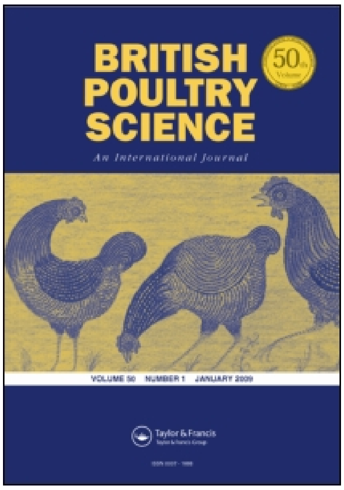

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Environment and management factors affecting Pekin duck production and welfare on commercial farms in the UK

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Environment and management factors affecting Pekin duck production and welfare on commercial farms in the UK

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Abstract 1. Forty-six flocks of commercially-reared Pekin ducks were studied in 23 houses differing in their ventilation and brooding systems, and water and feed resources, in order to identify factors affecting duck welfare in commercial practice.

2. A wide range of environmental variables were measured, together with the physical and plumage condition of the ducks at two ages, whilst companies supplied mortality and growth rate data.

3. At 23 d, more than 98% of ducks had clean eyes, nostrils and feathers and an upright posture, and 86% had no gait abnormalities. By 41 d, body condition had deteriorated slightly with 84% of ducks having clean eyes, 67% clean feathers and 79% no gait abnormalities.

4. Gait worsened with increasing temperature and litter moisture, and atmospheric ammonia concentrations. The incidence of foot pad lesions was 10% (moderate) and 3% (severe) and was positively correlated with increasing humidity and ammonia.

5. Average mortality rates were 5·2% for ducks reared to 3·35 kg at 48 d with average growth rates of 60·3 to 81·3 g/d. High temperatures correlated with high mortality and reduced growth rate; growth rate was not related to poor gait.

6. Controlling the ducks' environment, particularly temperature, humidity, litter moisture and ammonia is crucial to duck welfare. Effective ventilation systems, high quality straw and access to some form of open water were considered important for duck welfare.

INTRODUCTION

There is currently little information available on the welfare of domestic ducks (*Anas platyrhynchos*) reared for meat in commercial systems (Raud and Faure, 1994; Rodenburg *et al.*, 2005). The Council of Europe (1999) stated that some methods of duck husbandry in commercial use often fail to meet all essential needs, particularly the need to bathe in water, and hence result in poor welfare. This concern over the type of water access available to ducks has led to research investigating the preference of ducks for open water (Cooper *et al.*, 2002; Ruis *et al.*, 2003; Jones *et al.*, 2008) and how this may be achieved in practice (Benda *et al.*, 2004; Knierim *et al.*, 2004; Heyn *et al.*, 2006). Currently, there is little evidence documenting welfare standards on commercial duck farms or identifying factors and conditions that adversely affect their welfare.

Reiter *et al.* (1997), reported increased growth in Pekin ducks with access to free range and open water, while Knierim (see Rodenburg *et al.*, 2005) demonstrated a reduction in foot pad dermatitis in Muscovy ducks with access to open water; whereas the effects of stocking density are inconsistent (Rodenburg *et al.*, 2005). Raud and Faure (1994) studied ducks reared in intensive systems and highlighted the importance of maintaining a good micro-climate (humidity and ammonia concentrations) and dry litter for good leg health. Comprehensive studies conducted with broiler chickens have also shown the importance of controlling the environment

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for the maintenance of health and well being (Dawkins *et al.*, 2004). For ducks, the Council of Europe (1999) recommend the environment is kept so that air temperature, velocity, and dust, do not adversely affect health and welfare and that stocking densities take into account the capacity of the ventilation system to prevent overheating.

The aim of this study was to assess the welfare of Pekin ducks reared commercially in a variety of housing systems currently in use in the UK and to determine factors that affect their welfare. Welfare was measured using a wide range of variables, including body and plumage condition, walking ability, foot pad dermatitis, hockburn and mortality. Potential factors affecting duck welfare were the house environment (measured for temperature, humidity, litter condition, and atmospheric ammonia) and the variable components of the housing design, namely, type of ventilation, provision of feed and water, brooding system, orientation and size of house, and stocking density.

MATERIALS AND METHODS

Study houses

Twenty-three commercial houses on 7 farms belonging to the three major duck companies in the UK were used to assess the effect of housing system on the welfare and production of Pekin strains of meat duck. Housing systems were indicative of those currently in use in the UK and differed primarily in their ventilation, drinking and brooding systems, so they could be categorised into 5 overlapping systems. Two flocks were studied in each house over a 2-year period; one in cold-season conditions (winter/spring) and one in warm-season conditions (summer/autumn), so that in total 46 commercial flocks (involving 448 011 ducks) were studied. Each flock was visited on 4 occasions: (i) at placement, (ii) mid growth cycle (average 22·5 d, range 19–25 d), (iii) at the end of the growth cycle (average 41·3 d, range 33–49), and (iv) at slaughter (average 48 d, range 40–56).

