WELFARE OF MALE AND FEMALE BROILER CHICKENS IN RELATION TO STOCKING DENSITY, AS INDICATED BY PERFORMANCE, HEALTH AND BEHAVIOUR

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Abstract

The purpose of this experiment was to provide information relevant to the current debate concerning the optimisation of terminal stocking density for commercial broiler production. In a modern, controlled-environment house with 24 floor pens (each 11.4 m^2), 4020 day-old broilers (Ross 308) were allocated to three terminal (42 days) stocking densities (28, 34 and 40 kg m^{-2}) x two sexes x four replicates, according to a randomised block design. Group sizes varied from 130 to 208. Husbandry conditions were in accordance with normal commercial practice. Performance and behaviour were measured systematically during each of the six weeks of life, and additional measurements were made of leg health and litter condition. Data were analysed using ANOVA to determine the effects of stocking density, sex and age. The realised mean terminal stocking densities were 28.2, 33.5 and 38.5 kg m^{-2}. The main significant effects of stocking density treatment were a linear decline in food intake with increasing density during week six (the final week), and a reduced proportion of time spent panting deeply during weeks five and six at the lowest density. Increased (shallow and deep) panting shown by females in weeks two to five suggests that if thermal discomfort becomes a problem at higher stocking densities later in the growing period, it may do so earlier in females. There was no conclusive evidence from this study that broiler welfare is compromised any more at 40 than at 34 kg m^{-2}. The fact that the proportion of time spent panting deeply in week six was considerably lower at 28 kg m^{-2} than at 34 and 40 kg m^{-2} suggests that thermal comfort (and hence welfare) at this age may be improved at densities of less than 34 kg m^{-2}. However, the significant effects of age, age x density, and age x sex on time spent panting deeply suggest that the age at slaughter and the sex of birds in single-sex flocks should be taken into account in future considerations of optimal maximum terminal stocking density.

Keywords: *animal welfare, behaviour, broiler, performance, stocking density, thermoregulation*

Introduction

In the UK, the recommended maximum terminal stocking density for commercial broiler chicken production has been 34 kg m^{-2} for many years (MAFF 1987). In other European countries, recommendations vary from 22.5 to 42.5 kg m^{-2} (EC Report 2000). These limits apply to littered-floor systems, the main type of housing used worldwide (Elson 1993). Since the UK limit was established, controlled-environment housing has become increasingly sophisticated, and consequently there has been discussion about whether UK producers should be allowed to stock at higher densities in houses with the best climate control, as is the case in Sweden (Ekstrand 1993). By contrast, the RSPCA Freedom Food Standard (1999), a scheme designed to improve welfare standards, stipulates a lower maximum density of 30 kg m^{-2}. In general, higher densities are economically beneficial because they reduce the fixed costs of production and result in a greater weight of broiler meat per unit area. However, there has been increasing concern over the welfare of broilers stocked at high densities (FAWC 1992, 1995), particularly in the final week of life when available floor space is minimal. In addition to advances in housing, broiler genotypes have changed greatly since the mid-1970s, particularly with regard to increased growth rate. Hence, the interaction between stocking density and bird welfare may have changed considerably since earlier studies (for a review, see Ekstrand 1993).

The impact of stocking density on broiler performance has been the subject of many studies, and the densities used range from around 10 to 50 kg m^{-2}. While an increase in stocking density provides a greater monetary return per m^2, the economic return per bird tends to decrease. The latter is mainly because of a reduction in growth rate. However, the point at which this occurs has differed between studies. In the majority of reports, growth depression occurred from 30 kg m^{-2} onwards (Proudfoot *et al* 1979; Shanawany 1988; Cravener *et al* 1992; Gordon 1992; Elwinger 1995). However, other work demonstrated no reduction in growth rate when density was raised to 30 and 32 kg m^{-2} (Scholtyssek 1971; Scholtyssek & Gschwindt-Ensinger 1983). Several studies have found a reduction in food intake with increasing stocking density (Scholtyssek 1974; Scholtyssek & Gschwindt-Ensinger 1983; Shanawany 1988; Puron *et al* 1995). Effects on conversion of food to bodyweight gain have been less consistent, with either no response (Scholtyssek & Gschwindt-Ensinger 1983; Puron *et al* 1995), better conversion (Scholtyssek & Gschwindt 1980; Shanawany 1988; Grashorn & Kutritz 1991; Cravener *et al* 1992), or poorer conversion (Coenen *et al* 1996) at higher densities. Broiler mortality has usually not been affected by stocking density (eg Proudfoot *et al* 1979; Shanawany 1988; Cravener *et al* 1992; Gaardbo Thomsen 1993; Puron *et al* 1995). In one study, however, lower mortality was found at a density of 33 compared with 38 kg m^{-2} (Coenen *et al* 1996).

