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EFFECTS OF STOCKING DENSITY AND STRING ON BROILERS

Effects of stocking density and string provision on welfare-related measures in commercial broiler chickens in windowed houses

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ABSTRACT

Lower stocking densities are sometimes used in windowed houses for broilers as part of systems designed to produce high welfare products. However there is little scientific information on the effects of stocking density (SD) on welfare-related measures in broilers in windowed houses, and on whether these effects are influenced by environmental enrichment. Commercial windowed broiler chicken houses were assigned to four target SD's (30, 32, 34 and 36 kg/m^2) and two levels of access to string (+S (one piece per 1 000 birds/house), -S) in a 4 x 2 factorial arrangement. Treatments were applied in one of four houses on each of two farms, and replicated over ten production cycles. Levels of lying behavior, apparent fear-related behavior and gait score were observed in weeks 3-5. The incidence and severity of dermatitis lesions were assessed at day 30, and at slaughter. Environmental and production performance parameters were also measured. No significant treatment effects were obtained for levels of lying or fear-related behavior, final body weight, presence of dermatitis lesions at slaughter, or percentage of downgraded carcasses. There were no significant treatment effects on measures of gait, but the percentage of birds with gait score of ≥ 2 tended to increase at higher SD's. The severity of dermatitis lesions at day 30 increased with increasing SD, and was significantly greater at densities of 34 and 36 kg/m^2, than of 30kg/m^2. Litter moisture content was not significantly affected by treatment, which may have reflected a numerical decline in water consumption with increasing SD. Results suggest that increasing SD is a risk factor for more severe dermatitis, however increasing density from 30 to 32 kg/m^2 did not significantly affect this variable. In addition, the proportion of lame birds, levels of lying behavior and performance were not significantly affected by increasing SD. Providing suspended string at typical commercial levels did not have beneficial effects on welfare-related measures, and further research should perhaps investigate effects of greater levels of provision.

Key words: Broiler, stocking density, behavior, welfare

INTRODUCTION

There is anecdotal evidence of an increased use of windowed housing for broiler chickens in the UK, and this is supported by the fact that these systems are now recommended as part of the UK Assured Chicken Production quality assurance scheme (Assured Food Standards (AFS) Poultry Standards - Broilers & Poussin v3.0, 2014). However there is very little applied research on how to manage these systems such that optimum welfare and production efficiency is achieved. The effect of stocking density is key in this respect. A number of the major British retailers offer high welfare chicken products which require birds to be stocked at a maximum density of 30kg/m^2 within windowed house systems. This is consistent with the minimum requirements of the UK Royal Society for the Protection of Animals (RSPCA) freedom foods welfare assurance scheme (RSPCA Welfare Standards for Chickens, 2013). However the effect of increasing stocking density on welfare, and also on performance parameters, has not been scientifically assessed within windowed systems to determine if adverse effects occur. Previous research has shown that providing natural light to commercial broiler chickens increases activity levels and improves litter quality (Bailie *et al*., 2013), and it is possible that these effects may help to mitigate potential adverse effects on welfare associated with increasing stocking density.

As meat yield per unit of space increases with increasing density (Puron *et al*., 1995; Feddes *et al*., 2002), increasing the stocking density within these systems would allow for a significant increase in economic return, even taking into account the extra feed costs incurred by rearing additional birds. In addition, heating outlay may actually reduce in more densely stocked flocks; helping to offset these extra costs. However, results from past research suggest that broiler health and welfare may be compromised at stocking densities of 34 kg/m^2 and above (Estevez, 2007). In research carried out with broilers under artificially-lit conditions, high stocking densities have previously been associated with a reduction in locomotion and exploratory behaviors (Febrer *et al.*, 2006), with increased disturbance of resting behavior (Martrenchar *et al.,* 1997; Febrer *et al.,* 2006), and with increases in leg health problems such as pododermatitis and hock lesions (Martrenchar *et al.*, 1997).

Environmental enrichment has previously been shown to reduce fearfulness (Jones, 1996), inactivity and lameness in poultry (Kells *et al.*, 2001; Bailie *et al.,* 2013; Bailie and O'Connell, 2015) and may therefore influence the extent to which increasing stocking density affects broiler welfare. In particular, the provision of suspended string has been shown to exert a positive impact on the walking ability of commercial broilers reared in natural light (Bailie and O'Connell, 2015).

