (15%) DW (85%)	3589	No/HFN/white
		2	33	48	67	BB (20%) DW (80%)	2890	
2	None	1	31	48	68	LB	4250	Yes/HFN, LED/white
		2	33	46	65	LB	4018	
3	None	1	33	45	65	LB	5453	Yes/HFN, lightbulbs/white
		2	32	45	65	LB	5336	
4	Free range + winter garden	1	31	46	65	LSL	5897	Yes/HFN, LED, lightbulbs/white
		2	32	46	67	LB (50%) LSL (50%)	5912	
5	Free range + winter garden	1	30	46	65	LB	5044	Yes/ HFN, LED, lightbulbs/white
		2	30	45	66	LB (50%) LSL (50%)	5065	
6	Free range + winter garden	1	31	45	66	LB	4194	Yes/ HFN, LED, lightbulbs/white
		2	30	45	67	LB	4234	
7	Free range	1	33	44	65	LB (50%) DW (50%)	1450	Yes/LED, lightbulbs/white, yellow
		2	33	46	53	BB (50%) DW (50%)	1450	
8	Free range	1	32	48	66	LB (50%) LSL (50%)	2004	Yes/lightbulbs/white
		2	31	47	68	LB (50%) LSL (50%)	2100	
9	Free range + winter garden	1	30	46	68	LB (75%) LSL (25%)	2000	Yes/HFN, lightbulbs/white
		2	32	44	67	LB (63%) LSL (37%)	1999	

Table 2. *Cont.*

Flock No.	Additional Space	Laying Period	LV1	LV2	LV3	Hybrid Line(s)	Flock Size	Daylight/Artificial Light Type/Color
10	None	1	31	46	65	LB	4500	No/HFN, lightbulbs/white
		2	32	47	61	LB	5194	
11	None	1	32	45	64	LB	5700	Yes/HFN/white
		2	-	-	-	-	-	
12	None	1	33	47	65	LB	5746	No/HFN, LED/white
		2	32	47	66	LB	5261	
13	Winter garden	1	31	46	66	LB (50%) LSL (50%)	2963	Yes/HFN, lightbulbs/white
		2	30	48	67	LB (50%) LSL (50%)	1500	
14	None	1	33	45	62	LB	5020	Yes/HFN/white
		2	31	47	66	LB	4954	
15	None	1	33	45	65	LB	4200	Yes/HFN/white
		2	32	46	67	LB	1550	
16	Winter garden	1	33	44	65	LB (50%) DW (50%)	2200	Yes/HFN, lightbulbs/white
		2	-	-	-	-	-	

In the rearing period, each flock was visited twice: rearing visit 1 (RV1), between the 9th and 13th week of life; and rearing visit 2 (RV2), between the 15th and 20th week of life (at the end of the rearing period). In the course of the laying period, each flock was examined three times: laying visit 1 (LV1) was at the peak of the laying period, between the 30th and 33rd week of life; laying visit 2 (LV2), was in the middle of the laying period between the 44th and 48th week of life; and laying visit 3 (LV3), was at the end of the laying period, between the 62nd and 68th week of life (Figure 1)—except for flocks 11 and 16, which were gradually slaughtered, beginning in the 53rd week of life.

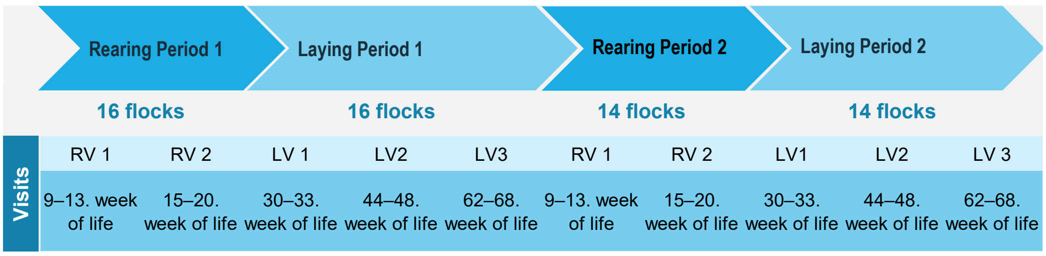

Figure 1. Schematic diagram for the experimental design.

Owing to economic reasons, not all flocks for the second laying period were raised on the same rearing farms as for the first laying period. Two flocks were only studied for one rearing and laying period and, in one case, only pullets for the second laying period could be investigated (Table 1). All animals were fed and vaccinated according to the management guidelines of the respective breeding companies.

2.2. Plumage Scoring

Thirty birds of each flock (15 of each hybrid line in cases of mixed flocks) were scored during each rearing visit and each laying visit. Overall, 1755 non-beak-trimmed pullets and 3390 non-beak-trimmed laying hens were scored. The scoring system was based on the 'henscore' [58], modified by Niebuhr et al. [59] and Tauson et al. [60], where plumage damage and integument lesions were scored separately for each of the three body regions—neck dorsal, back, and wings (Table 3)—for pullets and layers, respectively. These body regions were chosen because plumage damage there was likely to be due to SFP [14,38,61]. The three single body region scores were summed up to a triscore. A triscore $\leq$ 10 was defined as an indicator of the occurrence of SFP. This threshold was chosen because birds with a triscore > 10 could not have had a nude area (score 3–1) on more than one body region, and birds with a triscore $\leq$ 10 had a nude area (score 3–1) on at least two body regions.

