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Welfare of broiler chickens reared under two different types of housing

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Abstract

We compared closed- and open-sided industrial houses with respect to the welfare of broiler chickens in southern Brazil. Ten flocks from each design were evaluated and measures divided into the following categories: i) bird health: contact dermatitis on the breast and abdominal areas, bird soiling, foot-pad dermatitis, hock burn, lameness, fractures, bruising, scratches, dead on arrival, diseases; ii) environmental measurements: relative humidity, temperature, air velocity, ammonia (NH_3), carbon dioxide (CO_2), light intensity, litter moisture; iii) behaviour: bird behaviour, touch test; and iv) affective states: qualitative behaviour assessment. Closed-sided houses showed worse contact dermatitis on the breast and abdominal areas, lower exploratory behaviour prevalence, higher NH_3 (11.2 [± 6.8] vs 7.5 [± 3.9] ppm) and CO_2 (1,124.9 [± 561.5] vs 841.0 [± 158.0] ppm), lower light intensity (6.9 [± 6.3] vs 274.2 [± 241.9] lux), while open-sided houses had a higher prevalence for scratches and panting behaviour, and lower air velocity (2.1 [± 0.7] vs 1.1 [± 1.0] m s^{-1}). Stocking densities of 13.9 (± 0.4) and 12.0 (± 0.3) per m^2 for closed- and open-sided houses, respectively, likely influenced some results. All values shown are means (± SD). Even though open-sided houses presented fewer animal welfare restrictions (according to five indicators as opposed to three for closed-sided houses), both revealed important welfare problems, evidenced by poor environmental indicators, behavioural restrictions and injuries.

Keywords: *animal welfare, behaviour, dark-house, semi-climatised, slaughter, summer/autumn*

Introduction

Poultry is the most traded livestock species in the world, in terms of numbers of animals involved and meat tonnage, and Brazil is one of the leading producers and exporters. In 2020, around 5.9 billion birds were slaughtered (IBGE 2021) in Brazil, and the country produced 13.8 million tons of poultry meat, behind only the US (with 20.2 million tons) and China (14.6 million tons) (ABPA 2021). Due to the numbers of animals involved, poultry production becomes a major priority regarding animal welfare initiatives (Broom 2001; Rowe *et al* 2019). Improvements may stem from consumer and market pressure, company interests, new policies, funding availability, country and regional specificities and climate as well as individual specifications on-farm, such as house design and management.

No standard system is in place for raising broiler chickens in developing countries. However, there are concerns as regards striking a balance amongst farm maintenance conditions, animal welfare and production sustainability (Lima *et al* 2020). The Brazilian poultry industry utilises multiple systems with different house sizes and partial or absolute control over indoor environmental conditions. Most Brazilian broiler chickens are reared in open-sided poultry houses, so-called conventional and semi-climatised houses, with fans and access to natural lighting, combined with adjustable polypropylene curtains (Paranhos da Costa *et al* 2017). Closed-sided houses are fully enclosed by fixed curtains or walls and thermal insulation panels (Olanrewaju *et al* 2010) and usually equipped with negative pressure and evaporative cooling systems, exhaust fans and sprinklers, and exclusive artificial lighting (Olanrewaju *et al* 2010; Abreu & Abreu 2011; Baracho *et al* 2018). There are concerns about the lighting: for example, 75% of animal welfare experts studied by Rioja-Lang *et al* (2020) agreed on the potential negative impact of artificial lighting regimes on poultry welfare; there is also concern from consumers regarding lighting (Vanhonacker *et al* 2009). A number of authors recognise the importance of light, especially natural lighting, and offer recommendations for the inclusion of windows in closed-sided poultry house designs

(Bailie *et al* 2013, 2018; European Union [EU] 2017). However, in direct contrast to this, Souza *et al* (2015a) described that out of 15 poultry export companies in the State of Paraná, Brazil, 14 had declared an intention to increase their numbers of closed-sided houses. Despite the increased use of negative pressure systems for broiler chicken production, Lima *et al* (2020) recommended open-sided poultry houses, due to the benefits associated with natural ventilation and higher litter quality. On the other hand, Rovaris *et al* (2014) observed better control of environmental indoor conditions as well as improved bird performance when rearing occurred in closed-sided houses; however, there was also a higher prevalence of foot calluses, probably due to the high stocking density practiced in this type of housing. In general, open-sided houses may allow for increased animal behaviour possibilities due to access to natural light; however, the birds may suffer from thermal stress (Bailie *et al* 2013; Lima & Silva 2019).

Regardless of the poultry house design, it is important that animal welfare levels are acceptable. Issues such as leg problems and contact dermatitis are amongst the major problems faced by broiler chickens (European Food Safety Authority [EFSA] 2010) and these may be influenced by type of housing. Additionally, in both designs, indoor conditions, such as temperature, relative humidity, air velocity, litter quality, light intensity and gases affect animal welfare. There are acceptable ranges for indicators such as relative humidity (45–70%), light intensity (at least 20 lux), carbon dioxide concentration (< 3,000 ppm) and ammonia concentration (10–20 ppm; EFSA 2012a; Royal Society for the Prevention of Cruelty to Animals [RSPCA] 2017). High gas concentrations increase susceptibility to respiratory diseases (Nääs *et al* 2007) and poor litter quality may lead to foot-pad dermatitis (De Jong *et al* 2014). Curtain management in open-sided poultry houses is reported as important for better air quality (Lima *et al* 2020), and it may also influence lighting, which is considered crucial in regulating broiler chicken production and welfare (EFSA 2012a). According to House *et al* (2020), when birds were reared in environments illuminated with lighting emitting diode (LED) supplemented by ultraviolet light, they showed decreased stress susceptibility and fear responses, indicating improved welfare and suggesting lighting to be an important factor to consider when comparing types of housing. Furthermore, data on injuries such as scratches, bruises and fractures may assist the detection of on-farm critical points of animal welfare that may lead to broiler chicken suffering (Allain *et al* 2009). Injuries may be assessed at the slaughterhouse during carcase inspection, potentially contributing to the overall assessment of broiler chicken welfare (Souza *et al* 2018a).