As mentioned, previous research has examined the effects of providing broiler chickens with access to natural light through windows on welfare-related measures (Bailie et al., 2013). The aim of the current study was to investigate the effects of stocking density and the provision of string on activity levels, apparent fearfulness, leg health and productivity of commercial broiler chickens reared *within* windowed houses. We hypothesised that fearfulness would increase and activity levels, leg health and productivity would decline with increasing stocking density and that the provision of string would mitigate at least some of these adverse effects.

MATERIALS AND METHODS

Treatments and experimental design

The effects of stocking density (SD) and the provision of string (S) on the welfare of commercial broiler chickens was assessed in 4 x 2 factorial arrangement which took place in Northern Ireland between May 2013 and November 2014. The numbers of birds placed in each house were manipulated in order to produce target stocking densities of 30, 32, 34 and 36 kg/m^2 which equated to initial densities of 17, 18, 19 and 20 birds/m^2 and, allowing for mortality, thinning of the flock and an end weight of 2.5 kg, resulted in maximum final densities of 12, 13, 14 and 15 birds/m^2. The target densities at which houses were stocked within the current trial conformed to the legislative requirements found in the EU broiler directive (Council Directive 2007/43/EC), and were perceived to be representative of the range of stocking densities most likely to be implemented by the UK poultry industry in windowed houses at this time. Multiple pieces of string (one piece per 1000 birds, each measuring 60 cm x 10 mm) were distributed as evenly as possible throughout the house in the string (S) treatments. One piece of string was tied at its mid-point to the wire above each of the four feeder lines within the house at approximately even intervals. String was presented at the midpoint between individual feeders. The wire was positioned 33 cm above the litter at the beginning of the rearing cycle and was gradually raised to a maximum height of approximately 50 cm above the litter (as feeders were raised to encourage growing birds to feed in a standing position). The ends of the string were therefore situated between 3 and 20 cm above the litter at different points in the rearing cycle depending on the growth rate of the birds.

Eight houses were selected for this study, and included two matched pairs of houses on each of two farms. On Farm 1 Pair 1 comprised Houses 1 and 2, and Pair 2 comprised Houses 3 and 4. On Farm 2 Pair 3 comprised Houses 5 and 6 and Pair 4 comprised Houses 7 and 8. All eight houses were of an identical rectangular design and had the same number of windows, with the exception that Pair 1 and 3 houses had a central doorway and Pair 2 and 4 houses had a door that was offset to either the right or left. Orientation of houses also differed between farms (Figure 1). The birds used were part of the normal commercial enterprises of the company and each treatment was replicated 10 times, with each treatment randomly presented in one of the eight houses each cycle (Supplementary Table). In each cycle, the date when chicks were placed was matched exactly for all four houses on each farm and did not differ by more than a week between the farms. Ethical approval for the study was granted by the School of Biological Sciences Animal Research Ethics Committee at Queen's University, Belfast (Approval reference number QUB-BS-AREC-16-002).

Animals, husbandry and housing

A total of 1 970 000 Ross 307 broiler chickens (Aviagen Ltd, UK) were used in this experiment. Birds were placed in houses 'as hatched', resulting in mixed sex houses. An average of 38% of birds per house were removed early for slaughter ('thinned') after day 31 of the production cycle, and the remaining birds were removed between days 36 and 44 ('final clearing'). Stocking densities did not exceed 36 kg/m^2 at any stage of the production cycle. Temperature, ventilation and feeding regimes, sources and blends were identical between houses. Birds were fed on an *ad libitum* basis and received 3 different commercially-available diets across the production cycle. Houses 1, 2, 3 and 4 contained 354 feeders and 1 970 drinkers, and Houses 5, 6, 7 and 8 contained 348 feeders and 2 260 drinkers. These numbers remained fixed across the rearing cycle. All drinkers were of the nipple variety and included cups.

The artificial lighting regime was identical across all houses (see Bailie *et al*., 2013). The dark period was between 2300 and 0500 hours for Farm 1 and between 0000 and 0600 hours for Farm 2. Both lights and shutters, which blocked external light, were automatically controlled using timers. The artificial light source in all houses consisted of 2 rows of 24 fluorescent strip lights running parallel to each other along the length of the house.