Table 3. Definitions for individual plumage and integument scoring for pullets and laying hens, modified according to Niebuhr et al. [59] and Tauson [60]. Ø = diameter. For the individual plumage and integument scoring, separate body region scores per bird were given for: neck dorsal, back, and wings.

Points	Plumage Scoring: Pullets	Plumage Scoring: Layers
5	-	$\leq$5 feathers damaged, no nude areas
4	No damage	>5 feathers damaged, nude areas Ø $\leq$ 1 cm
3	Damaged feathers	Nude areas Ø > 1 cm to $\leq$ 5 cm
2	Single feathers missing	Nude areas Ø > 5 cm up to $\leq$ 75% of the body region
1	Nude areas Ø > 1 cm	Nude areas >75% of the body region

2.3. Housing and Management Data

For each rearing and laying flock, a management and animal health questionnaire was filled in, together with the farm manager (Supplemental File). These data included the housing system and the flock size (Tables 1 and 2). The number of persons in charge of caring for the birds was documented, as was the time spent on the daily care of the birds (time spent with the animals in the barn). These data were used to calculate the following variables, as indicators of the time and effort involved in animal care:

- The number of animals per caregiver;
- The attendance (care) time per 1000 birds per day (in minutes).

For both the rearing and the layer farms, the resources available to the birds were documented, to calculate the following variables:

- Stocking density: birds per usable square meter;
- Perch length per bird (in centimeters);
- Feeding trough length per bird (in centimeters);
- Number of birds per drinking nipple.

In some rearing facilities, the pullets remained in the aviaries up to the 35th day of life, before getting access to a litter area. Similarly, on some layer farms the hens were confined to the aviaries for up to 14 days without, or with only partial access to, a litter area. For further analysis, the available resources, after the animals had been granted access to the entire barn, were used.

During each farm visit, a data collection sheet was filled in. For litter scoring, the method described in the Welfare Quality Assessment Protocol for Poultry [62] was used. Additionally, the depth of the litter was measured by using a ruler. Finally, the provision of manipulable environmental enrichment material, in addition to litter (e.g., straw bales, pecking stones), was documented.

2.4. Statistics

All data were processed and prepared for further statistical analysis by using Excel (version 2013, Microsoft Corporation, Redmond, WA, USA). In the second rearing and laying period, flock 7 was excluded from further statistical analysis, owing to a severe infectious disease in the middle of the laying period. For the further analysis, the percentage of birds with plumage damage (triscore $\leq$ 10) was calculated.

In both rearing and laying periods, housing and management data's relation to plumage damage was analyzed in two steps, using univariate analysis first. For the rearing periods, the effect or the correlation was analyzed for the following variables:

'mixed flock'; 'housing system'; 'daylight'; 'hybrid line' (LB, LSL, DW, BB); 'stocking density' (pullets per square meter of usable area); 'perch length per pullet' (in centimeters); 'feeding trough length per pullet' (in centimeters); 'number of pullets per drinking nipple'; 'flock size'; 'number of pullets per caregiver'; and 'attendance time per 1000 pullets per day' (in minutes). In the second rearing period, additionally, 'litter quality' and 'litter depth' were analyzed.

For both laying periods, either the effect or the correlation of the following variables, regarding the occurrence of SFP and cannibalistic injuries, were analyzed: 'mixed flock'; 'free range'; 'enrichment'; 'daylight'; 'hybrid line' (LB, LSL, DW, BB); 'stocking density' (laying hens per square meter of usable area); 'flock size'; 'perch per laying hen' (in centimeters); 'feeding trough length per laying hen' (in centimeters); 'number of laying hens per drinking nipple'; 'number of laying hens per caregiver'; and 'attendance time per 1000 laying hens per day' (in minutes). Additionally, 'litter quality' and 'litter depth' were analyzed for the second laying period, to account for findings in the literature [39,43,49].

For categorial data, a Shapiro–Wilk test was calculated for the mean values of plumage damage percentage, to test for normal distribution. Not all variables were normally distributed; therefore, a Mann–Whitney U test for independent samples was chosen. The effect (Cohen's d) was calculated, using the means and standard deviations [63] to describe small, medium, and large effects [64]. For ratio data, Kendall's tau correlation coefficient (r) was calculated.

To analyze the influence of management and housing on the occurrence of SFP and cannibalism in all flocks, in both rearing and laying periods, models using multifactorial analysis were calculated. The calculated partial eta-squared explained the percentage of independent variables on the variability of the dependent variables. The corrected partial eta-squared incorporated the number of factors analyzed.

Cramér's V and a chi-squared test were used to calculate the relation between plumage damage in the rearing period and plumage damage in the laying period.

Details for the plumage and integument scoring results for the first rearing and laying period can be found in Lenz [65], and for the second rearing and laying period in Szczepanek [66].

