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Correspondence and requests for materials should be addressed to J.H.N. (nguyen29@llnl.gov).

Chicken welfare is influenced more by housing conditions than by stocking density

Marian Stamp Dawkins, Christl A. Donnelly* & Tracey A. Jones

Department of Zoology, University of Oxford, South Parks Road, Oxford OX1 3PS, UK

* Present address: Department of Infectious Disease Epidemiology, Faculty of Medicine, Imperial College London, St. Mary's Campus, Norfolk Place, London W2 1PB, UK

Intensive broiler (meat) chicken production now exceeds 800 million birds each year in the United Kingdom and 2×10^{10} birds worldwide[1], but it attracts accusations of poor welfare[2,3]. The European Union is currently adopting standards for broilers aimed at a chief welfare concern—namely, overcrowding—by limiting maximum 'stocking density' (bird weight per unit area). It is not clear, however, whether this will genuinely improve bird welfare because evidence is contradictory[4–10]. Here we report on broiler welfare in relation to the European Union proposals through a large-scale study (2.7 million birds) with the unprecedented cooperation of ten major broiler producers in an experimental manipulation of stocking density under a range of commercial conditions. Producer companies stocked birds to five different final densities, but otherwise followed company practice, which we recorded in addition to temperature, humidity, litter and air quality. We assessed welfare through mortality, physiology, behaviour and health, with an emphasis on leg health and walking ability. Our results show that differences among producers in the environment that they provide for chickens have more impact on welfare than has stocking density itself.

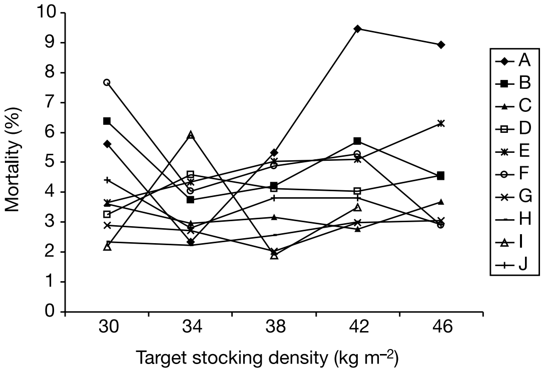

Figure 1 Total mortality in relation to target stocking density. The percentage of total mortality is shown separately for each company (A–J) taking part in the trial.

Across companies, there was a wide range of house sizes (455–1,901 m^2), house ages (5–40 yr) and numbers of birds per house (7,500–53,000); 75% of flocks were Ross 308 (see Supplementary Information). Each company contributed two houses to each target stocking density for a trial. With two companies, we repeated trials with the same ten houses in summer and winter to examine the effects of season. Within a company, houses were randomly assigned to stocking density (Supplementary Information), which was manipulated by altering the numbers of day-old chicks placed to achieve a projected 'target' maximum stocking density just before the birds were killed (39–42 d at 2–3 kg). The five target stocking densities were 30, 34, 38, 42 and 46 kg m^{-2} (refs 1, 11, 12). Actual stocking density was measured as mean weight × number of birds per area of house. The same person (T.A.J.) made or checked all measurements with the help of trained assistants.

Welfare[13–15] was assessed through mortality, physiology, behaviour and health, emphasizing leg health and walking ability[16–20] (Table 1). We found that the effect of experimentally manipulating stocking density was overshadowed by much larger differences among companies (Table 2 and Fig. 1). Chickens grew more slowly at the highest stocking densities and jostled each other more, and fewer of them showed the best gaits (Table 3); however, for the most obvious measures of bird welfare—that is, the numbers of birds dying, being culled as unfit and showing leg defects—there was no effect of stocking density. There were, however, substantial differences among companies in almost all measures examined (Table 2). At no point was breed a significant explanatory factor in any outcome variables, suggesting that the differences were due to environmental influences.