Large gas pan heaters were placed in 2 uniform lines down the length of all houses. Straw bales (2 per 1 000 birds), each measuring 800 x 400 x 400 mm, were dispersed evenly throughout each house from day 10 of the rearing cycle. Sixty-six kg of wood shavings per thousand birds was placed in the house for bedding prior to the birds arriving. Additional shavings were added to specific areas of the houses when deemed necessary by the farmer.

Measurements

Behavioral Observations. Behavior was assessed during two days each week between weeks 3 and 5 of the rearing cycle. Video observations of lying behavior (as a measure of general inactivity) were made on day 1, and a fearfulness test and gait scoring were conducted on day 2. All behavioral observations were taken between the hours of 0900 and 1700. The entire house was mapped and virtually divided into thirty-six equal size quadrants.

On each farm, two video cameras on tripods were employed to record lying behavior in one house from each of the two pairs of houses simultaneously, before repeating the procedure in the second house of each pair. The house in which initial observations were carried out was alternated on a weekly basis for each pair of houses. Video recordings were taken in four quadrants per house per week. Quadrants were preselected using a random number table and a different set was chosen each week (with the same quadrants used across houses within a week). Quadrants that were selected did not contain strings or straw bales in order to ascertain whether or not the presence of enrichment stimulated increased activity in the population as a whole. In addition, quadrants were categorized as either ‘edge’ or ‘centre’ quadrants, and were selected in pairs for video recording, each pair comprising one edge and one centre quadrant.

The quadrant was filmed for a period of 15 min in the absence of the researcher. The birds did not appear to show significant interest in the tripods when they were placed in the house, but the first 5 min of film was cut from all videos in order to ensure a settling period had been imposed after the exit of the researcher from the house. Instantaneous scan sampling for each 10 minute clip involved recording both the total number of birds and the numbers of birds lying at 180 second intervals. The percentage of birds lying was then determined.

A novel object test to determine apparent fearfulness was conducted in one randomly-selected quadrant in each house each week. The same quadrant was used in all houses within a given week. The experimenter gently placed a novel object upright among the birds and walked to a distance of approximately 4 m away. The latency of the first bird to approach and contact the object after it had been placed on the ground was measured using a stop watch. If no bird approached the object within 10 min a maximum latency of 600 s was recorded and the test was terminated. The number of times the object was contacted in the 60 s following the first contact with the object was also recorded, along with the number of birds within 50 cm of the object at 600 s. In order that the latter measure is representative of the degree of fearfulness rather than simply stocking density differences, the difference between the number of birds expected within a 50 cm radius of the novel object and the actual numbers of birds recorded within this area was calculated for each treatment. The total floor area and number of birds per house were used to calculate the expected number of birds in the area around the NO (assuming an equal distribution of birds across the house). In order to prevent habituation, a different novel object was used in all houses each week; a green plastic watering can, a 750 ml clear water bottle filled with water containing red food colouring and a blue cool box. However, the same novel object was presented in all houses during the same week throughout all cycles.

Walking ability was assessed using spontaneous gait scoring. Each assessment was performed in 25 quadrants in each house on day two of each week. Quadrants were randomly selected each week with the added provision that each quadrant was only selected once. During the first four monitored cycles of this experiment an ‘x’ was drawn on a randomly chosen section of a perspex grid divided into thirty-six 5 cm² squares (Kells *et al.,* 2001). The Perspex was held up at arm's length at the edge of the selected quadrant. The bird observed closest to the ‘x’ was gait scored. The same protocol was followed during cycles five-ten with the exception that the selected bird in each quadrant was videoed for at least 10 steps and gait scored at a later date. Gait scoring was performed by the same researcher throughout the trial and was scored on a scale of 0-5 where 0 = normal movement and 5 = unable to walk (Kestin *et al.,* 1992). The selection, gait scoring/ videoing of birds was conducted within 1 house before moving on to a subsequent house on a given farm, and the first house used in observations was alternated weekly. The proportion of birds in each treatment assigned a score of 3 or above (deemed to be lame) and assigned a score of 2 or above was ascertained from gait score data.