3. Results

3.1. Risk Factors for Plumage Damage in the Rearing Period

There was a large variance in the plumage condition between the rearing flocks in both rearing periods, ranging from zero to >90% pullets with plumage damage (triscore $\leq$ 10). In the first rearing period, less plumage damage was recorded at RV1 (24.9%) than at RV2 (44.7%); however, in the second rearing period, there was less plumage damage at RV2 (33.6%) than at RV1 (41.3%).

The univariate analysis for RV1 of the first rearing period (Table 4) revealed a medium-to-large effect (Cohen's d) for the housing system 'aviary' and the hybrid lines DW and BB on plumage damage, which was significant only for hybrid line DW (p = 0.017). For RV2, no significant effects were found, but a medium effect (Cohen's d) of the hybrid line BB and large effects of 'no daylight' and the hybrid line DW. The stocking densities of the rearing flocks varied strongly (12–25 pullets per square meter). The effect of the stocking density on the plumage score was significant for RV2 (p = 0.045). There were significant correlations (r = −0.735; p = 0.001) between the variables 'pullets per drinking nipple' and 'perch length per pullet' and between 'pullets per drinking nipple' and 'feeding trough length per pullet'. Therefore, only 'pullets per drinking nipple' remained in the model. DW was not used in the model, because of the small sample size (n = 2).

The model (univariate multifactorial analysis of variance, Table 5) for both rearing periods described 52.6% (corrected 34.1%) of the variance of the dependent variable 'plumage damage in the rearing period' for RV1. The explanation of variance in the model was significant (p = 0.035). The variable 'litter quality' nearly reached significance (p = 0.055). The model (both rearing periods) for RV2 described 65.8% (corrected 57.5%) of the variance of the dependent variable 'plumage damage in the rearing period'. The explanation of variance was again significant ($p = 0.000$). The variables 'stocking density' and 'litter quality' were significant (Table 5).

Table 4. Analysis of the influence of management and housing factors on the occurrence of plumage damage in pullets. Effect size (d) and significance (p) for categorial data: $d \geq 0.5$ = medium effect; $d \geq 0.8$ = large effect [64]. Kendall's tau correlation coefficient (rho) and significance (p) for ratio data. * = Significant effect ($p \leq 0.05$). Abbreviations: RP = rearing period; RV = rearing visit; BB = Bovans Brown; DW = Dekalb White; LB = Lohmann Brown or Lohmann Brown Extra; LSL = Lohmann Selected Leghorn.

Variable	RP1: RV1	RP1: RV2	RP2: RV1	RP2: RV2
Mixed flock	$d = 0.01$, $p = 1.000$	$d = -0.64$, $p = 0.145$	$d = 0.83$, $p = 0.245$	$d = 0.58$, $p = 0.220$
Housing system	$d = 0.78$, $p = 0.439$	$d = 0.10$, $p = 1.000$	$d = 1.72$, $p = 0.106$	**$d = 2.19$, $p = 0.030$**
LB	$d = 0.16$, $p = 0.800$	$d = 0.43$, $p = 0.611$	$d = 1.82$, $p = 0.250$	$d = 0.60$, $p = 0.833$
LSL	$d = 0.03$, $p = 1.000$	$d = -0.40$, $p = 0.313$	$d = 0.30$, $p = 0.709$	$d = 0.90$, $p = 0.109$
DW	**$d = 1.92$ *, $p = 0.017$**	$d = 1.12$, $p = 0.267$	$d = 1.82$, $p = 0.250$	$d = 0.60$, $p = 0.833$
BB	$d = 1.41$, $p = 0.250$	$d = 0.56$, $p = 0.875$	$d = 1.82$, $p = 0.250$	$d = 0.60$, $p = 0.833$
Stocking density	rho = 0.086, $p = 0.650$	**rho = 0.381 *, $p = 0.045$**	rho = 0.202, $p = 0.369$	rho = 0.438, $p = 0.53$
Flock size	rho = −0.252, $p = 0.186$	rho = −0.254, $p = 0.185$	**rho = −0.431 $p = 0.054$**	rho = −0.233, $p = 0.300$
Perch/pullet (cm)	**rho = −0.453 *, $p = 0.016$**	rho = −0.233, $p = 0.220$	**rho = 0.554 *, $p = 0.013$**	rho = −0.016, $p = 0.945$
Feeding trough/pullet (cm)	**rho = −0.402 *, $p = 0.033$**	rho = −0.181, $p = 0.340$	rho = 0.92, $p = 0.679$	rho = 0.109, $p = 0.629$
Drinker/pullet	**rho = 0.535 *, $p = 0.005$**	rho = 0.287, $p = 0.133$	rho = −0.308, $p = 0.168$	rho = −0.388, $p = 0.084$
Pullets/caregiver	**rho = −0.597 *, $p = 0.002$**	rho = −0.363, $p = 0.060$	rho = −0.159, $p = 0.528$	rho = −0.023, $p = 0.928$
Attendance time/1000 pullets and day (min)	rho = −0.009, $p = 0.964$	rho = −0.026, $p = 0.891$	rho = −0.114, $p = 0.625$	rho = −0.023, $p = 0.928$
Litter quality	**rho = 0.577 *, $p = 0.054$**	rho = −0.257, $p = 0.186$	rho = 0.422, $p = 0.062$	rho = −0.394, $p = 0.082$
Litter depth	**rho = −0.468, $p = 0.033$**	rho = −0.039, $p = 0.844$	rho = 0.047, $p = 0.864$	rho = −0.394, $p = 0.126$

Table 5. Univariate multifactorial analysis of variance for the dependent variable 'plumage damage at rearing' for both rearing periods. * = Significant effect ($p \leq 0.05$). RV = Rearing visit.