From a health perspective, high stocking densities may have adverse effects on litter quality and hence on the incidence of skin lesions (Ekstrand 1993). Another problem is the high frequency of leg disorders in broilers (FAWC 1992; Kestin *et al* 1992; Reiter & Bessei 1998). Kestin *et al* (1992) developed a method for measuring the prevalence of leg weakness in broilers by assessing their walking ability (gait scoring). The birds in that study were grown according to commercial practice and 90 per cent had a detectable gait abnormality. The effect of stocking density on walking ability has been little studied, but existing work indicates that this declines with increasing density (Grashorn 1992; Kestin *et al* 1994; Sanotra *et al* 1995; Sorensen *et al* 2000).

As well as affecting performance and health, high stocking densities are very likely to influence behaviour. This may take the form of a physical restriction of movement, with the greatest effects likely to occur in the last week of life. Blokhuis and van der Haar (1990) studied the behaviour of broilers at densities varying from 4 to 42 kg m^{-2}. In that experiment, pecking and scratching declined with increasing density, and preening and walking showed a similar response in the last week of life. Several other studies also report a reduction in locomotor activity and/or scratching as density increases (Lewis & Hurnik 1990; Reiter & Bessei 1994, 1999; Andrews *et al* 1997). Bessei (1992), however, referring to observations at densities of 10–30 birds m^{-2}, noted no significant effects of density on locomotor activity, feeding, drinking, scratching or resting. The relationship between stocking density and behaviour is thus unclear. The variability in these results may be attributable to differences in the range of densities and ages of birds studied.

Another concern in relation to broiler welfare is the increased risk of heat stress at high stocking densities (FAWC 1992), especially as there is evidence of increased sensitivity to such stress resulting from faster growth in modern genotypes (Cahaner *et al* 1998). Considerable attention has been given to the thermoregulatory demands placed on broilers during transport and lairage (Webster *et al* 1993; Mitchell & Kettlewell 1994, 1998; Quinn *et al* 1998). As yet, however, there is little information on how thermoregulation relates to stocking density. Recent work has revealed that temperatures in the litter and between birds increase with increasing stocking density, whereas the temperature of the air above the birds remains constant (Reiter & Bessei 2000). An important behavioural indicator of heat stress in broilers is panting (polypnea). There exist a number of reports documenting the respiratory patterns and the physiology of panting in domestic fowl (eg El Hadi & Sykes 1982; Arad 1983; Arad & Marder 1983; Gleeson & Brackenbury 1983; Zhou *et al* 1999). As yet, however, there has been no systematic study of broiler panting behaviour in relation to age, sex and stocking density.

It is virtually impossible to achieve an ideal experimental design for investigating the effects of stocking density on broiler welfare. This is because the small group sizes that are required to provide enough replicates for statistically valid comparisons will not necessarily be commercially relevant (Cunningham *et al* 1992; Classen *et al* 1994). Also, the work is likely to be performed in a common environment. Even if a commercial-scale flock, in a single house with modern climate control, is divided into smaller units of differing sex and density, the problem of the shared environment could still influence the results. This design was used in the present study and this point is dealt with in more detail in the Discussion.

The present study investigates the effects of three predicted terminal stocking densities (28, 34 and 40 kg m^{-2}) on the welfare of male and female broiler chickens as indicated by performance, health and behaviour. It provides the first detailed investigation of changes in panting behaviour with age, sex and stocking density.