Dermatitis measurements. The severity of hock burn and pododermatitis lesions was scored by the same veterinarian in all treatments at day 30 of the rearing cycle. This involved corralling a number of birds into a wire pen placed in a randomly preselected area of the house. Pens were placed in identical areas within all houses in order to limit possible placement effects. Twenty five birds (2 000 birds in total across the experiment) were then removed from the pen individually and the foot pads of both feet and hocks washed with a damp cloth. Both pododermatitis and hock burn were scored using the 5 point Welfare Quality recommended scale (Welfare Quality™: Assessment of animal welfare measures for layers and broilers, 2009) with 0=no lesion and 4=very severe lesion. For each measure, the bird was assigned the highest score observable on either leg/foot. The score assigned to each bird for both pododermatitis and hock burn was summed to create an overall dermatitis severity score.

The prevalence of pododermatitis and hock burn at slaughter was also recorded by slaughterhouse staff in birds that were ‘thinned’ and slaughtered at the final house clearing. All ten personnel involved in this scoring received identical industrial training in how to carry out these assessments and birds were assessed in a standardised way (as in Bailie *et al*., 2013). Briefly, this involved assessing the presence or absence of hock burn in 200 birds at thinning and 200 birds at slaughter. Two-hundred feet from birds at thinning and 200 feet from birds at clearing were examined for the presence of pododermatitis. The presence of pododermatitis and hock burn was recorded when lesions larger than a match head, or 3mm in width, were evident on the sole of the foot or on the hock, respectively.

Litter moisture content. During weeks 5 and 6 of the rearing cycle samples of litter were taken from 8 random areas throughout the house. Four samples were taken from the edge and four from the centre of the house, and therefore sampling was balanced for proximity to drinkers across treatments. Samples were stored in plastic bags and transported in a cool box to limit drying. Samples were thoroughly mixed to produce a 100 g whole house sample and dried at 70 ˚C for 24 hours. The dry matter percentage of the litter was then assessed by weighing the litter before and after drying (McLean *et al*., 2002).

Productivity and mortality. The cumulative percentage of dead birds (culled or mortalities) and water consumption per thousand birds at day 30 of the rearing cycle were recorded for each cycle in each house using company records. Slaughter weights and the percentage of birds downgraded at slaughter were taken from abattoir records for birds that were 'thinned' or slaughtered at the final house clearing. The farmers culled as normal throughout the study.

Statistical Analysis

Data were analysed using IBM SPSS Statistics (v22). Due to equipment malfunction and operational issues approximately 10% of the video files for scan sampling and 11% of gait scores were missing. A smaller number of novel object test and environmental data were also missing. However the majority of these missing data were balanced across treatment groups. Restricted Maximum Likelihood (REML) analysis of linear mixed models was used to assess the effects of 'stocking density', 'provision of string' and 'week' on variables recorded in weeks 3, 4 and 5. These variables included lying behavior, novel object test behaviour and the percentage of birds in different gait score categories. The random factor used in these analyses was 'Cycle(House)' and the covariance structure was 'variance components'. For variables that were only recorded at one timepoint in the production cycle, and therefore where effects of 'week' were not being explored, a repeated measures model was chosen. This involved a linear mixed model (with 'cycle' as the repeated effects and 'house' as the subject variable) which was used to assess the effects of 'stocking density' and 'provision of string' on litter moisture content, water consumption, the cumulative proportion of dead birds, the summed dermatitis severity score at day 30, and on average weight and incidence of podo dermatitis and hock burn at slaughter. The covariance structure in these analyses was first-order autoregressive. Choice of covariance structure used was based on optimal model fit. All main effects and interactions were determined in analyses, and all significant effects ($P < 0.05$) are presented in the results section. Results were adjusted for effects of multiple comparisons using a Bonferroni adjustment. Some percentage data were converted to proportions and subjected to Arcsine square root transformation prior to analysis (including lying behavior, the percentage of birds that were downgraded at slaughter, the cumulative percentage of dead birds at day 30 and the percentage of birds with a gait score of at least 2 or 3). Back-transformed mean values are presented in the results section. Kruskal-Wallis tests were used to determine the effects of stocking density and string treatments on ranked data relating to pododermatits and hock burn severity scores (average scores are presented in results).

RESULTS

Behavioral Observations

Lying behavior. Although no significant effects of stocking density and string treatments were found, the percentage of birds observed lying was affected by week ($F_{(2, 781)} = 29.55$, $P < 0.001$, Table 1).