Of the commercially relevant factors that seemed to allow some companies to 'cope' better than others with high stocking densities, the most likely candidates were those that affected litter moisture

Table 1 **Scoring of gait, hockburn, pad dermatitis and leg deviations**

Leg health measure	Score 0	Score 1	Score 2
Gait	Bird walks with ease, has regular and even strides and is well balanced	Bird walks with irregular and uneven strides and appears unbalanced	Bird is reluctant to move and is unable to walk many strides before sitting down
Hockburn*	No discolouration or lesions	<10% hock with lesion	>10% hock with lesion
Pad dermatitis†	No lesions	<5 mm lesion on pad	>5 mm lesion on pad
Angle: in	Legs straight	Inward bow at intertarsal joint so that the two legs meet >22°	
Angle: out	Legs straight	Outward twist at intertarsal joint with ≥30° between the legs	
Rotation	Legs straight, pads facing away from handler	Rotation of the tibia shaft so that pads face each other >15°	

*Pink hocks were also recorded.
†Pervasively dirty pads also scored.

Table 2 **Density and company effects on principal parameters**

	Mean	s.e.m.	Range	Target density	Company	Actual density
Gait score 0 (%)	72.6	2.0	10–100	$P = 0.027$	$P < 0.0001$	$P = 0.002$
Gait score 2 (%)	0.9	0.3	0–20	NS*	NS	NS
Hock score 0 (%)	80.6	1.7	20–100	NS	$P < 0.0001$	NS
Hock score 2 (%)	1.5	0.5	0–47.5	NS	$P = 0.0003$	NS
Pad score 0 (%)	81.2	2.1	12.5–100	NS	$P < 0.0001$	NS
Pad score 2 (%)	2.8	0.7	0–47.5	NS	NS	NS
Angle: in (%)	12.3	0.7	0–35	NS	$P < 0.0028$	NS
Angle: out (%)	3.5	0.4	0–17.5	NS	$P < 0.0001$	NS
Rotation (%)	6.9	0.7	0–47.5	NS	$P < 0.0001$	NS
Total leg deviation (%)	23.3	1.2	0–62.5	NS	$P < 0.0001$	NS
Corticosteroid (ng ml^{-1})	18.9	1.1	3.5–50.4	NS	$P < 0.0001$	NS
Growth rate (g d^{-1})	49.4	0.4	39.1–7.9	$P = 0.011$	$P < 0.0001$	NS
Total mortality (%)	4.1	0.2	1.4–14.7	NS	$P < 0.0001$	NS
Leg cull (%)	0.6	0.1	0–2.4	NS	$P < 0.0001$	NS
Other cull (%)	1.5	0.1	0.4–4.7	NS	$P < 0.0001$	NS
Dead birds (%)	2.0	0.1	0.6–4.8	NS	$P < 0.0001$	NS
Downgrades (%)	0.9	0.1	0–4.24	NS	$P < 0.0001$	NS
Litter moisture (%)	18.3	0.4	10.7–2.5	$P = 0.05$	$P < 0.0001$	NS
Ammonia (p.p.m.)	10.4	0.7	1.3–29.8	NS	$P < 0.0001$	NS

*NS, not significant.

Table 3 **Gait 0, jostle and growth rates* for given target stocking densities**

	30 kg m^{-2}	34 kg m^{-2}	38 kg m^{-2}	42 kg m^{-2}	46 kg m^{-2}
Gait score 0 (%)	80.8^{a} (3.7)	74.2^{ac} (4.9)	76.1^{ac} (4.3)	68.0^{bc} (4.2)	61.1^{bc} (4.5)
Jostle rate (incidents per min)	0.316^{a} (0.039)	0.431^{ab} (0.046)	0.455^{ab} (0.049)	0.566^{b} (0.071)	0.618^{b} (0.112)
Growth rate (g d^{-1})	50.3^{a} (0.8)	49.9^{a} (0.8)	49.7^{ab} (0.9)	48.8^{ab} (0.9)	47.7^{b} (0.9)

*Values are the mean, the s.e.m. is given in parentheses. Values with different superscripts are significantly different, $P \leq 0.05$ (Tukey post hoc comparison).

and air ammonia, because these differed significantly among companies (Table 2). Whereas 56% of the variation in litter moisture could be explained by effects such as heater position in the house and the number of drinkers per 1,000 birds, 73.3% of the variation in air ammonia could be explained by effects such as season and ventilation type.