Management data were recorded on the first visit and included: ventilation system (natural/forced, air inlet/outlet points, and number of fans); feeder type (hopper, pan, tube) and drinker type (nipple, plasson (bell drinker), trough); number and dimensions of feeders and drinkers (available space (mm) per bird was calculated), distance between feeders and drinkers (next to each other, half a house width apart, opposite sides of the house); brooding system (whole house, half house, circular, nursery); heater type and numbers of heaters during brooding; number of one-day-old ducks placed in the house, floor area and target stocking density; floor type and litter, with manual or machine bedding-up; lighting source and pattern; access to the outdoor environment and condition of the range. Available space provided per bird was calculated as total provision mm/number of ducks placed. For troughs, provision mm = 2 L, where L = length of trough, for plassons (bell drinkers), provision mm = circumference = $2\pi r$, for nipples, provision mm = 15·7 N, where 15·7 = circumference and N = number of nipples.

Environmental data

Temperature and relative humidity (RH) were measured every hour throughout the production cycle using two 'TinyTag Plus' data loggers (Gemini dataloggers, Chichester, UK) placed at two predetermined random points in the house (height 1·0 m). Average weekly temperature and RH, along with their standard deviation, were calculated.

Litter moisture {(weight difference in sample after drying at 80°C/sample weight) × 100}, litter temperature and pH at 6 cm depth (Hanna H1 991000 combination probe, www.hannahinst.co.uk), as well as atmospheric ammonia (Gastec pump-set GV-100s, Kanagawa, Japan) and light intensities (ISO-Tech digital meter, www.rswww.com) (both at duck height ~40 cm) were measured at 5 predetermined random points in each house on visits (ii) and (iii) (afternoon). Average values and their standard deviation were calculated for each flock.

Production data

Company data for percent mortality within the growth cycle, flock weight at slaughter and percent downgrades at processing was collected and checked for each flock. Average flock growth rate and maximum stocking density (kg/m^2, total weight of ducks removed from house at slaughter/area of the house) for each flock were calculated.

Duck condition scores

Ten ducks at 5 predetermined random points in the house (same points as above) were visually inspected and scored according to the condition of their eyes, nostrils, feathers, posture, and walking ability on visits (ii) and (iii). The observer walked slowly to the predetermined grid and approached the ducks calmly. A random sample of 10 birds towards the centre of the grid was isolated by the observer walking around them. The ducks walked in response to the observer and were scored as they were herded in a circle several times. Catching frames were not used

Table 1. *(a) The scoring system used for the assessment of duck body condition, posture and walking ability and (b) the scoring system used for the assessment of feather cleanliness and foot pad dermatitis at the processing plant*

Condition	Score	Definition
(a)		
Eye	0	*Best:* Eyes are clear, clean and bright
Condition	D	There is a crust or dirt around the outside of the eye
	1	*Moderate:* Eyes are wet and weepy or are red rimmed
	2	*Worse:* Eyes are closed or half closed permanently, or there is conjunctivitis
Nostril	0	Nostrils are clear and clean
Condition	D	Nostrils are dirty
Feather	0	*Best:* Feather cover is even and the feathers are clean
Condition	D	Feather cover is even but the feathers are dirty (the degree of soiling was not differentiated)
	1	*Moderate:* Feather cover is patchy on wings
	2	*Worse:* Feather cover is patchy to bare on wings and patchy on the back
Posture	0	*Best:* The duck lifts its body on standing and stands straight
	1	*Moderate:* The duck does not fully raise body on standing, it adopts a horizontal posture or is stooped or twisted
	2	*Worse:* Includes severe postures outlined above or the duck will not lift off ground
Walking	0	*Best:* The duck waddles and walks freely
Ability	1	*Moderate:* The duck walks with a slight limp, or has excessive cross over of the feet or slightly deformed legs (bowed), causing it to walk awkwardly
	2	*Worse:* The duck is reluctant to walk and walking is laboured, mostly due to severe cases of 1 above
(b)		
Feather cleanliness	0	*Best:* Feathers are clean (photographic score 1 Wilkins *et al*., 2003)
	1	*Slightly soiled*: There is a coating of dirt in the upper layers of feathers (scores 2, 3 Wilkins *et al*., 2003)
	2	*Soiled*: (scores 4, 5 Wilkins *et al*., 2003),
	3	*Heavily soiled*: The dirt penetrates the under layers of feathers and forms clumps (scores 6–8 Wilkins *et al*., 2003).
Stubbly quill		Feathers on the breast are short and broken/stubbly (probably due to friction/primarily rubbing on wet litter)
Foot pad Dermatitis	0	*Best:* The pads are free of lesions and ingrained dirt
	IN	*Ingrained:* Ingrained lines filled with dirt transverse the pads
	R	*Raised papillae*: Dirt pervades the pad and the papillae are raised
	1	*Moderate:* Lesions are visible and cover< 50% of the pad
	2	*Severe:* Lesions are visible, feel deep and cover> 50% of the pad
Callous toe		Lesions or callouses are present on the digits

due to the flight distance of the ducks and their crowding behaviour within the frame. The sampling points were sufficiently spaced so that there was a low probability of scoring an individual duck more than once.