Materials and methods

Experimental design

In a randomised block experiment, 4020 newly hatched broiler chickens (Ross 308; Ross Breeders [now Aviagen Ltd], Midlothian, UK) were assigned, in separate sex groups, to three predicted terminal (42 days) stocking density treatments of 28, 34 and 40 kg m^{-2} with four replicates per sex and treatment (ie 24 pens in total). The stocking density treatments were achieved by varying the group size from 130 to 208 birds (Table 1) while pen size was kept constant (11.4 m^2). The number of birds to be placed for each treatment was calculated assuming male and female mortality rates of 9 and 5 per cent, respectively, and male and female liveweights of 2.7 and 2.3 kg by 42 days of age (these estimates were based on previous unpublished work at SAC, Auchincruive, and advice from Ross Breeders Ltd).

Table 1 Initial placement density and numbers of birds per stocking density treatment and sex. Experimental design based on three stocking density treatments x two sexes x four replicates (n = 4020 birds in total).

Treatment (kg m^{-2})	28		34		40	
Sex	M	F	M	F	M	F
Birds per pen	130	146	158	177	186	208
Birds per m^2	11.4	12.8	13.8	15.5	16.3	18.2

Bird management

The experiment was conducted in a controlled-environment house under normal commercial husbandry conditions. The litter comprised soft-wood shavings to a depth of approximately 7 cm. The birds were brooded using whole-house brooding and kept on a 23L : 1D lighting programme from days 0–2, and on 20L : 4D thereafter. Light intensity was around 80 lux at bird level for the first two days and was then maintained at 20 lux throughout the study. Birds in each pen had continual access to three tube feeders and 17 nipple drinkers. Hence, feeding and drinking space was in the range of 43–69 birds per tube feeder and 8–12 birds per nipple, respectively, depending on the number of birds per pen. Feeding and drinking space complied with or exceeded the recommendations (70 birds per tube feeder [38 cm diameter] and 12 birds per nipple) of the Ross 308 Broiler Management Manual (Ross Breeders 1999). The birds were fed four commercial diets: starter crumb (days 0–7), grower pellet (days 7–28), finisher pellet (days 28–35) and withdrawal pellet (days 35–42). The withdrawal diet contained no anti-coccidial drug. A minimum ventilation rate of 2 m^3 sec^{-1} per tonne of feed consumed was maintained within the house (and as such was not specifically related to the needs of any one treatment). An automated climate-control system (SKOV Euromatic Dol 34H) was set to maintain ambient temperature within desired limits. There was less rigorous control of atmospheric relative humidity. Incorporated heating was supplied by a propane building heater (LB White Agricultural, model AW230). The targets for ambient temperature (see Table 7) were 'in-house' figures that were set on the computer. The Ross Broiler Management Manual (Ross Breeders 1999) recommends a target temperature of 29°C at one day old declining by 1°C every three days to 21°C by 24 days of age. The normal recommended range of relative humidity is 60–70 per cent.

Performance

Mortality

Mortality was recorded daily, with birds undergoing *post mortem* examination. These included birds that were culled when they were deemed to be unable to reach feeders and drinkers or were obviously lame.

Bodyweight gain, food intake, food conversion ratio

At placement (day 0), the birds in each pen were double counted and bulk weighed. Individual bodyweights were obtained for a random sample of 30 birds per pen on days 35 and 42. The birds were sampled using a catching frame. Bodyweight gain (g $bird^{-1}$) was calculated as the difference in average bodyweight at the start and end of a specified period. Food intake was measured for each pen of birds over each dietary phase by subtracting the weight of food remaining in the hoppers at the end of the period from the total weight of food added to the hoppers. Food intake per bird per day was calculated and divided by bodyweight gain to obtain the food conversion ratio (FCR).

Health

From day 21, a random sample of 30 birds per pen was assessed weekly for evidence of contact dermatitis of hocks and/or feet (resulting from poor litter quality). This was measured on a scale of 0–4, 0 representing a bird with no discolouration or "burning" and 4 where the hock or foot was enlarged with a large scab or burnt area. Hock- and foot-score data were pooled across the measurement period. On day 37, walking ability was determined for 10 birds per pen. The birds were individually gait-scored according to the Bristol gait-scoring scheme (Kestin *et al* 1992). This uses a score from 0–5, where 0 indicates a normal gait and 5 represents a bird that is unable to walk. The birds were gait-scored in the pens without confining them. Scoring was performed by three people, and agreement between them for each bird was required before a score was recorded.