Novel object test. Results showed no significant effect of stocking density or string treatment on the latency to touch a novel object, on the standardised number of birds within 50 cm of a novel object at 600 s, or on the number of contacts with the novel object in the 60 s following the first contact occurring (Table 1).

Age had a significant effect on latency to touch a novel object, which decreased significantly between weeks 4 and 5 ($F_{(2, 143)} = 5.44$, $P<0.01$, Table 1). There was also a significant decrease in the standardised number of birds within 50 cm of the novel object across each week (($F_{(2, 141)} = 13.86$, $P<0.001$). The number of contacts with the novel object in the 60 s following the first contact occurring did not differ significantly between weeks.

Gait score

There was no significant effect of stocking density or string treatment on the percentage of lame birds (i.e. birds assigned a gait score of 3 or above). Although no significant difference was found, there was a tendency for the percentage of birds with a gait score of 2 or more to increase at higher stocking densities ($F_{(3, 188)} = 2.16$, $P < 0.1$) (Table 1).

There were significant age effects on gait score variables, with percentages of birds with gait scores of at least 2, or of at least 3, increasing significantly between each of weeks

3, 4 and 5 (gait score ≥ 2: $F_{(2, 188)} = 344.8$, $P < 0.001$; gait score ≥ 3: $F_{(2, 127)} = 253.4$, $P < 0.001$; Table 1).

Incidence and severity of dermatitis

On-farm recordings at day 30 of the rearing cycle found evidence of dermatitis (hock burn, pododermatitis or both) on 88% of birds (75.7% had pododermatitis and 39.6% had hock burn). There was no significant effect of stocking density or string treatment on the individual severity score for either hock burn or pododermatitis lesions recorded at day 30 (Table 2). However, the combined score for severity of dermatitis lesions (sum of hock burn and pododermatitis scores) differed significantly between stocking density treatments, and was greater in birds reared at 34 and 36 kg/m^2 compared to birds reared at 30 kg/m^2 ($F_{(3, 50)} = 3.65$, $P<0.05$, Table 2). There was no significant effect of string treatment on this variable.

There was no significant effect of stocking density or string treatment on the individual prevalence of hock burn and pododermatitis lesions recorded at the abattoir (Table 2).

Culls, mortality and productivity

Results showed no significant effect of stocking density or string treatment on the percentage of downgraded carcasses and mean body weight recorded at the abattoir (Table 2). In addition, there were no significant treatment effects on the percentage of birds that had died by day 30 of the cycle.

There was no significant effect of stocking density or the provision of string on water consumption per thousand birds recorded at day 30 of the rearing cycle. However, there were numerical differences between stocking density treatments which suggested a decrease in water consumption per 1000 birds as stocking density increased (Table 2).

Litter moisture content

There were no significant treatment effects on percentage litter moisture content (Table 2).

DISCUSSION

The current study evaluated the effects of stocking density and environmental enrichment with string on a range of variables in broiler chickens kept in commercial windowed houses. Past research suggests that broiler activity levels decrease with increasing stocking density and group size (Lewis and Hurnik, 1990; Newberry and Hall, 1990; Andrews *et al*., 1997; Estevez *et al*., 1997; Hall, 2001). Despite this, increasing the density at which birds were stocked had no significant effect on levels of lying behavior within the current trial. Incremental differences between the target densities to which houses were stocked, though commercially relevant, were relatively small (1 bird per m^2) compared to those implemented in past research (eg. Lewis and Hurnik, 1990; Estevez *et al*., 1997; Hall, 2001). This may also explain why adverse effects of increasing stocking density on production-related measures such as body weight at slaughter were not observed. Previous research by Dawkins et al. (2004) found adverse effects on growth rate, however larger incremental increases in stocking density were evaluated. As with past research (Bailie and O'Connell, 2015), there was no significant effect of the provision of string, in the amount often provided on commercial farms within the UK, on general activity levels of birds when they were away from the string.