Over the two visits, 4610 live ducks were scored for body condition and walking ability, and the average incidence of each score calculated for each flock (Table 1a). In addition, 150–300 birds per flock (depending on flock size) were scored for feather cleanliness (total 10 252 ducks) and hockburn and foot pad dermatitis (total 10 279) at the processing plant (Table 1b) and average incidence of each score calculated for each flock.

Statistical analysis

The independent statistical unit was the flock, so that where multiple measurements were made a single mean-per-flock value was used in the analysis. Repeat data between visits (ii) and (iii) (23 and 41 d) were not amalgamated and were analysed separately, however, the effect of age was tested using a paired *t*-test. Data were analysed for the effects of housing system and season by Analysis of Variance, general linear model (ANOVA, GLM), and system effects were further examined by house component (Table 2). Multivariate linear models were constructed using a stepwise model procedure (with backward elimination) for house components (categorical predictors) and univariate linear correlations (continuous predictors) between outcome duck variables and continuous environmental variables (with Pearson correlation at $P < 0{\cdot}001$), in line with Dawkins *et al.* (2004). Each model was tested for normality of residuals and appropriate transformations and inclusion of company or trial year as fixed effects were made where necessary (Grafen and Hails, 2002). Main factor significant effects were examined by *post hoc* Tukey comparison, whilst continuous predictors were examined by fitted line regression. Because a large number of statistical tests have been undertaken results of borderline

Table 2. *Components of the housing system included in the analysis*

Component	Type	Number of flocks
Ventilation	Natural	26
	Forced side-inlet	10
	Forced drop-down	10
Drinker system	Trough	20
	Plasson	10
	Nipple	16
Feeder system	Hopper	34
	Pan and tube	12
Brooding system	Nursery	5
	Circle	15
	Half house	8
	Whole house	18
House orientation	North-South	26
	East-West	20

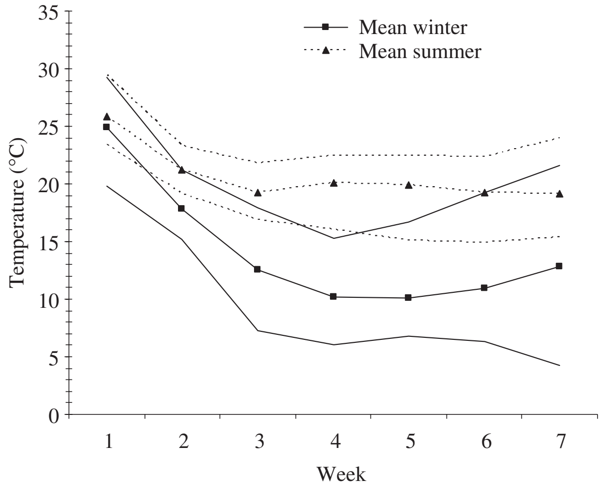

Figure 1. *Mean weekly house temperatures in cold (winter) and warm (summer) seasons for all flocks studied. Minimum and maximum lines are below and above the mean line for each season.*

significance should be interpreted with caution; for this reason meaningful significance was defined as $P<0{\cdot}01$.

RESULTS

Study houses

Of the 23 houses used in the study, 13 were naturally ventilated, 5 had forced ventilation with side-inlet, roof outlet, and 5 had drop-down forced ventilation (roof inlet/side outlet); 13 were built in a north-south orientation and 10 in an east-west orientation. Heat was provided only during brooding (up to 14 d); 5 houses brooded in circles (where ducklings were kept in the area of the heat source by a ring of cardboard that could be expanded daily), whilst 9 houses operated whole house brooding and 4 half-house brooding (where either the left or right side of the house was heated and the ducklings confined to that area). Five houses operated a 'nursery' in the first season, where a central room was heated and the ducks were moved into the two ends of the house at the end of brooding. The nursery was removed prior to the second season assessment and circular brooding in one half of the house was then conducted; ducks were spread out between the two ends of the house after brooding, which also occurred in 4 other houses. Three houses on a single farm were free-range.

Most houses provided feed in hoppers (17); three houses (single farm) provided tube feeders and three (single farm) provided pans. Feed space per bird was greatest in the pan feeders at 12 mm/bird; hoppers provided an average 7·3 mm/bird (range 5·3–9·5 mm/bird) and tubes provided 4·3 mm/bird (no range). Ten houses provided water from troughs (average 5·3 mm/bird, range 4·1–5·9 mm/bird), whilst 5 provided turkey plasson drinkers (average 6·1 mm/bird, no range), and 8 houses provided nipple drinkers (average 5·8 mm/bird, range 2·5–10 mm/bird). There was no difference in drinker space per bird between the different types of provision (average 5·7 mm/bird). Troughs were at least 12·5 cm wide and 10 cm deep and allowed head dipping; they were situated on grids over a drainage channel in 5 houses, otherwise they were placed directly on to the straw; all other drinkers were situated over the straw.