Factor	Significance (p)	Partial Eta-Squared
RV1		
Corrected model	0.035	0.526
Constant term	0.957	0.000
Litter quality	0.055	0.337
Stocking density	0.086	0.155
Pullets/drinking nipple	0.178	0.098
Litter depth	0.327	0.053
Pullets/caregiver	0.762	0.005
RV2		
Corrected model	0.000	0.658
Constant term	0.949	0.000
Stocking density	**0.002 ***	**0.400**
Litter quality	**0.005 ***	**0.337**
Pullets/caregiver	0.183	0.087
Pullets/drinking nipple	0.595	0.014
Litter depth	0.832	0.002

3.2. Risk Factors for Plumage Damage in the Laying Period

In the first laying period, 5 out of 16 non-beak-trimmed flocks showed no plumage damage, or only minor plumage damage, at the end of the laying period, and 11 flocks showed severe plumage damage (triscore ≤ 10). The percentage of laying hens with severe plumage damage increased from 3.2% in LV1 to 32.9% in LV2, and up to 57.8% in LV3. In the second laying period, 7 out of 14 non-beak-trimmed flocks showed minor plumage damage at the end of the laying period. Large differences between the different flocks, regarding plumage damage, were noticeable. Again, the percentage of severe plumage damage increased during the laying period (LV1: 8.13%, LV2: 32.5%, LV3: 50.4%).

In the first laying period, the calculation of the effect size (Cohen's *d*) in LV1 showed a medium effect on severe plumage damage for flocks without access to free range, and a large effect of the variables 'mixed flock' and the hybrid lines DW and BB on severe plumage damage. The effect sizes for 'mixed flock' and DW were significant (p = 0.007 and p = 0.047, respectively). There were significant negative correlations of 'flock size' (p = 0.046), 'number of laying hens per caregiver' (p = 0.025), and 'perch length per laying hen' (p = 0.036) with severe plumage damage (Table 6). At LV2, Cohen's *d* showed medium effects of a lack of environmental enrichment and daylight, and large effects of mixed flocks, no free range, and the hybrid lines DW and BB on severe plumage damage. The effect sizes for the variables 'mixed flock' and DW were significant (p = 0.007 and p = 0.032, respectively). For this visit, significant correlations of severe plumage damage with high stocking density (p = 0.027) and short perch length per hen (p = 0.046) were found. Similar results were found for LV3: Cohen's *d* revealed large effects of the variables 'mixed flock', 'no free range', 'no enrichment', 'no daylight' and the hybrid lines DW and BB on the occurrence of severe plumage damage. Effect sizes for 'free range' and 'no daylight' were significant (p = 0.003 and p = 0.032, respectively). The correlation between high stocking density and severe plumage damage was significant (p = 0.010). In the second laying period, the lack of free range had a medium (LV2) or large (LV1 and VL3) effect. Lack of daylight had a large effect at LV2 and LV3 on severe plumage damage. The hybrid line had medium-to-large effects at LV1 and LV2, but without reaching significance. At LV2, the litter quality had a significant influence (p = 0.018) on severe plumage damage.

Table 6. Analysis of the influence of management and housing factors on the occurrence of plumage damage in laying hens. Effect size (d) and significance (p) for categorial data: $d \geq 0.5$ = medium effect; $d \geq 0.8$ = large effect. Kendall's tau correlation coefficient (rho) and significance (p) for ratio data. * = Significant effect ($p \leq 0.05$). Abbreviations: LP = laying period; LV = laying visit; BB = Bovans Brown; DW = Dekalb White; LB = Lohmann Brown or Lohmann Brown Extra; LSL = Lohmann Selected Leghorn.