Despite the potential of environmental enrichment to reduce fear in poultry (Jones, 1996), results from the current study are in agreement with those of past research suggesting that the provision of string had no effect on reaction to a novel object, and hence apparent fearfulness, in commercial broilers reared in windowed houses (Bailie and O'Connell, 2015). Past research has indicated a reduction in tonic immobility (TI) duration in birds reared at reduced stocking densities; suggesting that stocking density may be a factor in the ontogeny of fear in broiler chickens (Andrews *et al*., 1997; Sanotra *et al.,* 2002). However, no difference in reaction to a novel object was apparent between stocking density treatments within the current trial. The stocking densities of birds tested for fearfulness within past literature tended to be lower (Andrews *et al*., 1997) or higher (Sanotra *et al.*, 2002) than the range of target densities implemented within this trial and the incremental differences in density between groups included in both of these past trials was higher. Stocking density was also manipulated in the current trial by altering the numbers of birds placed in houses. It is therefore possible that a greater number of birds were initially closer to the novel object at higher stocking densities, potentially resulting in a decreased latency to approach the objects in these flocks, and confounding fearfulness with space allowance. For this reason, TI may have been a more appropriate measure of fear, and the apparent absence of a difference in fearfulness between treatments may have been due to methodological shortcomings.

It has been suggested that the reduction in the distance travelled by broilers stocked at high densities, and the resultant decline in activity levels, may negatively influence walking ability (Lewis and Hurnik, 1990; Estevez *et al*., 1997). Although the distance moved by broilers was not measured in the current study, activity levels measured through lying behavior appeared to be unaffected by increasing stocking density. We also found no significant effect of stocking density on the proportion of lame birds, although the proportion of birds with a gait score of at least 2 appeared numerically higher at densities of 34 and 36kg/m^2 than at 30 or 32kg/m^2. Previous research, conducted on birds reared at a stocking density of 30 kg/m^2, indicated a positive effect of suspended string on walking ability in certain weeks of the production cycle (Bailie and O'Connell, 2015). Investigations of interactions between treatment and week in the current study did not yield similar findings in relation to the percentage of birds with gait scores of at least 2 or 3. These findings, coupled with those of previous work (Bailie and O'Connell, 2015), suggest that provision of pecking objects in the form of string at levels provided commercially (e.g. one piece of string per

1000 birds) is not likely to lead to strong and consistent beneficial effects on broiler leg health.

Dermatitis lesions also have the potential to adversely affect the movement of birds (Harms and Simpson, 1975; Hester, 1994), and it is possible that the increases in the severity of these lesions (observed at day 30 of the rearing cycle) contributed to the apparent (although not statistically significant) increase in birds with poorer gait scores at higher stocking densities. Past research has also found that dermatitis increases with increasing stocking density in broilers (eg. Sorensen *et al*., 2000; Hall, 2001; Dozier *et al*., 2006). This was previously reported to reflect increased litter moisture at higher stocking densities (Dozier *et al*., 2006), however this measure did not differ significantly between stocking density treatments in the current study. It is possible that other litter quality characteristics, such as level of 'caking' (Shepherd and Fairchild, 2010) differed between stocking density treatments in the current study and affected dermatitis levels, however this was not assessed.

It is clear that differences existed between levels of dermatitis recorded at the abattoir and directly on farm (on day 30 of the cycle). Abattoir data suggested an average prevalence of 56 % and 15 % for pododermatitis and hock burn, respectively, whereas on-farm records suggested corresponding figures of 76 % and 40 %. This suggests that on-farm monitoring of a smaller number of birds using a 5 point scale, rather than the 3 and 2 point scales used for abattoir monitoring of pododermatitis and hock burn respectively, is more sensitive in detecting the incidence of dermatitis, while also providing more detailed information on the severity of lesions. These data collected on farm also clearly demonstrated that the vast majority of birds monitored displayed evidence of pododermatitis by week 5 of the cycle. Differences in data collected on farm and from the abattoir may also have been due to the experience level of observers, speed of observations (which is likely to be much faster at the abattoir) and differences in light conditions. As the number of birds scored at the slaughterhouse outweighed those scored on farm, it is also possible that the slaughterhouse data was a better representation of the flock as a whole.

In conclusion, the increase in severity of dermatitis shown at higher stocking densities in the current study suggests that increasing stocking density within windowed houses is a risk factor for reduced leg health. No evidence of increased lying behavior or litter moisture at higher stocking densities was found, and it is suggested that dermatitis effects possibly reflected other litter quality aspects such as level of ‘caking’. The effects on leg health shown in this study were not accompanied by increases in clinical lameness or mortality, or by reduced performance, and this may perhaps reflect the relatively small incremental changes in stocking density that were investigated. The provision of suspended string as a form of environmental enrichment at levels typically provided commercially did not significantly affect any of the variables measured. Further research should perhaps investigate if greater levels of provision of pecking objects such as string lead to significant effects on activity levels and leg health in commercially-reared broiler chickens.