In addition to monitoring physical health, behavioural observations are important, as they may be an essential tool in helping to understand environmental effects on animal welfare (Pereira *et al* 2005). The assessment of emotional states and human-animal relationships may also assist the improvement of management practices. As guiding principles, it seems fair to consider that chickens seek safety, comfort, absence of fear, pain and diseases, access to food, water and light, and the expression of positive behaviours, such as dustbathing, scratching and foraging (Butterworth 2018).

Considering a broader range of opinions, the increased attention to animal welfare by citizens, politicians and farmers appears linked to the increasing numbers of animal welfare definitions, which may relate to different values regarding animal welfare (Lundmark *et al* 2014). For instance, according to Miele and Evans (2006), consumers place greater emphasis on natural living conditions, while scientists are more concerned with the absence of suffering. However, these differences do not prevent meaningful animal welfare assessment, based both on ethical and scientific information (Lundmark *et al* 2014, 2018). In addition, irrespective of differing priorities, there is recognition of the importance of assessing animal welfare using animal-based indicators (Anonymous 2012). Thus, much can be learned and improved by regular animal welfare assessment, even though it is not always possible to reach consensus when comparing situations in which different aspects of welfare have been compromised.

Thus, for a variety of reasons, animal welfare is a complex concept, and its assessment relies on a variety of indicators. Additionally, many managerial actions, including house design, will have consequences for animals' welfare. It is important that those involved in the production chain consider birds' needs, not to mention specific regional characteristics, before new housing designs from other countries are implemented, with climatic, economic and cultural conditions that differ greatly from those seen in Brazil (Abreu & Abreu 2011; EU 2015). To provide support for such decision-making, this is the first research comparing poultry houses from the perspective of bird welfare that sought specifically to assess the effect of closed- (CS) and open-sided (OS) poultry house designs on broiler chicken welfare in southern Brazilian conditions.

Materials and methods

Ethical approval

This project was approved by the Animal Use Ethics Committee of the Agricultural Campus (No 046/2018; July 5th, 2018), of the Federal University of Paraná.

Bird husbandry

The farms were selected according to availability, taking into account bird age and CS and OS houses (only those CS houses with black curtains and exclusive use of artificial lighting were selected). From March to April 2019, a period incorporating the end of summer and the beginning of autumn, in the west of Santa Catarina State, south of Brazil, ten CS and ten OS poultry houses from the same company were visited to assess bird welfare. External temperatures ranged between 20.5 and 34.0°C, relative humidity between 38 and 99%, air velocity between 0.0 and 1.6 m s^{-1} and light intensity between 848 and 6,900 lux, as measured outside the barns during visits. A brief farmer questionnaire and flock records were used to obtain general information such as initial number of birds, number of birds at the visit, their

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Table 1 Mean (± SD) characteristics of ten closed- and open-sided poultry houses included in the study and assessed from March to April 2019, in the west of Santa Catarina State, south of Brazil.

Variable	Closed-sided houses (n = 10)	Open-sided houses (n = 10)	*P*-value
Stocking density (birds per m^2)	13.9 (± 0.4)	12.0 (± 0.3)	$P < 0.001$
House size (m^2)	1,631 (± 409)	1,200 (± 300)	0.001
Flock size, number of birds at visit	34,940 (± 15,919)	20,563 (± 10,221)	0.013
Age at visit (days)	33.9 (± 0.3)	34.5 (± 1.2)	0.745
Age at slaughter (days)	39.0 (± 2.4)	41.0 (± 1.8)	0.133
Bodyweight at slaughter (kg)	2.74 (± 0.14)	2.79 (± 0.10)	0.189
Mortality (%)	2.1 (± 1.3)	2.9 (± 0.8)	0.515
Culls (%)	1.2 (± 0.7)	0.8 (± 0.4)	0.951
Reused litter (number of flocks per litter)	7.2 (± 3.5)	4.0 (± 2.7)	0.016

Figure 1

View of a (left) closed- and (right) open-sided poultry house in the west of Santa Catarina State, south of Brazil.

age, breed, as well as mortality and culling rates. The same animal scientist, with experience in poultry welfare and trained since 2011 in the use of the Welfare Quality® protocol for poultry, performed all on-farm assessments.

The participant farms raised male Cobb MX (nine CS and six OS houses) and Ross TM4 (one CS and four OS houses) and operated in an integrated system within the same company. The birds were evaluated between 33 and 36 days of age, at a mean (± SD) of 6 (± 2) days before slaughter. The summary description of the studied units per house design is shown in Table 1.

All CS houses presented black curtains as fixed material to supplement partial walls and transform the buildings into CS houses; negative ventilation, exhaust fans, sprinklers, light intensity controllers, heating system with automatic control and, in the case of four CS houses, air inlets were also present. The OS houses were semi-climatised, showing laterals with wire mesh covered by double yellow (nine OS houses) or blue (one OS houses) roll-up curtains, positive ventilation by fans, sprinklers, natural and artificial lighting. The company recommended an intermittent lighting programme from the age of 22 days until pre-slaughter, for both CS and OS houses, exposing the birds to 16–18 h of artificial lighting in CS, and natural light complemented with artificial lighting in OS houses. All farms used LED, incandescent, fluorescent, or mixed light types in the same unit, wood-shaving litter and automatic (ten CS and nine OS houses) or manual feeders (one OS house) (Figure 1).

To optimise the data collection time, in 6/10 CS and 5/10 OS farms, which maintained more than one poultry house with comparable conditions, behavioural data were recorded in one house, while other animal welfare indicators were collected in another. On farms with only one house available, data collection started with the behavioural

Table 2 Mean (± SD) indoor relative humidity, temperature, air velocity, light intensity, ammonia (NH_3), carbon dioxide (CO_2) and litter moisture in ten closed- and open-sided poultry houses, from March to April 2019, in the west of Santa Catarina State, south of Brazil.