Environmental monitoring

From day 21, the litter condition in each pen was assessed using a subjective score of 1–5, where 1 indicates friable litter with no capping or compaction and 5 indicates litter that is wet and dough-like. At the same time, a sample of litter material from each pen was collected and analysed for dry-matter content. The samples were dried in an oven for 24 h at 70°C. Litter scores and dry matter data were pooled across the measurement period. Ambient temperature and atmospheric relative humidity were monitored continuously and logged onto a computer using two probes situated in the centre of the house (in a central walkway) at a height of 45 cm from the ground.

Behavioural observations

Observations of bird behaviour were recorded weekly. Six birds in each pen (three in the morning and three in the afternoon) were chosen at random from different parts of the pen and scored for activity every Thursday and Friday for weeks one to six. There was thus a small probability of the same bird being observed more than once in any one day. The order in which pens were observed was random and differed for each recording period. One observer followed each subject visually for 2 min, and every 10 s reported its behaviour at that moment to another person, who recorded it according to one of the following 16 mutually exclusive categories: standing (only); sitting (only); resting (neck outstretched with head on the ground or on another bird, sometimes with eyes closed); feeding (from tube feeders); drinking (from nipple drinkers); walking; running; litter-directed activity (pecking and scratching) while standing; litter-directed activity while sitting; preening while standing; preening while sitting; aggressive pecking (overt, rapid or forceful); non-aggressive pecking (furtive, deliberate, gentle or vigorous); dustbathing; stretching (leg fully extended out behind the bird, often accompanied by simultaneous wing stretch); and wing flapping. Special attention was also given to whether the subject was panting and whether this occurred while sitting, resting or standing (because heat dissipation while standing is an additional form of thermoregulatory behaviour). Panting was classified into two types: shallow panting when the mouth was only slightly open; and deep panting when the mouth was wide open, sometimes associated with gular flutter (vibration of the throat) (Richards 1970).

The mean proportion of time spent performing each activity in each week was calculated for each pen from the 144 observations (6 birds x 2 min x 6 observations min^{-1} x 2 days). Descriptive statistics for behavioural data are presented as the proportions of time spent in different activities.

Statistical analyses

The various performance, health and environmental (except temperature and humidity) data were subjected to analysis of variance, with stocking density, sex, and their interaction as factors (Minitab, release 10.51). All percentage data were transformed by angular (arcsine root) transformation to give approximately equal variances between treatments before statistical testing. Significant ($P < 0.05$) differences between treatment means were determined using the Tukey–Kramer method (Sokal & Rohlf 1981). Raw per cent values are presented in the tables. Performance results were analysed to show effects of treatment, sex, and their interaction over the whole study (days 0–42) and during the final week (days 35–42). The additional analysis with data from the final week was because any effects of stocking density on bird performance were likely to be greatest then.

For the behavioural data, age was included as a factor in the analysis in addition to stocking density and sex. This allowed an investigation of longitudinal patterns of behaviour. For each activity, the transformed data were subjected to split-plot analysis of variance with pens as plots and age as the split-plot factor (Genstat 5, release 4.1). Differences between treatment means were determined using the Tukey–Kramer method, as before.

Exclusion of pen 20 from analyses

Because of exceptionally high mortality in one pen (pen 20) in the first week of life (see Mortality, in Results section) it was excluded from all analyses and regarded as a missing value.

Results

Performance

Mortality

The frequency of the number of deaths per pen in any one week was distributed in a negative exponential way (Figure 1). There was exceptionally high mortality (27 deaths) in pen 20 (40 kg m^{-2} female treatment) in the first week of life, as can be seen from the outlier in Figure 1. This meant that pen 20 effectively became a medium-density treatment from the first week onwards. As such, it was regarded as atypical and treated as a missing value in all subsequent analyses.