Litter moisture and ammonia, in turn, were related to bird health. Higher levels of both were correlated with more dirty pads (moisture, correlation coefficient, $r = 0.24$; ammonia, $r = 0.27$), more legs scored as angle-out (moisture, $r = 0.24$; ammonia, $r = 0.36$) and fewer birds with unblemished hocks (moisture, $r = -0.36$, ammonia, $r = -0.26$). In addition, birds had more hock lesions with wetter litter (score 2, $r = 0.27$). High concentrations of ammonia[21] were, unexpectedly, associated with lower mortality, but both litter moisture and air ammonia were correlated with higher faecal corticosteroid (a 'stress' hormone[22,23]; see Supplementary Information). Eighty-four per cent of the variation in faecal corticosteroid could be explained by effects such as temperature in week 1, humidity in week 5, season and ventilation type. Corticosteroid concentrations were also correlated with mortality (Supplementary Information), which suggests that stress on birds and their risk of dying depend on the extent to which companies can control the house environment.

The key house variables were temperature and humidity. The percentage of birds dying over the whole growth period was positively correlated with humidity and temperature in weeks 3–5 (Supplementary Information). The number of birds walking well (gait 0) was negatively correlated with the percentage of time that temperature and humidity were outside the breeder's recommended range[24] in weeks 1 and 4. All companies deliberately altered house temperature[24] as the birds grew: 84.6% of that variation was explained by week, company (which included litter type and number of stockman visits), and the covariates drinker type, season and numbers of drinkers per 1,000 birds. None of the companies measured or controlled humidity directly, but this also changed as the birds grew. Week, company (including the number of stockman visits, position of heaters, ventilation type and age of house) and the number of drinkers per 1,000 birds explained 71.2% of variation in humidity.

Differences between summer and winter (when ventilation is reduced to conserve heat) confirm the importance of house environment. Both mortality and corticosteroid concentrations were lower in summer than in winter (mean summer mortality, 4.2%; mean winter, 5.3%; mean summer corticosteroid, 8.6 ng ml^{-1}; mean winter, 36.2 ng ml^{-1}). Foot pad condition was correspondingly better with more birds scoring pad 0 in summer (88.9%) than winter (71.6%) and fewer birds having pervasively dirty pads (8.8% in summer versus 30.3% in winter).

Although house environment is crucial to bird welfare, we emphasize that stocking density is also important. At the two highest target stocking densities (42 and 46 kg m^{-2}), there were fewer birds with the best gait score 0. Culling rates were not greater (Table 2), which suggests that at least some aspects of leg health are compromised at or above a stocking density of 42 kg m^{-2}.

We conclude that, although very high stocking densities do affect chicken welfare, stocking density *per se* is, within limits, less important than other factors in the birds' environment that differ among companies. Good stockmanship counts even in highly automated houses. Legislation to limit stocking density that does not consider the environment that the birds experience could thus have major repercussions for European poultry producers without the hoped-for improvements in animal welfare. These will come from improving the environment[25], nutrition[26] and genetics[27,28] of the millions of birds that we eat. ☐

Methods

Management and husbandry

We recorded the following information: house age; ownership (company or contract grower); size; orientation; fabric; light pattern and source; dawn/dusk dimming; percentage of wheat feed; feeder type and number; drinker type and number; heater type, number and position; type of ventilation system; misting systems; floor and litter type; number of stockmen and number of visits per house; vaccination programme; feed withdrawal; and thinning or clearance programme.

Environment

We recorded temperature and relative humidity every hour throughout the growth cycle (by using four randomly positioned Tiny Talk data loggers in each house at a height of 60 cm); and atmospheric ammonia (by a Gastec GV-100S pumpset), light at bird height (ISO-Tech digital light meter) and litter moisture content ([sample weight difference after drying/sample weight] × 100) at target density.