Variable	Closed-sided houses (n = 10)	Open-sided houses (n = 10)	*P*-value
Relative humidity (%)	74.7 (± 13.2)	72.3 (± 11.3)	0.660
Temperature (°C)	25.9 (± 1.8)	25.9 (± 2.2)	0.995
Air velocity (m s^{-1})	2.1 (± 0.7)	1.1 (± 1.0)	$P < 0.001$
NH_3 (ppm)	11.2 (± 6.8)	7.5 (± 3.9)	0.014
CO_2 (ppm)	1,124.9 (± 461.5)	841 (± 158)	0.025
Light intensity (lux)	6.9 (± 6.3)	274.2 (± 241.9)	$P < 0.001$
Litter moisture (%)	39.5 (± 13.1)	38.6 (± 6.4)	0.422

video-recording and, after recording ended, other animal welfare indicators were evaluated. As a result, a total of 31 houses were evaluated, comprising the collection of complete data from 20 farms.

Health assessment and environmental indicators

Welfare assessments were performed between 0930 and 1740h, and the mean duration for bird health assessment was 185 (± 48) min per flock. The collected on-farm health indicators were contact dermatitis on the breast and abdominal areas, scored on an ordinal scale from 0 (absence) to 3 (severe), bird soiling from 0 to 3, foot-pad dermatitis from 0 to 4 and hock burn from 0 to 4, assessed on the same sample of 150 birds per flock by the same assessor (Welfare Quality® 2009; Souza *et al* 2018b). Lameness was assessed in another sample of 150 birds, from 0 (normal gait) to 5 (unable to walk; Welfare Quality® 2009). The assessment was performed throughout the house, which was divided into 30 equidistant locations, with ten randomly selected birds per location, giving a total of 300 birds assessed per flock.

Health indicators were also collected at the slaughterhouse from four CS and five OS houses. All these flocks were slaughtered in the same slaughterhouse. Two assessors, both with previous experience in collecting animal welfare data at slaughterhouses, were responsible for this phase. For harmonisation of procedures, the assessors were trained in broiler chicken lesion classification with the same pictures showing fractures, bruising and scores of scratches. To accommodate assessment of the high-speed line, selected carcases were assessed, identified by the colour of the bird's hanging hook, which was randomly selected. This was possible because, in the studied slaughterhouse, hooks were often different colours, which meant an interspace between the same coloured hooks of, on average, ten birds or 5 s. This skipping method allowed assessment to be carried out at a slower rhythm compared to the line speed (Souza *et al* 2018b). Due to the speed of the slaughter line and the complexity of certain indicators, the observer assessed one indicator at a time. A total of 100 carcases were assessed for the presence of fractures and a further 100 carcases for the presence of bruises (adapted from Ludtke *et al* 2010). Scratches were scored from 0 (absence) up to score 3 (severe; Souza *et al* 2018b) in 100 additional carcases, giving a total of 300 carcases assessed per flock.

Data provided by the slaughterhouse regarding dead on arrival (DOA), total and partial carcase condemnation for ascites, arthritis, dermatosis, myopathy and air sacculitis were analysed. For two OS houses, it was not possible to assess data for arthritis, dermatosis and air sacculitis, as these data were not available.

Environmental parameters were collected to characterise the indoor living conditions in all units simultaneously to the assessment of health indicators (Table 2). Data were obtained from 30 equidistant locations, at bird level. Relative humidity, temperature and carbon dioxide concentration (CO_2) were assessed with Akso AZ 77535 (Akso, Brazil), as well as the external temperatures at the beginning and end of data collection. Air velocity, ammonia concentration (NH_3) and light intensity were measured with AK 821 Akso, SP2nd NH_3 Senko Portable Single-Gas Ammonia Detector SP22N7 (Senko, South Korea) and Highmed Multifunctional Meter THDLA-500 (Highmed, Brazil), respectively.

For the litter moisture analysis, approximately 400 g of litter were collected at 12 locations per house, avoiding areas near or below the feeders or drinkers. These samples were packed into plastic bags, identified and sent for analysis at the laboratory. Following Tedesco *et al* (1995) for the measurement of litter moisture, 20 to 30 g of litter samples were homogenised and placed in a forced ventilation oven for 24 or 48 h, or until no change in weight was observed with increasing drying time, at 65–70°C.

Bird behaviour

Bird behaviour was recorded with two Canon Vixia HF R800 video cameras (Canon Inc, China). Two 1.5 × 1.5 m steel cable structures were used to demarcate the bird observation area on the floor, one placed in the middle of the house and the other near the wall. The behaviour of birds that were completely visible and with more than half of their bodies within the physical structure was assessed, according to a pre-

Table 3 Ethogram used to record broiler chicken behaviour in ten closed- and ten open-sided poultry houses, from March to April 2019, in the west of Santa Catarina State, south of Brazil.

Behaviour	Definition
Feeding	Having the head in the feeder or pecking at the feed in the feeder
Drinking	Having the beak in touch with the drinker
Foraging	Pecking and/or scratching on the floor
Exploration	Interacting with physical structures that are used to delimit the bird observation area
Comfort	Preening, wing flapping, wing stretching, feather ruffling or shaking, and elements of dustbathing behaviour
Resting	Sitting, lying, or standing while not engaged in other activities, eyes are opened or closed
Locomotion	Running, walking, or jumping
Other	Any additional behaviour performed by broiler chickens other than those included in the ethogram such as vigilance and panting. Elements of aggressive behaviour towards another broiler chicken, such as threatening, leaping, kicking, wing flapping or feather pecking, being disturbed by another bird or disturbing another bird and positive social behaviour such as allow grooming

defined ethogram (Table 3). Observations were made during 4 h per day, for each site of the house, using scan sampling with instantaneous recording every 10 min (Martin & Bateson 1993), totaling 8 h of behavioural observations per unit during the hours of day-time.

Feeding behaviour was not assessed in nine CS and four OS houses next to the wall, and in four CS and three OS in the middle of the house due to the absence of feeders and drinkers within the physical structure. Behaviours with fewer than 20 events during the 4 h observation period were aggregated into the class 'other', except for exploration. Exploratory behaviour was affected by the assessment method, since the birds showed interest in and interacted with the physical structures.