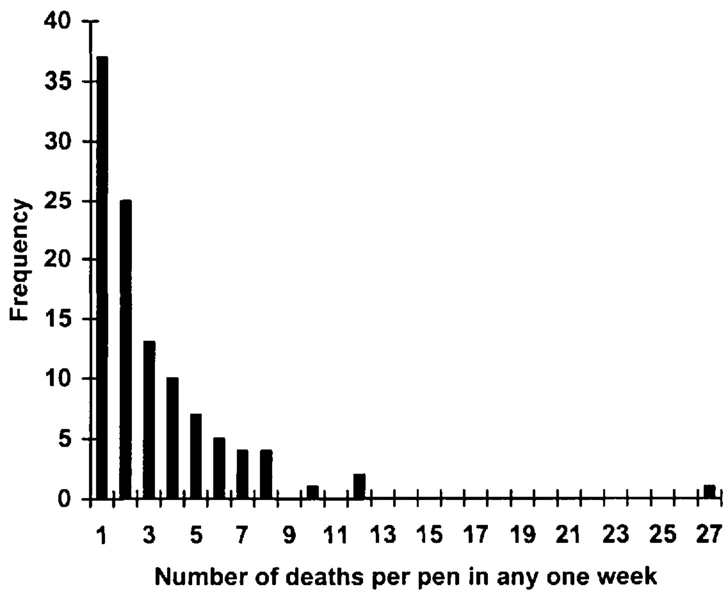

Figure 1 **Histogram showing number of deaths per pen in any one week over the six-week growing period. Data include pen 20, which had exceptionally high mortality in the first week of life.**

Even when pen 20 was excluded from the data, the level of mortality in the first week (across the whole population) was still higher than at other times (Figure 2). Mortality over the whole study was 8.2 per cent (excluding pen 20) and, of the 311 deaths, 85 (27.3%) birds were culled. The main causes of death were sudden-death syndrome, ascites and yolk-sac infection (T Pennycott, personal communication 1999). There was no significant effect of stocking density treatment on either total mortality (Table 3) or mortality in the final week (Table 4). During both periods, more males died than females, and this effect was highly significant in the final week.

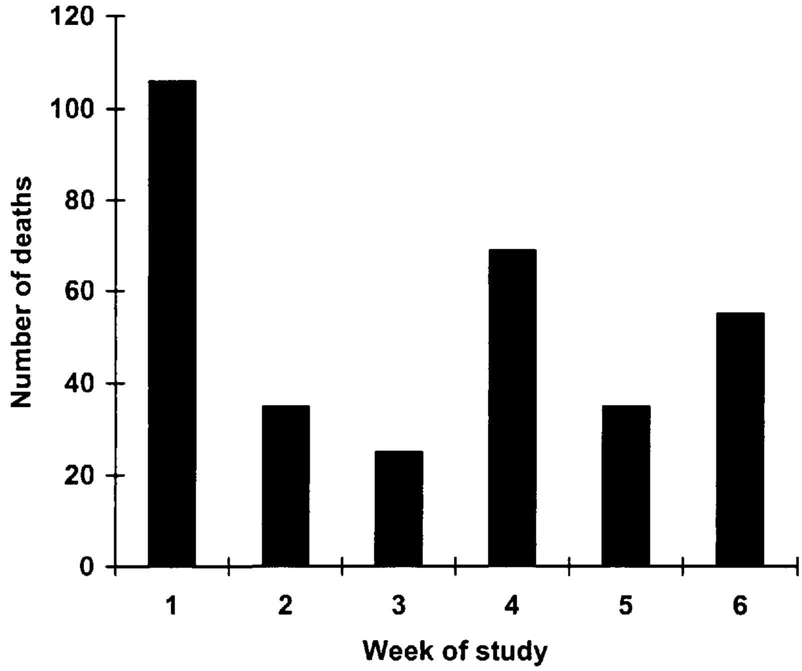

Figure 2 Total number of deaths in each week of the study. Data exclude pen 20.

Realised terminal stocking density

Realised day 42 stocking densities were close to predicted levels, except at the highest density treatment (38.5 instead of 40 kg m^{-2}). Realised densities differed significantly between treatments, but not between sexes (Table 2).

Food intake, bodyweight gain and food conversion ratio

There was a significant effect of stocking density on total food intake (0–42 days), with birds at the highest density consuming 169 g bird^{-1} less than those at the lowest (Table 3). However, this effect was almost entirely attributable to the highly significant difference during the final week (days 35–42), when birds at the highest density ate 128 g bird^{-1} less than those at the lowest density (Table 4). (A separate ANOVA showed no significant effect of density on food intake during days 0–35.) Food intake in the 34 kg m^{-2} group was intermediate, resulting in a significant linear decline in food intake with increasing stocking density over days 35–42 (least-squares regression analysis: $r^2 = 0.23$, $F_{1,21} = 6.10$, $P = 0.022$). Males consumed more than females, and this effect was highly significant throughout the whole experiment and in the final week alone.