Birds

We recorded the source, breed, sex (all-male, all-female or mixed), age of parent flock, date and time of arrival, position of chicks on delivery lorry, type of vehicle (rigid or articulated), ventilation (fans, vents) and on-board temperature. The numbers of trays of chicks per house and chicks per tray were audited.

Leg health

At target density, a single bird chosen at random from each of ten points in each house, was observed walking for at least ten paces before being scored for gait (Table 1, $n = 1{,}140$ birds). Groups of ten birds were subsequently caught at four random points per house; individuals were inverted (ventral side facing handler), held by the legs with the handler's thumbs just below the intertarsal joint and assessed for leg straightness (Table 1, $n = 4{,}370$), weighed and then released.

Corticosteroid measurements

Fresh faecal samples were collected at five random positions in each house, dried at 40 °C and analysed for corticosterone[19,20].

Behaviour

Four battery-operated video cameras radio-linked to a VCR (Tracksys) were placed in each house at a height of 155 cm. Eight 10-min sequential records of each camera view were made between 10:00 and 12:00 at target density. One randomly chosen focal bird from each 10-min section of video was analysed for 5 min for frequency and duration of stand, lie, feed, drink, preen, rest (eyes closed) and lie stretched out; frequency of walk (including number of strides) and peck litter, peck other bird, scratch litter, scratch head, stretch head, wing or leg, shake body, shake head, dust bathe, wing flap, aggressive interactions and perch; changes of posture (up or down); jostling or being jostled by other birds; and being disturbed or walked on by other birds ($n = 741$ from 107 houses).

Production

We recorded mortality (numbers of birds found dead plus numbers of birds culled because of illness or leg problems), feed conversion ratio, water intake, date, numbers and weights of birds removed from the house (thinned or cleared) and number of birds rejected at the processing plant. Growth rate was calculated as: individual weight(average chick weight)/number of days.

Statistical analysis

The independent statistical unit was house. Where many measurements were made per house, a single mean-per-house value was used in the analysis. Variables were first analysed for effects of target stocking density, actual stocking density and company by analysis of variance. Where actual density effects were significant, they were further analysed by regression analysis (fitted line model) and post-hoc Tukey comparison.

Univariate linear correlations were examined between outcome variables and predictors treated as continuous variables. Multivariate linear models were constructed using a stepwise model selection procedure (starting from a model with no predictors) with possible predictors, including those continuous predictors with substantial linear correlations (<-0.2 or >0.2) and categorical predictors. We discuss only effects where $P < 0.01$.

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Correspondence and requests for material should be addressed to M.S.D. (marian.dawkins@zoo.ox.ac.uk).

Travelling waves in the occurrence of dengue haemorrhagic fever in Thailand

Derek A.T. Cummings[1,2], Rafael A. Irizarry[3], Norden E. Huang[4], Timothy P. Endy[5], Ananda Nisalak[6], Kumnuan Ungchusak[7] & Donald S. Burke[2]

[1] *Department of Geography and Environmental Engineering, Johns Hopkins University, Baltimore, Maryland 21218, USA*
[2] *Department of International Health, and* [3] *Department of Biostatistics, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland 21205, USA*
[4] *Laboratory for Hydrospheric Processes/Oceans and Ice Branch, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, USA*
[5] *Virology Division, United States Army Medical Research Institute in Infectious Disease, Fort Detrick, Maryland 21702, USA*
[6] *Department of Virology, Armed Forces Research Institute of Medical Sciences, Bangkok 10400, Thailand*
[7] *Bureau of Epidemiology, Ministry of Public Health, Nonthaburi 11000, Thailand*

Dengue fever is a mosquito-borne virus that infects 50–100 million people each year[1]. Of these infections, 200,000–500,000 occur as the severe, life-threatening form of the disease, dengue hemorrhagic fever (DHF)[2]. Large, unanticipated epidemics of DHF often overwhelm health systems[3]. An understanding of the spatial–temporal pattern of DHF incidence would aid the