Light was provided via incandescent bulbs in 7 of the houses and fluorescent strips in 9 houses; a mix of both types was used in the remaining 7 houses. Straw was the only litter type used; this was topped up daily by machine in 9 houses (delivering chopped straw) and manually (delivering long straw) in 14 houses. Average house age and floor area were 18·5 years (range 6–40 years) and 1837·5 m^2 (range 892–3261 m^2), respectively, and on average 9739 one-day-old ducks were placed per house (range 4080–17 220).

Environmental data

Average weekly temperature fell from 25·4°C in week 1 during brooding, to an average 11·3°C (weeks 3–7) in winter and 19·5°C in summer, as shown in Figure 1. Mean weekly temperatures were correlated to all previous week temperatures ($r=0{\cdot}55$–$0{\cdot}96$, $P<0{\cdot}001$). Meanwhile, RH

Table 3. *Mean, standard error and range of litter temperature, pH, and moisture, and light and ammonia levels recorded at 41 d*

	Mean (SE) (range)	Model	F ratio & significance	R^2 %
Litter Temperature (°C)	24·5 (0·8) (13·6–32·3)	Trial	–	91·9
		Higher in houses with forced drop-down ventilation than natural ventilation, during winter	$F=8·0$***	
		Drinker type		
		• Winter: Highest in houses with nipple drinkers then plasson drinkers then troughs	$F=37·3$***	
		• Summer: Highest in houses with plasson drinkers then nipple drinkers then troughs	$F=17·7$***	
		Increases with increasing week 6 temperature ($r=0·79$)	$F=15·8$***	
		Increases with increasing litter temperature (visit 1 $r=073$)		
Litter pH	7·2 (0·1) (6·0–8·3)	System	–	28·5
		Decreases with increasing week 1 RH ($r=-0·4$)	$F=4·4$ *	
Litter Moisture (%)	42·8 (1·5) (17·6–59·4)	Trial	–	64·2
		Lowest in houses with whole house brooding	$F=4·2$*	
		Highest in houses with forced side-inlet ventilation	$F=3·0$*	
		Decreases with increasing week 3 variation ($r=-0·587$)	$F=6·0$*	
Light levels (lux)	52·6 (11·7) (2·2–429·2)	Trial	–	28·2
		Highest in houses with natural ventilation	$F=7·1$**	
		Interlinked with house area	$F=5·3$*	
Ammonia levels (ppm)	11·3 (1·0) (1·8–34·6)	Trial	–	69·6
		Highest in houses with nipple drinkers	$F=22·7$***	
		Highest in houses with forced side-inlet ventilation then forced drop-down then natural ventilation	$F=9·8$***	
		Increases with increasing litter moisture (visit 1 $r=0·51$)	$F=5·7$*	

Significant effects are detailed along with the percent variation explained by the model (R^2).
*$P<0·05$, **$P<0·01$, ***$P<0·001$.

increased from 53% in winter and 61% in summer (week 1) to 81·4 and 86%, respectively (weeks 4–7); mean weekly RH in weeks 4–7 were correlated to the previous weeks RH ($r=0·52$–$0·86$, $P<0·001$). Higher temperatures ($F=10·0$, $P<0·001$) and lower RH values ($F=9·4$, $P<0·001$) were maintained throughout the growth cycle after whole house or circle brooding than were with half house or nursery brooding. Temperature in week 1 was higher in houses with an east-west orientation ($F=8·1$, $P<0·01$), whilst RH was correspondingly lower ($F=27·1$, $P<0·001$). There was evidence that in week 6 temperature was higher in houses with nipple drinkers ($F=5·3$, $P<0·01$) while in week 6 RH was higher in houses with drop-down ventilation ($F=3·3$, $P<0·05$).

Litter temperature ($t=-7·9$, $P<0·001$) and ammonia concentration ($t=-7·5$, $P<0·001$) were higher when the birds were older, whereas intensities were higher when they were younger ($t=3·9$, $P<0·001$) and there was no difference in litter moisture between the two visits. Environmental conditions in the house measured at 41 d are given in Table 3 along with the final explanatory model and the percentage of variation explained. On average litter temperature was 21·8°C in winter and 27·6°C in summer. Across seasons, litter moisture and pH were 42·8% and 7·2, respectively, whereas light intensity was 52·6 lux and ammonia 11·3 ppm. Litter temperature correlated with ambient house temperature and was higher in houses with forced drop-down ventilation and in houses with nipple drinkers in winter. Ammonia was highest in houses with nipple drinkers and forced ventilation and correlated with increasing litter moisture. Light intensities were highest in houses with natural ventilation.