Despite the significant effect of stocking density on food intake, there was no significant effect of density on either bodyweight gain or FCR over either the whole growing period or the final week. Bodyweight gain was greater in males than in females during both periods, and FCR was lower in males over the whole six weeks.

Table 2 **Realised terminal (at 42 days of age) stocking density. *P* values are taken from two-way ANOVA. Rows by treatment with no common superscript are significantly different (Tukey–Kramer method, *P* < 0.05).**

	Treatment (stocking density, kg m^{-2})			Sex		*P* value		
	28	34	40	M	F	Stocking density	Sex	Density x Sex
Realised stocking density (kg m^{-2})	28.2^{a}	33.5^{b}	38.5^{c}	33.4	33.4	0.001	NS	NS

Table 3 **Performance data over days 0–42 of the study. *P* values are taken from two-way ANOVA. Rows by treatment with no common superscript are significantly different (Tukey–Kramer method, *P* < 0.05).**

	Treatment (stocking density, kg m^{-2})			Sex		*P* value		
	28	34	40	M	F	Stocking density	Sex	Density x Sex
Mortality (%)	7.8	8.6	8.0	9.7	6.6	NS	0.034	NS
Food intake (g bird^{-1})	4163^{a}	4086^{ab}	3994^{b}	4314	3848	0.040	<0.001	NS
Bodyweight gain (g bird^{-1})	2492	2467	2398	2637	2267	NS	<0.001	NS
FCR (food intake/ weight gain)	1.67	1.66	1.67	1.64	1.70	NS	0.012	NS

Table 4 **Performance data over days 35–42 of the study. *P* values are taken from two-way ANOVA. Rows by treatment with no common superscript are significantly different (Tukey–Kramer method, *P* < 0.05).**

	Treatment (stocking density, kg m^{-2})			Sex		*P* value		
	28	34	40	M	F	Stocking density	Sex	Density x Sex
Mortality (%)	1.1	1.4	1.8	2.3	0.5	NS	0.001	NS
Food intake (g bird^{-1})	1215^{a}	1152^{ab}	1087^{b}	1222	1081	0.003	<0.001	NS
Bodyweight gain (g bird^{-1})	531	509	491	556	465	NS	0.003	NS
FCR (food intake/ weight gain)	2.31	2.29	2.26	2.22	2.35	NS	NS	NS

Health

Hock scores were low overall and, where lesions occurred, these involved only a slight discolouration (reddening) of the skin. Stocking density treatment had no significant effect, but males had higher scores than females, both over weeks three to six (Table 5) and during the final week (not shown). Foot lesions were uncommon: mean foot scores were lower than hock scores and were not affected either by stocking density or by sex. At 37 days, 95.8 per cent of all birds had a gait score of 2 or less, and mean gait scores did not differ significantly with either stocking density or sex.

Table 5 **Health data, including average hock, foot and gait scores. Hock and foot values represent average scores pooled over weeks 3–6 of the study. Gait score was measured at 37 days of age (n = 40 birds per treatment and sex). *P* values are taken from two-way ANOVA.**

	Treatment (stocking density, kg m^{-2})			Sex		*P* value		
	28	34	40	M	F	Stocking density	Sex	Density x Sex
Hock score	0.48	0.53	0.54	0.58	0.45	NS	0.002	NS
Foot score	0.03	0.07	0.03	0.02	0.07	NS	NS	NS
Gait score	1.61	1.65	1.55	1.68	1.54	NS	NS	NS

Environmental monitoring

There was a highly significant effect of stocking density on litter condition. Litter scores were lower in pens stocked at the lowest density compared to medium- and high-density pens (Table 6). Litter scores were also lower in male pens than female pens. Mean litter moisture content was higher at the highest stocking density than at the lowest, and pens containing females had a higher moisture content than those containing males.

Mean ambient temperature declined gradually from 28°C in week one to 19–21°C in weeks four to six. Mean atmospheric relative humidity increased from less than 40 per cent in week one to more than 75 per cent in the final week (Table 7).