For assessment of the human-animal relationship, a touch test was used in which the observer attempted to touch birds in 21 trials in each barn, recording the number of birds within an arm's length and the number of birds actually touched at each trial. For these results, the data were expressed as a number score that ranged from zero to 100, with zero meaning that no animals were touched, and 100 that all animals within reach touched, based on calculations in the 'Good human-animal relationship' section within the Welfare Quality® protocol (Welfare Quality® 2009).

Bird affective states

After a 10 min observation period, the Qualitative Behaviour Assessment (QBA) was performed before other indoor evaluation procedures were started. The assessor recorded 25 emotional descriptors on a visual analogue scale that ranged from 0 mm (indicating that the emotion seemed entirely absent in the group of animals observed) to 125 mm (the emotion seemed dominant) (Welfare Quality® 2009; Souza *et al* 2021). The terms used were the Portuguese equivalents for 'scared', 'inquisitive', 'painful', 'relaxed', 'aggressive', 'positively occupied', 'lethargic', 'comfortable', 'fearful', 'active', 'dull', 'confident', 'agitated', 'interested', 'apathetic', 'playful', 'desperate', 'apprehensive', 'attentive', 'distressed', 'calm', 'frustrated', 'lively', 'disturbed' and 'tranquil', developed for Brazilian Portuguese native speakers (Souza *et al* 2021).

Statistical analysis

Differences in stocking density, house size, flock size, age at visit, age at slaughter, bodyweight at slaughter, mortality, culls, touch test and litter moisture according to the type of poultry house were analysed by *t*-test for two independent samples.

For bird soiling, foot-pad dermatitis, hock burn, lameness and contact dermatitis on the breast and abdominal areas, data were fitted into a multinomial model that considered the type of house as the explanatory variable. The house effect was also incorporated into the models by means of a random effect assumed to follow a normal distribution with the mean equal to zero and constant variance (σ^2). Two classes of regression models were considered for the multinomial data, the proportional odds models and the generalised logit models. Due to the low frequencies of some indicators, scores were aggregated as follows: contact dermatitis on the breast and abdominal areas, where C1 corresponds to the 0 score, C2 = 1 and C3 = 2 + 3; for bird soiling, C1 = 0, C2 = 1 and C3 = 2 + 3; for foot-pad dermatitis, C1 = 0, C2 = 1 and C3 = 2 + 3 + 4; for hock burn, C1 = 0, C2 = 1 and C3 = 2 + 3 + 4; and for lameness, C1 = 0 + 1, C2 = 2 + 3 and C3 = 4 + 5. The likelihood ratio test was used for these five indicators to verify the assumption of proportional odds for ordinal scale data at 5% significance. The results provided by the fitted model were presented as odds ratios. The odds ratios were associated with lower scores of the indicators, meaning worse welfare, and respective confidence intervals. In addition, the estimated probabilities are also presented in plots. The Wald test, based on the asymptotic normality of the maximum likelihood estimators, was used to evaluate the effect of house type.

Table 4 Estimated odds ratios for worse scores on contact dermatitis on the breast and abdominal areas, bird soiling, foot-pad dermatitis, hock burn and lameness for ten closed- and open-sided poultry houses, from March to April 2019, in the west of Santa Catarina State, south of Brazil.

Variables	Closed- /open-sided poultry houses		
	Odds ratio	CI (95%)	*P*-value
Contact dermatitis on the breast and abdominal areas	2.16	(1.10; 4.28)	0.026
Bird soiling	0.71	(1.16; 3.06)	0.651
Foot-pad dermatitis	0.60	(0.15; 2.32)	0.467
Hock burn	0.83	(0.15; 2.32)	0.744
Lameness	1.10	(0.46; 2.63)	0.821

Data from the slaughterhouse were analysed with generalised linear models. The half normal plot for residuals with simulated bands was used in order to detect overdispersion or any other source of lack of fit. For fractures, bruises and scratches, a binary logistic regression model was used. Furthermore, for scratches, a proportional odds regression model, for ordinal data, was used. For DOA and diseases, such as ascites, arthritis, dermatosis, myopathy and air sacculitis, a regression model with Poisson response was initially fitted; however, due to data overdispersion, the negative binomial regression model was used. The negative binomial distribution allowed for the incorporation of the additional variation present in the available data which had not been accounted for the type of house, ie factors specific to the poultry houses. At this stage, the only explanatory variable considered was the type of house and log corresponding to the number of animals in each poultry house.

The environmental measurements were analysed by fitting linear models, including random effects for each poultry house design. To accommodate possible heterogeneity of variances in both types of house, an additional parameter was incorporated into the model to adjust eventual heteroscedasticity between house types. The difference between the mean environmental conditions of houses was tested based on the student's *t*-test.

Data from the animal behaviour assessment were analysed by fitting regression models to count data. The frequencies of the different types of behaviour were analysed through log-linear models, as usually applied to data available on multi-dimensional contingency tables. In such cases, the registered frequencies are taken as the response variable, and all categorical variables composing the contingency table are considered predictors. The effect of type of house on type of behaviour was assessed by testing their corresponding interaction. The effect of recording location, in the side- or mid-location in the barn, was considered also. As not all observed areas included feeder and drinker records, a possible effect of access or otherwise to feeders and drinkers was included in the fitting model by means of an indicator covariate. Finally, the total log frequencies of animals in each poultry house were included in the model. The data were firstly analysed using the Poisson distribution. However, as the data again showed overdispersion, we opted for the negative binomial distribution, with a logarithm link function. In the case of multiple comparisons, the *P*-values were adjusted using Tukey's method.

Principal Component Analysis (PCA) (Johnson & Wichern 2007) was conducted, with no rotation, in order to exploit the correlation structure of the 25 investigated features for QBA. Parallel analysis (Franklin *et al* 1995), based on simulated datasets under independence structure, was used to choose how many components to retain. Two components explained most of the variance in the data. With the results from PCA, the principal coordinates (scores) for each type of house were calculated and then the comparison of the scores for CS and OS houses were performed. The difference between house types was tested based on the *t*-test for two independent samples for each component.

All conclusions were based on a significance level of 5%, using R software (R Core Team 2019). The ordinal package was used to fit multinomial models, nlme package for mixed linear models, and the ggplot2 package for graphics.