Production data

Average mortality rates were 5·2% for ducks reared to an average 3·35 kg at 48 d, growing at a rate of 60·3 to 81·3 g/d. Production results are given in Table 4 along with the final explanatory model and the percent variation explained. Mortality was higher in houses with whole house brooding (6·4% compared to 4·5%) and was greater in the second year of the study (5·7% compared to 4·8%) as were the downgrades at slaughter (2·7% compared to 0·8%). Because companies tended to use their own genetic stock with differing growth potentials and a mix of early or late-maturing strains, growth rate and therefore age and weight at slaughter were all significantly affected by company. Fast-growing strains averaged 75·0 g/d growth and reached 3·32 kg at 44 d. Slower-growing strains averaged 62·8 g/d growth and reached 3·32 kg at 53 d.

Table 4. *Mean, standard error and range of duck mortality, weight at slaughter, calculated growth rate, stocking density, and rejects at processing*

	Mean (SE) (range)	Model	F ratio & significance	R^2 %
Total mortality %	5·2 (0·2) (2·6–9·9)	Trial: greatest in second trial (4·8% cf. 5·7%)	$F=9{\cdot}8$**	54·7
		Higher in houses with whole house brood than half house & circle brood	$F=9{\cdot}3$***	
Average weight kg	3·4 (0·04) (3·0–3·9)	Trial	–	61·2
		Company	$F=10{\cdot}4$***	
		Lower weight with higher levels of best pads ($r=-0{\cdot}49$)	$F=4{\cdot}4$*	
		Decreases with increasing litter moisture variation (23 d $r=-0{\cdot}44$)	$F=4{\cdot}2$*	
		Increases with increasing processing age ($r=0{\cdot}39$)	$F=7{\cdot}7$**	
Calculated growth rate g/d	70·2 (1·0) (60·3–81·3)	Trial	–	65·8
		Company	$F=21{\cdot}2$***	
		Decreases with increasing week 3 temperature ($r=-0{\cdot}53$)	$F=9{\cdot}7$***	
Calculated stocking density kg/m^2	17·2 (0·3) (13·9–22·5)	Trial	–	57·1
		Higher in houses with plasson drinkers then nipples then troughs	$F=18{\cdot}2$***	
Rejects %	1·8 (0·2) (0·02–5·25)	Trial:higher in the second trial	$F=49{\cdot}7$***	81·7
		Company	$F=4{\cdot}5$*	
		Increases with decreasing week 4 RH ($r=-0{\cdot}52$)	$F=32{\cdot}6$***	
		Increases with increasing best pads ($r=0{\cdot}60$)	$F=20{\cdot}7$***	

Significant effects are detailed along with the percent variation explained by the model (R^2).
*$P<0{\cdot}05$, **$P<0{\cdot}01$, ***$P<0{\cdot}001$.

There was strong evidence that growth rate (Growth rate = 83·9–0·86T), reduced with increasing week 3 temperatures so that rates of growth below average (70 g/d) occurred when average weekly temperature increased above 16°C. Maximum stocking density on average was 17·2 kg/m^2 and was highest in houses with plasson (19·8 kg/m^2) drinkers and lowest in houses with troughs (14·4 kg/m^2).

Duck condition scores

At 23 d, more than 98% of inspected ducks were scored as having clean eyes, nostrils and feathers. Almost 98% of ducks walked upright; however, walking ability was very variable. While nearly 86% (range 65–96%) of ducks were scored with no gait abnormalities (score 0), 13·0% were scored with moderate (range 4·0–32·0%, score 1) and 1·2% with severe gait problems (0–8·0% score 2). The incidence of moderate gait abnormalities (score 1) increased with increasing litter temperatures ($F=10{\cdot}2$, $P<0{\cdot}01$). Duck condition when older (41 d) is given in Table 5 along with final explanatory models and the variation explained by each model. On average, approximately 84 and 67% of ducks had clean eyes and feathers, whilst 98% had clean nostrils. Despite the wide range observed in all categories, moderate and severe conditions were generally low, with the alternative eye and feather condition scored as dirty (14·5 and 32·0%, respectively). Over 94% of ducks had an upright posture, whilst best gait (score 0) was reduced to 79·4%. The incidence of moderate posture and gait abnormalities (score 1) were significantly higher at an older than a younger age (minimum $t=3{\cdot}2$, $P=0{\cdot}001$).

The proportion of ducks with bright, clean eyes (score 0) was lower in houses with nipple drinkers and was positively correlated with clean feathers and higher growth rates (Table 5). Clean nostrils were lower in houses with drop-down ventilation. The incidence of the worse eye condition (score 2) was higher in houses with drop-down ventilation and correlated positively with increasing week 6 temperature. Feather condition was better in the first year of the trial and in houses with forced side-inlet ventilation and troughs, and least in houses with drop-down ventilation and nipple drinkers. Best posture (score 0) was correlated with best gait and gait correlated negatively with litter moisture, week 3 temperatures and ammonia. Regressions of best gait (no gait abnormalities) against week 3 temperature (gait 0 = 101·4–1·4T) and litter moisture (gait 0 = 110·3–0·76 litter moisture) indicate that on average gait was best at 15·4°C and 40% litter moisture. Regression of severe gait abnormalities (score 2) against ammonia (gait 2 = −0·5 + 0·3 ammonia), indicate gait was worse above 11·6 ppm ammonia.