Variable	LP1: LV1	LP1: LV2	LP1: LV3	LP2: LV1	LP2: LV2	LP2: LV3
Mixed flock	***d* = 1.97 *, *p* = 0.007**	***d* = 1.49 *, *p* = 0.007**	*d* = 0.81, *p* = 0.079	*d* = 0.16, *p* = 0.930	*d* = 0.17, *p* = 0.930	*d* = 0.48, *p* = 0.499
Free range	*d* = −0.63, *p* = 0.301	*d* = −0.88, *p* = 0.078	***d* = −2.08 *, *p* = 0.003**	*d* = −0.91, *p* = 0.446	*d* = −0.68, *p* = 0.349	*d* = −1.63, *p* = 0.057
Enrichment	*d* = 0.03, *p* = 0.743	*d* = −0.54, *p* = 0.277	***d* = −1.02 *, *p* = 0.050**	*d* = 0.32, *p* = 0.437	*d* = 0.10, *p* = 0.945	*d* = 0.34, *p* = 0.652
Daylight	*d* = −0.07, *p* = 0.703	*d* = −0.68, *p* = 0.163	***d* = −1.02 *, *p* = 0.032**	*d* = 0.22, *p* = 0.753	*d* = 0.82, *p* = 0.379	*d* = 1.16, *p* = 0.129
LB	*d* = −0.07, *p* = 1.000	*d* = −0.18, *p* = 1.000	*d* = 0.47, *p* = 0.768	*d* = 1.50, *p* = 0.143	*d* = 1.38, *p* = 0.500	*d* = 1.37, *p* = 0.385
LSL	d = 0.38, *p* = 0.721	d = 0.07, *p* = 0.879	d = −0.43, *p* = 0.328	d = 0.91, *p* = 0.446	d = 0.65, *p* = 0.548	d = 1.28, *p* = 0.158
DW	***d* = 1.31 *, *p* = 0.047**	***d* = 1.38 *, *p* = 0.032**	*d* = 0.95, *p* = 0.197	*d* = 1.50, *p* = 0.143	*d* = 1.38, *p* = 0.500	*d* = 1.37, *p* = 0.385
BB	*d* = 1.61, *p* = 0.235	*d* = 2.21, *p* = 0.118	*d* = 1.14, *p* = 0.118	*d* = 1.50, *p* = 0.143	*d* = 1.38, *p* = 0.500	*d* = 1.37, *p* = 0.385
Stocking density	rho = 0.263, *p* = 0.188	**rho = 0.406 *, *p* = 0.027**	**rho = 0.464 *, *p* = 0.010**	rho = −0.078, *p* = 0.729	rho = 0.035, *p* = 0.876	rho = 0.211, *p* = 0.325
Flock size	**rho = −0.396 *, *p* = 0.046**	rho = −0.167, *p* = 0.36	rho = 0.000, *p* = 1.000	rho = −0.062, *p* = 0.782	rho = 0.058, *p* = 0.781	rho = 0.182, *p* = 1.391
Hens/caregiver	**rho = −0.447 *, *p* = 0.025**	rho = −0.252, *p* = 0.169	rho = −0.03, *p* = 0.869	rho = −0.156, *p* = 0.488	rho = 0.268, *p* = 0.199	rho = 0.316, *p* = 0.140
Time/1000 hens/day (min)	rho = −0.322, *p* = 0.107	rho = −0.261, *p* = 0.156	rho = −0.367, *p* = 0.443	rho = −0.156, *p* = 0.488	rho = −0.175, *p* = 0.403	rho = −0.316, *p* = 0.140
Perch/hen (cm)	**rho = −0.415 *, *p* = 0.036**	**rho = −0.364 *, *p* = 0.046**	rho = −0.178, *p* = 0.322	rho = −0.247, *p* = 0.268	rho = 0.012, *p* = 0.956	rho = −0.156, *p* = 0.462

Table 6. *Cont.*

Variable	LP1: LV1	LP1: LV2	LP1: LV3	LP2: LV1	LP2: LV2	LP2: LV3
Feeding trough/hen (cm)	rho = −0.223, p = 0.263	rho = −0.137, p = 0.454	rho = 0.007, p = 0.967	rho = 0.155, p = 0.489	rho = 0.127, p = 0.541	rho = 0.286, p = 0.178
Hens/drinking nipple	rho = 0.125, p = 0.527	rho = 0.167, p = 0.360	rho = 0.222, p = 0.216	rho = −0.124, p = 0.580	rho = −0.380, p = 0.066	rho = −0.338, p = 0.111
Litter quality	**rho = 0.083 *, p = 0.022**	rho = −0.046, p = 0.216	rho = 0.098, p = 0.008	rho = −0.377, p = 0.114	**rho = −0.523 *, p = 0.018**	rho = −0.418, p = 0.070
Litter depth	**rho = −0.108 *, p = 0.002**	**rho = −0.286 *, p < 0.001**	rho = −0.039, p = 0.271	rho = −0.093, p = 0.678	rho = 0.023, p = 0.911	rho = 0.065, p = 0.870

For the model, the variables ‘free range’, ‘mixed flock’, ‘enrichment’, and ‘perch length per laying hen’ were chosen, because they had a significant effect size or correlation in at least one laying visit in the univariate analysis. The variables ‘stocking density’ and ‘flock size’ were not considered in the model, because of restrictions by law in Germany for the maximum flock size (6000) and stocking density (nine laying hens per usable square meter in aviaries with multiple tiers) [67]. ‘No daylight’ and the hybrid line DW (and BB) only appeared in two flocks each, and were not considered for the model, owing to the small sample size.