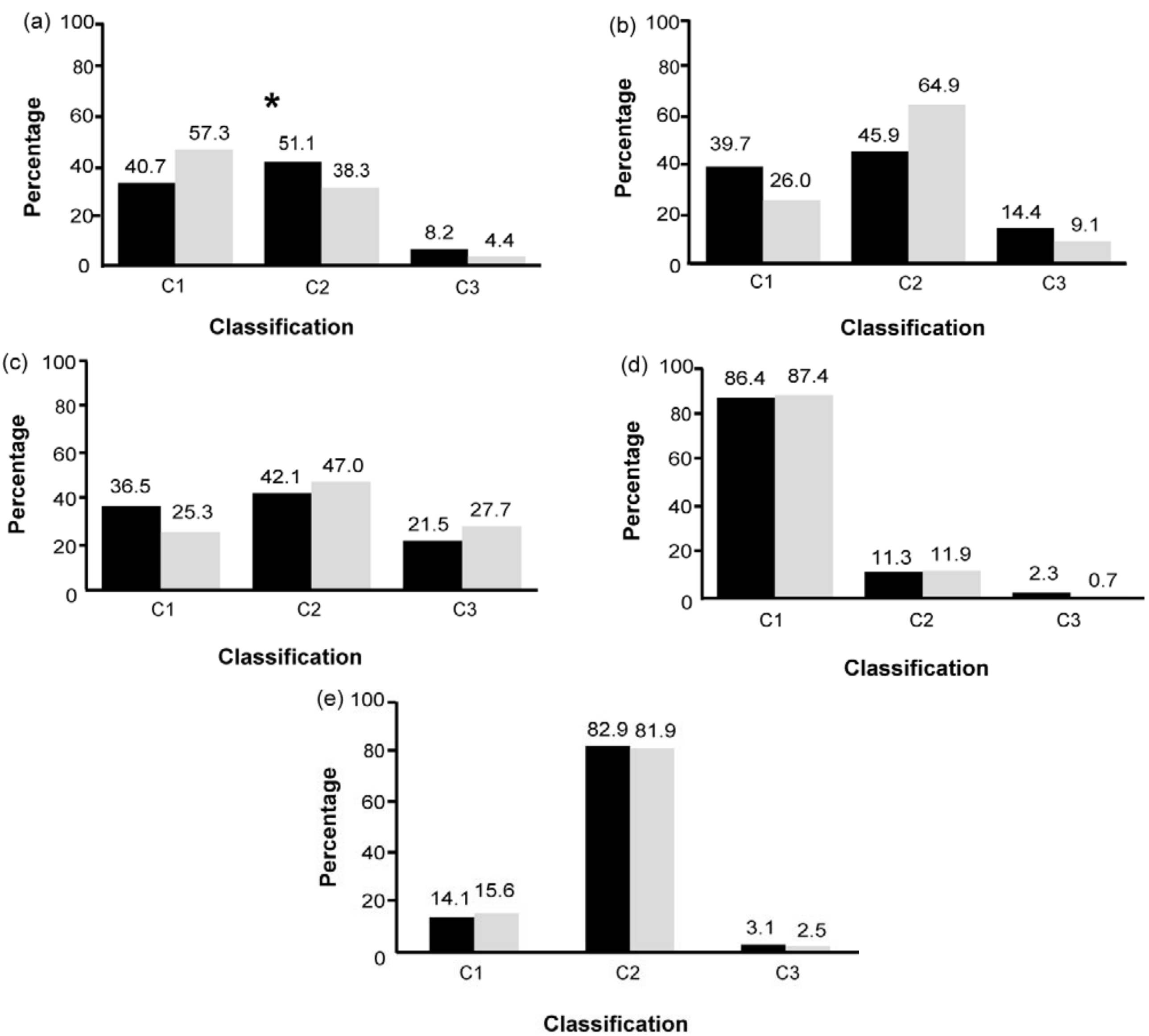
Results

Health assessment

The only health indicator assessed on-farm that differed between CS and OS houses was contact dermatitis on the breast and abdominal areas, with better scores in OS houses (Table 4, Figure 2).

The average DOA was 0.05 (± 0.02) and 0.04 (± 0.02)% for CS and OS houses, respectively. The only slaughterhouse health indicator that differed between house types was scratches. The odds ratio OS/CS houses estimated for this lesion was 1.29 (P = 0.043). Means of 59.5 and 66.8% of some level of scratches (score 1 to 3) were observed in CS (0 score = 40.5%, 1 = 39.3%, 2 = 16.5% and 3 = 3.8%) and OS (0 score = 33.2%, 1 = 44.0%, 2 = 16.0% and 3 = 6.8%) houses, respectively. And, finally, the frequencies of occurrence of fractures were 0.005 and 0.01% and of bruising were 0.18 and 0.14% for CS and OS houses, respectively.

Figure 2



Overall mean percentage of (a) contact dermatitis on the breast and abdominal areas (C1 corresponds to the 0 score, C2 = 1 and C3 = 2 + 3), (b) bird soiling (C1 = 0, C2 = 1 and C3 = 2 + 3), (c) foot-pad dermatitis (C1 = 0, C2 = 1 and C3 = 2 + 3 + 4), (d) hock burn (C1 = 0, C2 = 1 and C3 = 2 + 3 + 4) and (e) lameness (C1 = 0 + 1, C2 = 2 + 3 and C3 = 4 + 5). Black denotes closed- and grey open-sided housing. * $P < 0.05$.

Bird behaviour

Two behaviours presented different frequencies between CS and OS houses (Table 5). The odds ratio of exploratory behaviour was 75.1% higher (1.75 times) in OS compared to CS houses; for the category 'other' the odds ratio was 87.7% higher (1.87 times). Within the 'other' category, the main behaviour was panting (97.6%), with frequencies of 93.1% in CS and 97.4% in OS houses. The frequencies of drinking (P = 0.610) and feeding (P = 0.380) showed no significant difference between CS and OS houses.