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Table 1 *Main effects of stocking density, provision of string and bird age on lying behavior, novel object test behavior and percentage of birds in different gait score categories*

	Stocking Density (SD) (kg/m^2)				String (S)		Age					
	30	32	34	36	+S	-S	Wk3	Wk4	Wk5	p(SD)	p(S)	p(Age)
Percentage of birds lying*	75.4	74.8	76.3	75.6	75.0	76.0	67.1[a]	80.5[b]	78.9[b]	0.96	0.51	<0.001
Novel object (NO) test:												
Latency to touch NO (s)	514	527	484	489	503	504	505[ab]	540[b]	465[a]	0.96	0.49	<0.01
Number of touches of NO within 60 s	1.1	1.2	1.3	1.1	1.1	1.3	1.1	1.3	1.2	0.59	0.99	0.92
Adjusted number of birds within 50 cm of NO	7.0	7.5	7.7	6.6	8.1	6.3	9.8[c]	7.5[b]	4.3[a]	0.92	0.15	<0.001
Percentage of birds with gait score ≥2*	27.2	26.2	30.8	29.2	28.5	28.2	3.6[a]	22.6[b]	58.9[c]	0.09	0.72	<0.001
Percentage of birds with gait score ≥3 (deemed to be lame)*	6.3	5.1	8.2	6.3	6.7	6.3	0.7[a]	2.1[b]	16.7[c]	0.16	0.69	<0.001

The effects of stocking density, provision of string and week were determined through Restricted Maximum Likelihood (REML) analysis of a linear mixed model with 'Cycle(House)' as the random factor. All interactions were determined, but none reached statistical significance. *Subjected to arcsine square root transformation prior to analysis and back-transformed means presented. [a,b,c] means in the same row with a different superscript differ significantly.

Table 2 *Main effects of stocking density and string treatments on measures of dermatitis severity, mortality, carcass quality, water consumption and litter quality*

	Stocking Density (SD) (kg/m^2)				String (S)			
	30	32	34	36	+S	-S	p(SD)	p(S)
Severity of hock burn lesions at day 30*	1.6	1.6	1.6	1.6	1.6	1.6	0.99	0.74
Severity of pododermatitis lesions at day 30*	2.4	2.6	2.7	2.7	2.5	2.7	0.67	0.50
Severity of dermatitis lesions at day 30[1]	4.0[a]	4.2[ab]	4.3[b]	4.4[b]	4.1	4.3	<0.05	0.18
Incidence of hock burn at slaughter (%)	15.1	14.7	16.7	16.0	15.3	15.9	0.75	0.66
Incidence of podo dermatitis at slaughter (%)	59.3	57.0	48.1	54.7	53.6	55.9	0.14	0.55
Cumulative proportion of dead birds by day 30 (%)†	2.6	2.5	2.4	2.3	2.5	2.4	0.22	0.58
Bodyweight at slaughter (g)	2167	2129	2137	2137	2140	2146	0.72	0.80
Downgraded carcasses (%)†	1.49	1.63	1.36	1.37	1.47	1.45	0.52	0.83
Water consumption per thousand birds at day 30 (L)	233	220	212	210	218	220	0.13	0.74
Litter moisture content (%)	32.3	30.0	31.1	31.4	31.4	31.0	0.87	0.82

*Hock burn and pododermatitis lesions scored separately (0-4) and the highest score on either leg assigned to each animal. Kruskal-Wallis tests were then used to determine effects of stocking density and string treatments on ranked data relating to these scores (average score values presented). For other variables, the effects of stocking density and provision of string were determined through REML analysis of a linear mixed model with 'cycle' as the repeated effects and 'house' as the subject variable. Interactions were determined but none reached statistical significance. [1]Represents the sum of hock burn and pododermatitis scores. †Converted to proportions and subjected to Arcsine square root transformation prior to analysis. Back-transformed mean values are presented.

Figure 1 Diagram showing the layout of houses on farms 1 and 2 and the total floor area available to birds in each house included within a study measuring the effects of stocking density and string provision on welfare-related measures in commercial broiler chickens in windowed houses.