Foot and hock conditions at slaughter are given in Table 6, along with final explanatory models and percentage of variation explained. Nearly 50% of the ducks had foot pads that were clean, smooth and free of lesions (score 0) or had just a small line of ingrained dirt in the skin, while almost 40% of the ducks had raised papillae with dirt pervading the upper skin layer (though damage to underlying tissue was visible in some of these pads). The incidences

Table 5. *Proportion of ducks with different eye, nose, feather, posture and gait scores at 41 d*

	Mean (SE) (range)	Model	*F* value & significance	R^2 %
Best eyes (score 0) %	84·2	Trial	–	87·6
	(3·1)	Drinker type: lower in houses with nipple drinkers	$F = 8·8$***	
	(28·0–100)	Ventilation: lower in houses with forced drop-down ventilation	$F = 4·7$*	
		Higher with increasing levels of clean feathers (score 0 $r = 0·85$)	$F = 8·0$**	
		Increases with increasing growth rate	$F = 8·0$**	
Worst eyes (score 2) %	0·5	Trial	–	49·8
	(0·2)	Ventilation: highest in systems with forced drop-down ventilation	$F = 9·6$***	
	(0–8·0)	Increases with increasing variation in week 6 temperature SD ($r = 0·49$)	$F = 18·9$***	
Best nostrils (score 0) %	97·6	Trial	–	64·5
	(0·5)	Ventilation: lower with forced drop-down ventilation	$F = 9·3$***	
	(84·0–100)	Decreases with increasing litter temperature ($r = -0·46$)	$F = 5·2$*	
		Decreases with increasing levels of dirty feathers ($r = -0·44$)	$F = 4·1$*	
Best feathers (score 0)%	67·4	Trial: higher in the first trial	$F = 12·5$***	88·2
	(6·1)	Ventilation: higher in houses with forced side-inlet ventilation, then natural	$F = 39·4$***	
	(0–100)	ventilation then forced drop-down ventilation		
		Drinker (nested in ventilation system): higher in houses with troughs then plasson drinkers then nipples	$F = 16·2$***	
		Increases with decreasing week 1 RH ($r = -0·67$)	$F = 7·9$**	
		Increases with increasing litter pH ($r = 0·43$)	$F = 10·3$**	
Worst feathers (score 2)%	0·6	System	–	50·7
	(0·4)	Increases with increasing W1 RH ($r = 0·59$)	$F = 8·1$**	
	(0–18·0)	Increases with increasing worse posture (score 2 $r = 0·58$)	$F = 4·3$*	
Best posture (score 0) %	94·7	Trial	–	52·9
	(0·6)	Brood type: higher in houses with half house brood than whole house	$F = 4·7$**	
	(84·0–100)	Increases in flocks with higher levels of best walking (Gait 0 $r = 0·57$)	$F = 14·7$***	
Worse posture (score 2) %	1·0	System	–	36·5
	(0·2)	Increases in flocks with higher levels of worst walking (Gait 2 $r = 0·59$)	$F = 15·1$***	
	(0–6·0)			
Best gait (score 0) %	79·4	System	–	55·1
	(1·4)	Lower with increasing moisture in the litter (visit 1 $r = -0·63$)	$F = 9·8$**	
	(60·0–94·0)	Increases with decreasing week 3 temperature ($r = -0·60$)	$F = 11·4$**	
Worse gait (score 2) %	2·9	System	–	37·2
	(0·5	Increases with increasing ammonia levels ($r = 0·61$)	$F = 17·3$***	
	(0–12·0))			

Significant effects are detailed along with the amount of variation explained by the model (R^2).
*$P < 0·05$, **$P < 0·01$, ***$P < 0·001$.

of moderate (score 1) and severe lesions (score 2) were around 10 and 3%, respectively. In additional to foot pad dermatitis (FPD), 32% of ducks had calloused toes and 11% had pink hocks. There was no effect of season on FPD or pink hocks. The best foot pads were in ducks from houses with plasson drinkers followed by those in houses with troughs; the worse pads were from houses with nipple drinkers and there was some evidence that increasing RH and ammonia led to increased FPD. The incidence of pink hocks was higher with increasing week 1 temperatures and dirty feathers at 41 d. Feather condition and cleanliness at slaughter is shown in Figure 2. Ducks from houses with nipple drinkers (with drop-down and natural ventilation) had the highest incidence of heavily soiled feathers ($F = 3·4$, $P < 0·05$), whereas ducks from houses with forced side-inlet ventilation and troughs had the cleanest feathers (clean plus slightly soiled, $F = 5·8$, $P < 0·001$). The incidence of stubbly quill (broken feathers on the breast) averaged 8·2% (0–51·5%) and was highest in houses with

Table 6. *Mean, standard error and range of pad dermatitis, callous toes and pink hocks, measured at the processing plant*