The variable ‘rearing’ was used for the model, which refers to the mean plumage condition of the flock during the rearing period. Cramér’s *V* showed a medium-to-large effect of the plumage condition in the rearing period on severe plumage damage in the laying period for all visits (LV1: 0.443, LV2: 0.608, LV3: 0.451), which reached a significant level for LV2 (p = 0.031). Laying hens that grew up in rearing flocks with no plumage damage developed severe plumage damage later in life, and to a lesser extent than laying hens growing up in rearing flocks with plumage damage.

The model for both laying periods for LV1 described 49.8% (corrected 27.5%) of the variance of the dependent variable ‘severe plumage damage’. The explanation of variance of the model was not significant. There were significant effects of the variables ‘free range’, ‘litter quality’, and ‘enrichment’. For LV2, the model explained 67.6% (corrected 53.9%) of the variance of the dependent variable ‘severe plumage damage’. The explanation of variance for the model was significant (p = 0.002). There were significant effects of the variables ‘rearing’ and ‘litter quality’. For LV3, the model explained 72.2% (corrected 59.8%) of the variance of the dependent variable ‘severe plumage damage’. The variables ‘rearing’, ‘litter quality’, and ‘free range’ were significant (Table 7).

Table 7. Univariate multifactorial analysis of variance for the dependent variable ‘severe plumage damage’ for both laying periods. * = Significant effect ($p \leq 0.05$). LV = laying visit.

Factor	Significance (p)	Partial Eta-Squared
LV1		
Corrected model	0.075	0.498
Constant term	0.492	0.027
Free range	**0.006 ***	**0.346**
Litter quality	**0.027 ***	**0.242**
Enrichment	**0.036 ***	**0.222**
Rearing	0.562	0.062
Mixed flock	0.282	0.064
Perch/laying hen (cm)	0.739	0.006
Litter depth	0.994	0.000
LV2		
Corrected model	0.002	0.676
Constant term	0.023	0.244
Rearing	**0.004 ***	**0.443**
Litter quality	**0.021 ***	**0.248**

Table 7. *Cont.*

Factor	Significance (*p*)	Partial Eta-Squared
Free range	0.089	0.144
Perch/laying hen (cm)	0.165	0.099
Enrichment	0.450	0.030
Mixed flock	0.607	0.014
Litter depth	0.791	0.004
LV3		
Corrected model	0.001	0.722
Constant term	0.016	0.283
Rearing	**0.017 ***	**0.362**
Litter quality	**0.015 ***	**0.289**
Free range	**0.020 ***	**0.266**
Perch/laying hen (cm)	0.332	0.052
Enrichment	0.541	0.021
Litter depth	0.564	0.019
Mixed flock	0.901	0.001

4. Discussion

4.1. Rearing Period

4.1.1. Plumage Scoring

The plumage condition in some flocks was better at the visit at the end of the rearing period (RV2). This was most likely due to a partial molt in the 12th to 13th week of life (between RV1 and RV2), as previously found by Sepeur et al. [57]. The housing and management conditions and the plumage condition of the rearing flocks differed largely between the 16 visited farms, confirming the findings of another field study on commercial farms [57].

4.1.2. Influence of Litter

A range of management and housing factors was chosen according to the relevant literature and our own experience, to investigate their possible influence on the occurrence of SFP. Many authors emphasized the importance of litter provision during rearing [8,68], because access to litter from the first day of life onward had a significant effect on the prevention of SFP [68]. In our study, all rearing farms provided litter after opening the aviary sections in the fourth to fifth week of life; however, the litter was not renewed during the rearing period. During confinement to the aviary compartments until the fourth or fifth week of life, no litter had been provided, because the pullets were kept on wired slats within the aviaries during that period. Hence, the litter depth rose on average, from 3.1 cm to 6.7 cm between the first and second rearing visit, the litter was mixed up with feces, and its original texture was almost not recognizable at RV2. Not just the provision of litter but the litter quality may have an influence on the occurrence of SFP [69], which is why this variable was used in our study, in accordance with the Welfare Quality Assessment Protocol for Poultry [62]. The model showed an influence of the litter quality ($p = 0.005$ in RV2), but not the litter depth, on the plumage condition. These results were in line with those of Hartcher et al. [25], who did not find an effect of enrichment, including deeper litter, on plumage damage during the laying period. Only four rearing farms occasionally offered environmental enrichment (alfalfa bales, pecking stones); hence, this factor could not be analyzed statistically. Although the provision of a dust bath is discussed in the literature to be a risk factor of SFP [70], this factor could not be investigated, because none of the commercial rearing farms in this study offered a dust bath to the pullets.

4.1.3. Influence of Stocking Density

There was a significant effect of the stocking density on plumage damage in the first rearing period. The model for both rearing periods confirmed the significant effect of the stocking density for RV2. The factor explained 40% of the variability of the dependent variable 'plumage damage in the rearing period'. Presumably, this factor was significant only at RV2 because the birds had grown, and took up more space than at RV1, approximately eight weeks earlier. Our result is in line with the findings of several other studies, which found high stocking densities during the first four weeks of rearing to be a risk factor for the development of SFP [26,34]. Owing to a lack of binding regulations in Germany for the rearing of laying hens, some rearing flocks had very high stocking densities. Fifteen flocks exceeded the current recommendations for stocking density (18 pullets per square meter of usable area from the 21st day of life) [71]. A scientific approach to calculating maximum stocking densities suggests no more than 9–15 layer pullets per square meter of usable area [72], which was exceeded by 21 out of 30 flocks in our study.