Overall, there was a mean of 25.0 (± 7.0) birds within the physical structure for behavioural observation next to the wall and 29.6 (± 6.6) birds for the structure in the middle of the house; the same trend was observed for both house types. In both types of house and all observation sites, most birds (55.0%) exhibited resting behaviour. This behaviour accounted for 59.5% of total behavioural activities in CS and 50.5% in OS houses, followed by 'other' (9.0 and 16.2%), comfort (9.4 and 10.2%) and foraging (7.2 and 4.8%) behaviours, respectively.

The touch test presented high mean scores (min–max) of 90 (71–100) in CS and 86 (70–99) in OS houses (P = 0.179). The mean number of birds within arm's reach per attempt was 2.8 (± 2.0) birds in CS and 2.3 (± 1.8) birds in OS houses; the number of broiler chickens actually touched was 3.0 (± 1.0) and 2.0 (± 1.0) chickens for CS and OS houses, respectively.

Table 5 Relative frequencies of behaviours according to ten open- relative to ten closed-sided poultry houses, from March to April 2019, in the west of Santa Catarina State, south of Brazil.

Behaviour	Ratio	SE	*P*-value
Foraging	0.76	0.15	0.198
Exploration	1.75	0.39	0.012
Comfort	1.11	0.22	0.603
Resting	0.91	0.17	0.638
Locomotion	1.17	0.24	0.427
Other	1.87	0.37	0.002

Bird affective states

Principal Component Analysis of the 25 QBA terms revealed two principal components which explained 28.18 and 26.16% of the variation. Scores for the first and second components presented no difference between CS and OS houses. The mean (± SD) scores for the first component were 0.75 (± 0.72) and –0.75 (± 3.46) ($P = 0.227$) and, for the second, –0.95 (± 3.33) and 0.95 (± 2.99) ($P = 0.118$), for CS and OS houses, respectively. Figure 3 shows the overall component loadings of each QBA term across the two principal components. The first component suggests a mood dimension, with higher loadings representing positive emotions that ranged from playful to comfortable and lower loadings ranging from painful to apathetic. The second component ranged from distressed to aggressive.

Discussion

Our aim was to assess the effect of CS and OS house designs on broiler chicken welfare indicators. Results obtained in CS houses were worse for environmental measures, such as light intensity, NH_3 and CO_2 concentrations, and two animal-based measures (contact dermatitis on the breast and abdominal areas, and exploratory behaviour). The higher stocking density practiced in CS houses, as described in the literature (Tuyttens *et al* 2015; Lima *et al* 2020) was confirmed. The animal density results are relevant also because citizens perceive stocking density and pen sizes as very essential for farm animal welfare (Vanhonacker *et al* 2009). For OS houses, we observed slower air velocity as well as higher prevalences for two animal-based measures, namely scratches and panting behaviour. Other house effects on health and environmental indicators, bird behaviour and affective states were not observed.

It is important to consider that animal welfare may be understood in different ways. For the World Organisation for Animal Health (OIE 2019a), the scientific assessment of animal welfare involves diverse elements which need to be considered together; selecting and weighing these elements often involves value-based assumptions. Thus, the OIE (2019b) recommended some useful indicators of broiler chicken welfare, such as mortality, gait, contact dermatitis, feather condition, incidence of diseases, metabolic disorders, behaviour, water and feed consumption, performance, biosecurity, and animal health, that may be adapted to the different situations where these birds are managed, and most of these indicators were assessed in this study. Birds reared in CS houses were 2.16 times more likely to have contact dermatitis on the breast and abdominal area as compared to those reared in OS houses (Table 4). Contact dermatitis is an important animal-based indicator, and both hock burn and foot-pad dermatitis are associated with pain (EFSA 2012b). Besides, further evidence for the importance of dermatitis has been proposed by Souza *et al* (2015b), who observed absence of breast blister, the former indicator for this area of the body, in both certified and non-certified intensive poultry farms in the State of Paraná, Brazil, suggesting that a more sensitive indicator was needed. Therefore, the assessment of contact dermatitis on the breast and abdominal areas was developed and tested (Souza *et al* 2018b); this indicator was clearly useful in distinguishing bird welfare between two different types of houses in our work. Different factors may affect the prevalence of contact dermatitis. Although re-using litter is common practice in the Brazilian poultry industry (Carvalho *et al* 2011), this may lead to lesions and compromise broiler chicken welfare (Baracho *et al* 2013) as it relates to lower litter quality for animals raised in re-used bedding.

When moisture values are higher than 30%, litter may be considered wet, and this litter condition has been associated with dermatitis (Taira *et al* 2014); this value is close to those in both types of poultry house studied. The number of flocks per litter and the stocking density, both higher in CS than OS houses, are associated with higher litter moisture and may have contributed to decreased litter quality, which is considered an important factor in the appearance of skin lesions (Allain *et al* 2009). In general, higher stocking densities are associated with several animal health and behaviour problems, as well as poor litter quality (Buijs *et al* 2009; EFSA 2012a; Lima *et al* 2020). Bailie *et al* (2018) also suggest that increasing stocking density is a risk factor for more severe dermatitis. Thus, litter quality seems relevant for bird welfare and the monitoring and corrections for environmental quality may prevent its negative consequences for the animals.

Scratches were more prevalent in OS than CS houses. Allain *et al* (2009) evaluated various types of lesions in broiler chicken flocks in France and observed most of the flocks (48/55) with scratches, a prevalence equivalent to 79.7 (± 13.1)%, a value which is higher than our results. Souza *et al* (2018b) assumed the multiple occurrences of the same type of lesion as being indicative of a welfare problem and increased suffering. The higher the automation level of the house, the lower the incidence of scratches (Pilecco *et al* 2011a), thereby providing a general rationale for the lower occurrence of scratches in CS than OS houses. However, this rationale does not clarify the underlying causes for the lesions. Increased stocking density, lack of plumage, type of daily handling, age and gender of the bird, catching procedures, number of birds per transport box, transport quality and duration, and number of hours that birds await slaughter