	Mean (SE) (range)	Model	F ratio & significance	R^2 %
Best pads (score 0) %	20·6	Trial	–	73·2
	(2·8)	Higher in houses with plasson drinkers then troughs then nipples	$F=18{\cdot}8$***	
	(0·7–60·7)	Higher with increasing levels of dirty eyes (23 d $r=0{\cdot}67$)	$F=3{\cdot}8$*	
Ingrained dirt in pads %	28·5	Trial	–	40·0
	(1·4)	Higher in houses with troughs than nipple drinkers	$F=3{\cdot}6$*	
	(7·3–50·5)	Higher with lower ammonia levels (41 d $r=-0{\cdot}51$)	$F=5{\cdot}3$*	
Raised papillae %	38·5	Trial	–	61·9
	(2·5)	Drinker type: higher in systems with nipple drinkers than plassons	$F=20{\cdot}7$***	
	(8·6–71·0)	Increases with increasing week 6 RH ($r=0{\cdot}41$)	$F=5{\cdot}8$*	
Intermediate pads (score 1) %	9·9	Trial	–	80·4
	(1·0)	Higher in houses with nipple drinkers than plassons	$F=73{\cdot}4$***	
	(0–30·0)	Increases with increasing week 2 RH ($r=0{\cdot}41$)	$F=25{\cdot}4$***	
Worse pads (score 2) %	3·1	Trial	–	42·2
	(0·4)	Lower in houses with plasson drinkers	$F=3{\cdot}8$*	
	(0–11·0)	Higher in flocks with increasing levels of mild posture difficulties (41 d $r=0{\cdot}52$)	$F=11{\cdot}2$**	
Callous toes %	32·0	Trial	–	53·2
	(3·2)	Highest in houses with nipple drinkers	$F=8{\cdot}3$***	
	(2·7–69·0)	Increases with increasing ammonia levels (41 d $r=0{\cdot}47$)	$F=3{\cdot}1$*	
Pink hocks %	11·2	Trial	–	66·5
	(2·0)	Higher in houses with whole and half house brood	$F=5{\cdot}6$**	
	(0–46·7)	Increases with increasing W1 temperature SD ($r=0{\cdot}52$)	$F=18{\cdot}7$***	
		Higher with lower levels of clean feathers (score 0 41 d $r=-0{\cdot}49$)	$F=10{\cdot}9$**	

Significant effects are detailed along with the percent variation explained by the model (R^2).
*$P<0{\cdot}05$, **$P<0{\cdot}01$, ***$P<0{\cdot}001$.

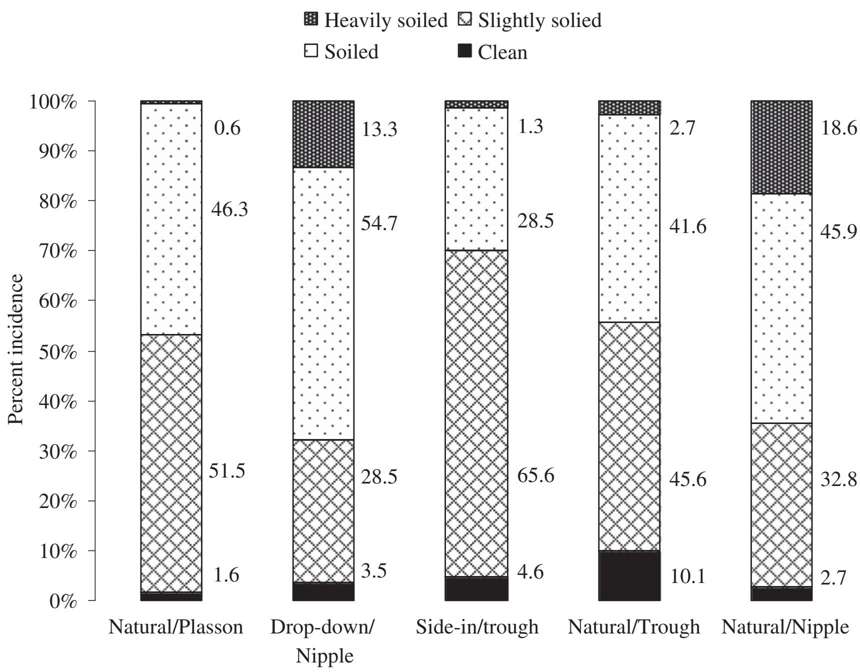

Figure 2. *The incidence of feather cleanliness at the processing plant by system: ventilation (natural, forced drop-down, forced side-in) and drinking (plasson, trough, nipple).*

forced side-inlet ventilation and troughs ($F = 8{\cdot}5$, $P < 0{\cdot}001$).

DISCUSSION

Duck welfare, as measured by physical and plumage condition and mortality, was considered good, particularly at the younger age. Condition and cleanliness however declined with age and under certain conditions. The results of our regression analyses clearly emphasise the importance of low ambient and litter temperatures, low relative humidity, dry litter and low ammonia concentrations, for good physical condition, walking ability, growth rate and reduced mortality. High ambient temperatures and to some extent high litter temperatures were implicated in reduced growth rates, increased mortality, increased downgrades at slaughter, increased incidence of dirty eyes, nostrils and feathers, increased pink hocks and worsening gait (walking ability). Wet litter and high ammonia were also implicated in worse gait, and increasing ammonia was implicated in the incidence of foot pad dermatitis. Stocking density was within the recommended limit of $23{\cdot}5\,kg/m^2$ for $3{\cdot}35\,kg$ ducks (DEFRA, 2007), and was not implicated in our analysis. Light values were also not related; average values were higher than those reported by Barber *et al.* (2004), who also found that ducks prefer some variation in illuminance.