According to von Eugen [37], overcrowding—even if pullets seem to be able to adapt to the situation in the short term—may have long-term aversive effects on behavioral and physiological parameters. Hence, it seems possible that stress due to overcrowding in the rearing period is the basis for the development of SFP later in life. Typically, problems with SFP start at the peak of the laying period, around the 30th week of life—which is a physically stressful phase for laying hens—and increase during the laying period [73,74]. Other studies on commercial pullet farms found significantly less SFP if the stocking density was approximately 18 pullets per square meter of usable area, compared with a 20% higher stocking density [32], although no significant difference in plumage condition was detected in the same flocks [36]. The authors presumed this may have been due to a not-detailed-enough scoring scheme. However, pullets—like any other animal—seek to maintain certain social distances to conspecifics. If this is not possible, owing to high stocking densities, certain behaviors (e.g., foraging) are reduced or stopped entirely. The lack of foraging behavior may lead to misdirected behavior and pecking on the feathers of conspecifics and, in due course, to SFP [7,8,15].

4.1.4. Influence of Resource-Based Parameters

One should consider that resource-based parameters such as 'feeding trough length', 'number of drinkers', and 'perch length' are directly linked to the stocking density. The dimensions of these parameters are fixed within a barn, so more animals need to share the available resources if the stocking density increases; this could add to the overcrowding problems discussed above. There was a significant effect of the 'perch length per pullet' in the univariate analysis of both laying periods, but not in the model. Other resource-based variables, such as 'feeding trough length per pullet' and 'number of drinkers per pullet' were significant in the univariate analysis for the first rearing period only, but not in the model. However, the availability of perches seemed to be of some relevance: hens use them to withdraw themselves from the flock, and to flee from aggressive attacks [16]. Some studies found resource-based risk factors, during rearing, for the development of SFP in the laying period, e.g., no access to heightened perches from the first day of life onward, high stocking densities, and no litter [35]. Considering that SFP happens predominantly in the litter area [1,14,38], a lack of space in the litter area may be a problem leading to more stress, and subsequently to more plumage damage. Insufficient feeding trough length per pullet, and number of drinkers per pullet may lead to competition for food and water, because pullets, as social animals, synchronize their behavior.

4.1.5. Influence of Hybrid Lines

It is widely recognized that hybrid lines differ in their pecking activity, and the breeding of commercial laying lines less prone to SFP has had some success [17,18]. Indeed, in our study, DW pullets showed significantly more SFP in the univariate analysis in the first rearing period. However, because this hybrid line was present on two farms, and in mixed flocks only, this factor could not be analyzed further. It would be of interest to future research to investigate differences in the pecking behavior of different hybrid lines on commercial farms without beak trimming.

4.1.6. Influence of Attendance Time

Our own practical experiences on the farms showed that it was sometimes difficult to walk through the barn, because the pullets were very nervous, and we often found old cadavers in the aviaries. Therefore, we decided to try to create variables accounting for the time and effort involved in caring for the birds. To our surprise, the univariate analysis of the first rearing period (but not the model over both rearing periods) showed that there was a significant correlation between a small number of pullets per caregiver and more plumage damage. The attendance time per bird was not significant. Larger rearing farms, with a higher animal-to-caregiver ratio, may have been more professionally organized, with more competent personnel. This would be in line with another study, which found a relation between more experienced personnel and less plumage damage [27]. According to this study, the attendance of experienced staff during rearing was protective against feather pecking, both in the rearing and in the laying period [27].

4.2. Laying Period

4.2.1. Plumage Scoring

Eighteen out of 30 laying flocks had severe plumage damage at the end of the laying period (LV3). By contrast, only 18.5% of Bavarian flocks had problems with feather pecking, according to a survey that was conducted in the same year that our data collection took place [46]. This discrepancy may have been due to beak trimming, which was still common practice at the time of data collection. On the other hand, some farmers who participated in the survey may not have judged the plumage damage of their flock to be 'severe'. This emphasizes the necessity for individual and exact plumage and integument scoring, including training of plumage assessment for farmers, and timely action after the detection of problems [28]. Plumage damage tends to increase during the laying period [14]. This was the case in our study, but there were large differences between the flocks, for which we tried to find risk factors.

4.2.2. Influence of Rearing

Pecking activity during rearing is supposed to influence pecking behavior during the laying period [1,26,27]. Our results confirmed a relationship between plumage damage during rearing and severe plumage damage during the laying period. In our study, the effect size (Cramér's *V*) showed a medium-to-large effect of plumage damage during rearing on severe plumage damage during the laying period, with a significant effect for RV2 in the second laying period. Therefore, the mean plumage condition was incorporated into the model (factor 'rearing'). The model revealed the effects of the plumage condition during rearing on the plumage condition during the laying period for LV2 and LV3. This finding emphasizes the importance of preventing SFP during the rearing period, as it is difficult to eliminate SFP and cannibalism in a flock once these behaviors have been established. However, other authors did not find a relationship between SFP during rearing and SFP in the laying period [16]. This may be due to the multifactorial nature of SFP [53]—there may have been other factors not related to rearing, such as inadequate feeding or housing conditions, that triggered SFP outbreaks in the laying period.