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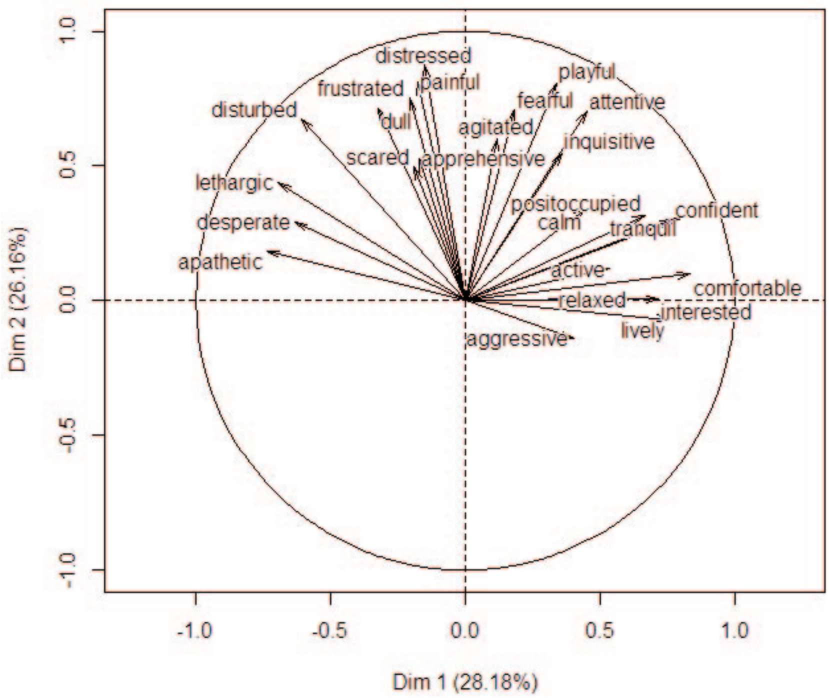
Figure 3



Principal component loadings for each QBA term across the two principal components, for ten closed- and open-sided poultry houses, from March to April 2019, in the west of Santa Catarina State, south of Brazil. Positoccupied = positively occupied.

may all be considered as potential risk factors for scratches (Elfadil *et al* 1996; Pilecco *et al* 2011a,b). The light intensity, one of the significant differences between CS and OS houses, may be related to the greater occurrence of scratches in OS, since a better lit environment tends to increase bird activity and this, in turn, may result in more scratches. On the other hand, an environment with low lighting, as was permanently the case in CS houses, may minimise fear reactions in birds (Humane Farm Animal Care [HFAC] 2014). However, it may not be possible to sufficiently reduce lighting in OS houses during catching procedures. This situation may be considered a critical point for animal welfare, due to the increased prevalence of scratches it may cause. In addition, according to Bailie *et al* (2013), the increased contrast between lighter and darker areas may increase birds' perception of items which are relevant to them. This information suggests that the birds perceive and better manage their environment when exposed to important environmental conditions, such as adequate lighting. This hypothesis also seems in accordance with the greater occurrence of exploratory behaviour observed in OS houses. However, the possible causes for the scratches require further investigation and the development of strategies for their avoidance, especially because scratches are painful to the birds.

Overall results regarding relative humidity (Table 2) were close to the acceptable limit of 70% (EFSA 2012a; Defra 2018). Both CS and OS houses presented higher average temperatures (Table 2) than the 21–22ºC recommended for six week old broiler chickens (Furlan & Macari 2002). Even though comfortable temperatures are more expected in CS when compared to OS houses (Carvalho *et al* 2015), our results did not confirm this expectation and birds in both house types were subjected to thermal discomfort. This situation is likely related to the fact that the welfare assessment was conducted during the summer, and more research is needed to understand whether results from these two types of housing differ during other seasons. Overall results for panting behaviour showed high frequencies in both types of houses, and significantly higher values for birds in OS houses. Federici *et al* (2016) observed median scores for thermal comfort, classified by the Welfare Quality® protocol as acceptable, in OS houses with extra fans and with high frequency of panting. However, the same authors emphasised that the increase in use of CS houses may not solve the problem of heat stress, because of the higher stocking densities commonly practiced in CS houses as compared to OS houses in Brazil. The excessive heat is a highly stressful factor for birds (Olanrewaju *et al* 2010), which emphasises the importance of controlling thermal stress in both types of houses. Our results for panting may be associated with the barn ventilation rates, which were different between CS and OS houses (Table 2). The ventilation may help to remove moisture and heat, promoting air renewal (Nääs *et al* 2014). Therefore, both panting and ventilation require monitoring, preferably by closely verifying animal-based indicators such as panting.

Although the concentrations of NH_3 and CO_2 did not exceed the respective limits of 20 and 3,000 ppm (EU 2007; RSPCA 2017; Defra 2018) in any type of house, CS houses

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showed higher concentrations of these gases. Probably the handling of the curtains favoured air renewal in OS houses, even though at the time of the assessment the air velocity was 0 m s^{-1} in 64/300 measurements in OS houses, whereas in CS houses air velocity was never lower than 0.5 m s^{-1}, the minimum recommended for broiler chickens after 14 days of age (Cobb 2018). Ventilation and air quality are recognised as key factors for animal welfare (Jones *et al* 2005; Baracho *et al* 2018). Stocking density is also an important factor along with environmental indicators (Jones *et al* 2005). Our results show that indoor environmental indicators need improvement in both poultry house types. This may be achieved by reducing the production of harmful gases, with strategies involving the reduction of stocking densities, improvement in litter quality and providing higher air renewal. In addition, our results indicate the need for managers of both types of poultry house to monitor more closely and take corrective actions for indoor air quality and velocity.

Different light intensity values were observed between house types. The CS houses (6.9 [± 6.3] lux) were far below the broiler chicken welfare recommendations of a minimum of 20 lux measured at bird eye level (EU 2007; EFSA 2012a), even though it complies with the recommendations from the breeder companies of 5–10 lux (Ross 2014; Cobb 2018). Clearly, private recommendations that are below regulatory animal welfare thresholds constitute an important problem to be addressed. Birds reared in 5 lux are less active than those in 20 lux (Rault *et al* 2017). Additionally, under 1 lux, fundamental eye characteristics, such as eye size, are affected (Deep *et al* 2010). Nonetheless, in CS houses very low light intensity was used for at least 60% of the birds' lives, which may force a constant resting state on broiler chickens. According to Paranhos da Costa *et al* (2017), bird behaviour under continuous low lighting may be confounded with a calm state; however, animals may be in an apathetic state instead. Our results did show that light intensity was, on average, much lower in CS, which may be aggravated by a lack of standardisation of the provided light types. Light characteristics may directly influence physical, psychological and behavioural aspects of chicken welfare. For instance, some light sources provide light without emitting relevant ultraviolet wavelengths (Bailie *et al* 2013), which affect the visual capabilities of chickens, that differ from human visual abilities (Prescott *et al* 2003). Therefore, new studies into the types of lighting used in commercial farms and their welfare consequences are warranted.