High weekly temperatures throughout the production cycle, which occurred predominantly in the warm season, were associated with whole house and circular brooding systems which in turn were related with higher rates of mortality. The causes of mortality were not recorded but ‘flip-over’, or sudden death syndrome (possibly of metabolic origin), and suspected aspergillosis, a fungal infectious disease of poor quality straw, were observed in some flocks. High temperatures at various stages in the production cycle correlated with decreasing growth rate and, together with wet litter, a reduction in the proportion of ducks with the best gait (no abnormalities). It is possible that the ducks ate less under higher temperatures and that high temperatures affected their cardiovascular system, thus affecting their walking, but further work would be needed to confirm this.

Higher temperatures in week 6 were linked to houses with drop-down ventilation and houses with nipple drinkers, which in turn were linked to more dirty eyes, nostrils and feathers (both on farm and at the processing plant). In the case of houses with natural ventilation and nipple drinkers, side vents could have been opened further on the assessment day to alleviate the effects of temperature and ammonia. It is unlikely however, without increasing the number and or power of the fans, that ventilation rates could have been improved in houses with drop-down ventilation, also with nipple drinkers. We have previously recorded higher temperatures in chicken houses with this type of ventilation system (Jones *et al.*, 2005*a*). Nipple systems do not allow ducks to splash water over their eyes and feathers and have been shown experimentally to be less effective at maintaining eye condition and plumage cleanliness than open water systems (Ruis *et al.*, 2003; Knierim *et al.*, 2004; Heyn *et al.*, 2006; Jones *et al.*, 2008), and delay the development of the breast, leg and mid tail feathers (Reiter *et al.*, 1997). Here we highlight the combined effect of poor ventilation (and the related high temperatures and ammonia) and nipple systems on eye condition, because only when nipples were combined with drop-down ventilation did we see ducks with the very worse cases of poor eye condition (closed eyes).

High RH exacerbates the problems of high temperatures by increasing the apparent equivalent temperature experienced by the ducks, particularly at an older age. Here, as in studies conducted in chicken houses (Dawkins *et al.*, 2004), RH increased with production week and was implicated along with ammonia in the incidence of foot pad dermatitis, FPD (Jones *et al.*, 2005*a*). Furthermore, drinker system affected FPD, which was worse in houses with nipple drinkers, intermediate in houses with troughs and best in houses with plasson drinkers. Knierim (in Rodenburg *et al.*, 2005) also found FPD to be worse in ducks reared with nipple drinkers than troughs. Here, these houses (with nipple drinkers) also had higher temperatures and higher ammonia which may have contributed to foot pad deterioration. Houses with plasson drinkers in this study were bedded-up twice daily towards the end of the production cycle, which may have positively influenced the condition of the feet. It does, however, emphasise the importance of the quality of the straw going into the house. The straw in the second year of the study was not as good as the first year, due to the wet harvest, and this was seen to negatively affect duck plumage and foot pad condition, mortality and the percent downgrades, which were all worse in the second year of the study.

High ammonia concentrations adversely affect chickens by causing irritation to the mucous membranes in the eyes and respiratory system and by depressing food intake and growth rate (Kristensen and Wathes, 2000; Homidan *et al.*, 2003). Chickens are averse to ammonia (Jones *et al.*, 2005b) at concentrations less than 25 ppm (Kristensen *et al.*, 2000) and it may affect leg health (Jones *et al*., 2005*a*). Duck leg health was affected by increasing ammonia in this study, because the most severe gait abnormalities were more frequent when ammonia was high. The mechanism for this is not known, but since poor duck posture and poor walking ability were correlated, respiratory problems may be implicated.

It is difficult in an observational study of this kind to separate the effects of correlated causes. For example, is it the high temperature, the high RH or the high ammonia which drives FPD or gait abnormalities, or is it generally poor litter quality that results in poor welfare and high ammonia? What is clear is that management of the ventilation system and maintaining litter quality are important aspects of maintaining the correct environment for the welfare of ducks, as previously suggested by Raud and Faure (1994). Here, we found that the climatic conditions suitable for best body and feather condition and walking ability, were average weekly temperatures below 16°C post brooding, litter with less than 40% moisture and air with less than 11 ppm ammonia.

In conclusion, control of the environment in which ducks are reared, particularly temperature, humidity, litter moisture and ammonia, is critical for duck welfare. Good ventilation and high straw quality are key to maintaining duck body and plumage condition and to reducing mortality. Access to open water in some form was seen to benefit eye and feather cleanliness and foot pad condition.

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