4.2.3. Influence of Stocking Density and Access to Free Range

The stocking density had a significant effect in the univariate analysis of the first laying period. This result corresponded with other studies that found the stocking density to be a risk factor of plumage damage [34]. Other resource-based factors, such as 'perch length per hen', were fixed in the barn, and therefore directly connected to the stocking density. The univariate analysis showed a significant effect of 'perch length per hen' for two visits in the first laying period (LV1 and LV2). This variable was chosen for the model, but was not significant. This finding is not surprising, because in Germany minimum requirements for stocking densities and resource-based parameters, such as 'number of hens per drinker' and the perch and feeding trough lengths, are regulated by law [67]. Therefore, as expected, there was little variance in these variables between the flocks, which were all housed on conventional (not organic) commercial farms in Bavaria.

Six farms provided free range for their laying hens. Laying-hen flocks with access to free range had less plumage damage in our study—a result also found in the study by Keppler [33]. The availability of free range was significant in the univariate analysis for LV1 and LV3 of the first laying period, and had large effects (Cohen's *d*) in the second laying period. The model over both laying periods confirmed the significant positive influence of free range on the plumage condition for LV1 (p = 0.006) and LV3 (p = 0.020). The second laying visit was in the cold season, during winter in most cases. This could explain the missing effect for LV2, because free range may not have been used as much in winter and may not have been available all the time. Some authors have pointed out that not just the availability but also the actual use of free range is crucial for preventing SFP [1,41,69]. The usage of free range could not be investigated in this study, but during our visits we noticed that free-range areas were sometimes closed during bad weather in winter, and that large free-range areas had little or no structure at all. Free-range areas are better-used if they have vegetation or shelters, or both [41].

4.2.4. Influence of Enrichment and Litter

According to a meta-analysis of the relevant literature, flocks provided with environmental enrichment on the layer farms have a reduced incidence of feather pecking, irrespective of the presence or absence of enrichment materials during rearing [52]. Several studies have demonstrated the positive influence of providing environmental enrichment during the laying period, on plumage damage and SFP [49,51]. Tahamtani et al. [49] suggested that husbandry procedures during the rearing and the laying periods can be used to prevent feather pecking, and thus to improve laying hen welfare. Our results point in the same direction. The variable 'enrichment' was significant for LV1 of the first rearing period in the univariate analysis and in the model. However, the enrichment materials used were very different, in regard to quality and quantity between the farms, which may explain why this factor was not significant for LV2 and LV3. Future research should focus on specific recommendations for enrichment that would be suitable for practical use on commercial farms.

The provision of litter and the litter quality are useful for preventing SFP [41]. Our univariate analysis showed a significant effect of the litter quality on plumage damage, whereas the litter depth had no effect. This result was confirmed in the model: the risk factor 'litter quality' was significant for all three visits (LV1: p = 0.027; LV2: p = 0.021; LV3: p = 0.015). Remarkably, another study found evident genotype–environment interactions between strains and groups [66]. In groups with environmental enrichment, plumage damage decreased in LB and LSL, but increased in BB. In view of the diverging effects between strains, the authors suggested that future practical recommendations for laying-hen husbandry should be strain-specific [51].

Feather pecking is a behavioral disorder with multifactorial reasons. Various aspects of pullet and laying-hen husbandry—such as housing conditions, management, feeding, and genetics—must be considered, to prevent negative outcomes such as severe plumage damage, skin injuries, and high mortality rates due to SFP [1,61,75]. All data for the present study were gathered on voluntarily participating commercial farms, which differed largely in terms of housing conditions and management. The lack of standardized conditions needs to be considered when interpreting the statistical analysis. The univariate multifactorial analysis of variance showed an overdetermination of the model used, because the adjusted partial eta-squared of the model was smaller than the partial eta-squared. This was most likely due to the influence of other risk factors, such as feed composition [54] and genetics [19,76], which were not analyzed in this study. The results need to be interpreted carefully, because there are many possible influencing factors for feather pecking and subsequent plumage damage. Future research should verify the herein-proposed risk factors with a larger number of flocks. Because beak trimming is not practiced anymore in several

European countries, it is highly important for farmers to gain knowledge on the prevention of feather pecking, by implementing optimized husbandry and management conditions.

5. Conclusions

In conclusion, in our study, high stocking density and poor litter quality in the rearing period were significant risk factors of SFP. In the laying period, a lack of free range, poor litter quality, insufficient enrichment, and plumage damage during rearing were significant risk factors of SFP. Therefore, we strongly recommend an individual risk analysis of pullet-rearing farms and layer farms, to prevent outbreaks of SFP and cannibalism, especially in non-beak-trimmed birds.

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