Weary (2014) suggests behaviour assessment as a method of identifying animal suffering, to observe if an animal is experiencing a negative affect such as pain, as animals tend to show a decline in highly motivated behaviours when in negative emotional states. We have observed a high prevalence of some lesions and a restricted behavioural repertoire. Statistical differences between birds from CS and OS houses were observed for exploratory behaviour and the 'other' category, mostly composed of panting. Classically, exploratory behaviour relates to the search for information about the environment. From an evolutionary perspective, it was probably important for birds to anticipate and seek changes through exploratory behaviour; however, the paucity of stimuli may lead the animals to decrease their motivation to explore (Newberry 1999). This information suggests that the OS houses may offer better conditions for birds than CS in terms of exploratory behaviour, as the broiler chickens, when motivated, may be more able to seek opportunities to explore novel stimuli (Newberry 1999). According to our observations, the physical structure used to delimit the experimental bird observation area served to promote exploration in both types of house, and the difference in exploratory behaviour may be related to the higher light intensity in OS. Birds reared in OS houses showed higher panting behaviour than those in CS houses, suggesting that OS houses require improvements regarding indoor temperature control. Although the OS houses may lead to better air quality and more behavioural opportunities for the birds, there is a risk for animals suffering due to exposure to high temperatures (Lima & Silva 2019), which was evident in our results.

Resting was the commonest behaviour, which may be related to bird age and locomotor problems. In a study by Weeks *et al* (2000), birds aged between 39 and 49 days remained lying, on average, 76% of the time, and this percentage increased to 86% for birds with score 3 for lameness, described as a bird with obvious gait abnormality that affects the ability to move. In our study, the mean resting time was 55.0% and lameness scores 2 + 3 showed high percentages in both CS (82.9%) and OS (81.9%). Lack of environmental complexity may also be a cause of high frequencies of resting behaviour. According to Bailie *et al* (2013), birds may engage in other activities if stimulated. During our data collection, exploratory behaviour, which is considered important for the birds (Newberry 1999), differed statistically between CS and OS houses. No environmental enrichment was available for the birds, emphasising that the industry is still very limited in relation to the consideration of birds' behavioural needs.

Results from QBA, which considers the expressive quality of how animals behave and interact with the environment and with each other (Welfare Quality® 2009), did not reveal differences according to house types and the set of terms displayed by first and second components seemed consistent between house types. For example, flocks with emotional states such as comfortable and tranquil did not express desperate or apathetic states, being observed in opposite directions (Figure 3). On the other hand, flocks in painful or distressed moods were also associated with fearful or agitated feelings. However, Tuyttens *et al* (2015) showed differences between broiler flocks assessed in Belgium, in CS houses and in Brazil, in OS houses. The authors observed Brazilian flocks as more comfortable, content, energetic and positively occupied than Belgian flocks. Therefore, greater understanding of the effects of house type on positive emotional states may benefit from further research.

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The touch test relies on the rationale that broiler chickens will withdraw from the observer if they are fearful (Welfare Quality® 2009). Our results showed high mean scores (90 in CS and 86 in OS houses) in both types of poultry houses, indicating few avoidance reactions towards humans. However, the results of this test may also be associated with reduced walking ability, when birds have more difficulty in reaching valued resources or expressing emotional states (Vasdal *et al* 2017). Our results for the touch test may be related to the prevalences of more severe lameness scores (3 and 4), which were 3.1 and 2.5% in CS and OS houses, respectively. These percentages were lower than the 14.0% observed by Federici *et al* (2016), in a study with a score of 99 for touch test. Thus, data considering lameness scores and touch test suggest that the higher the prevalence of severe lameness, the more birds are touched, indicating that the intuitive positive correlation between lameness and touch test may be correct and that the idea of the touch test as a measure of fear should be challenged. Additionally, although our results did not differ between types of poultry houses, Bassler *et al* (2013) found that length of dark period for broiler chickens at three weeks of age was a risk factor for the touch test results for 89 flocks assessed. Thus, it is also possible that the touch test results may differ according to lighting programmes (Federici *et al* 2016). Overall, our touch test results endorse the perceived flaws regarding its value as a measurement of birds' fear of humans.

Animal welfare implications

The implications of this work are highly relevant for the Brazilian poultry meat industry. The results suggest that both house types have different but considerable animal welfare problems. However, this study may help prioritise strategies that seek to address each problem according to on-field scientific knowledge. Additionally, detailed information on the welfare comparison between closed- and open-sided houses is timely, since there is a strong tendency for the Brazilian poultry industry to move from the conventional open-sided facilities to closed-sided houses. The motivation for this movement is that closed-sided houses are seen as better in terms of financial return and workload requirement. For the birds, this means that the industry is moving towards a system with specific animal welfare problems, such as increased behavioural and space restrictions, as well as lower light intensity, in a country where the number of chickens is in the scale of billions of individuals.

Conclusion

Closed-sided poultry houses showed worse welfare results considering environmental indicators such as light intensity, NH_3 and CO_2 concentrations, and for two animal-based measures, namely contact dermatitis on the breast and abdominal areas and exploratory behaviour. Air velocity and two other animal-based measures, namely scratches and behaviours classified as 'others', mostly composed of panting, showed worse results for open-sided houses. There were no other significant differences between both housing types on health assessment, environmental indicators, bird behaviour or affective states. This research has revealed that bird welfare in both house types, for the region and season assessed, was compromised as evidenced by poor environmental conditions, considerable behavioural restrictions and a high prevalence of injuries.

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