Table 6 **Litter score and litter moisture content. Values represent averages pooled over weeks 3–6 of the study. *P* values are taken from two-way ANOVA. Rows by treatment with no common superscript are significantly different (Tukey–Kramer method, *P* < 0.05).**

	Treatment (stocking density, kg m^{-2})			Sex		*P* value		
	28	34	40	M	F	Stocking density	Sex	Density x Sex
Litter score	1.11^{b}	1.23^{a}	1.26^{a}	1.16	1.24	0.005	0.037	NS
Litter moisture content (%)	21^{a}	24^{ab}	26^{b}	22	27	0.017	0.002	NS

Behaviour

Results of the behavioural observations are presented in Table 8. Overall, the most time was spent inactive in sitting and resting (total 64.9%), and standing accounted for 12.1 per cent of time. Less time was spent feeding than drinking. Litter-directed activity and preening both accounted for approximately 4 per cent of time, and were mostly performed while sitting. Dustbathing, stretching, wing flapping, running, and aggressive and non-aggressive pecking together accounted for less than 2 per cent of time.

Table 7 Mean ambient temperatures and atmospheric relative humidities. Data were averaged across daily measurements for each of weeks 1–6 of the study.

Week	Mean temp (°C)	Mean target temp (°C)*	Mean relative humidity (%)
1	28.1	30.3	35.5
2	25.5	26.9	41.5
3	22.7	23.4	53.8
4	20.4	20.4	58.9
5	19.4	20	73.7
6	21.3	20	78.3

* Mean daily temperature target settings on the computer in each week. (There was no such rigorous control of relative humidity level; see Materials and methods section.)

Table 8 Overall mean proportions of time spent by birds in different activities. Values represent averages of 144 observations on 12 birds per pen per week (ie 576 observations on 48 birds per stocking density treatment and sex). *P* values are taken from split-plot ANOVA with age, sex, density and their interactions as factors.

Activity	Overall mean (% time)	Age	Stocking density treatment	Sex	Age x Density	Age x Sex	Sex x Density	Age x Sex x Density
Sitting	45.0	<0.001	NS	NS	NS	NS	NS	NS
Resting	19.9	<0.001	NS	0.043	NS	NS	NS	NS
Standing	12.1	<0.001	NS	NS	NS	NS	NS	NS
Feeding	4.2	<0.001	NS	NS	NS	NS	NS	NS
Drinking	5.5	NS	NS	NS	NS	NS	NS	NS
Walking	3.8	<0.001	NS	NS	NS	NS	NS	0.018
Running	0.2	<0.001	NS	NS	NS	NS	NS	NS
*Litter (standing)**	1.6	<0.001	NS	NS	NS	NS	NS	NS
*Litter (sitting)**	2.0	NS	NS	NS	NS	0.050	NS	0.048
Preening (standing)	1.3	<0.001	NS	0.009	0.004	NS	NS	NS
Preening (sitting)	3.1	NS	NS	NS	NS	NS	NS	NS
Aggressive pecking	0.03	NS	NS	NS	NS	NS	NS	NS
Non-aggressive pecking	0.2	NS	NS	NS	NS	NS	NS	NS
Dustbathing	0.2	NS	NS	NS	0.025	NS	0.022	NS
Stretching	0.8	<0.001	NS	NS	NS	NS	NS	NS
Wing flapping	0.06	NS	NS	NS	NS	0.006	NS	NS

* Litter (standing) and (sitting) represent litter-directed activity (ie pecking and scratching).

There were significant effects of age on most activities (Figure 3). Thus, the times spent standing, feeding, walking, running, performing litter-directed activity while standing, preening while standing, and stretching all declined with age. Resting was most common during the first three weeks of life and declined thereafter. Conversely, time spent sitting increased consistently with age, reaching 63 per cent of the time in week six.

There was no significant effect of stocking density on any of these activities. With regard to sex, however, males rested more than females (21.9% of time compared to 17.9%), and females preened while standing more than males (1.6% of time compared to 0.9%). The significant age x sex interaction with litter-directed activity while sitting resulted from less of

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this activity being seen in females during week six. With regard to preening while standing, the significant age x density interaction resulted from less of this activity being seen at the highest density than at the medium density in week one, and less at the highest density in week five. The significant interactions with dustbathing were seen because there was more of this activity by birds in the medium-density group during week three and less by females in the high-density group. With regard to wing flapping, the age x sex interaction resulted from minor differences between males and females in weeks two and three only.

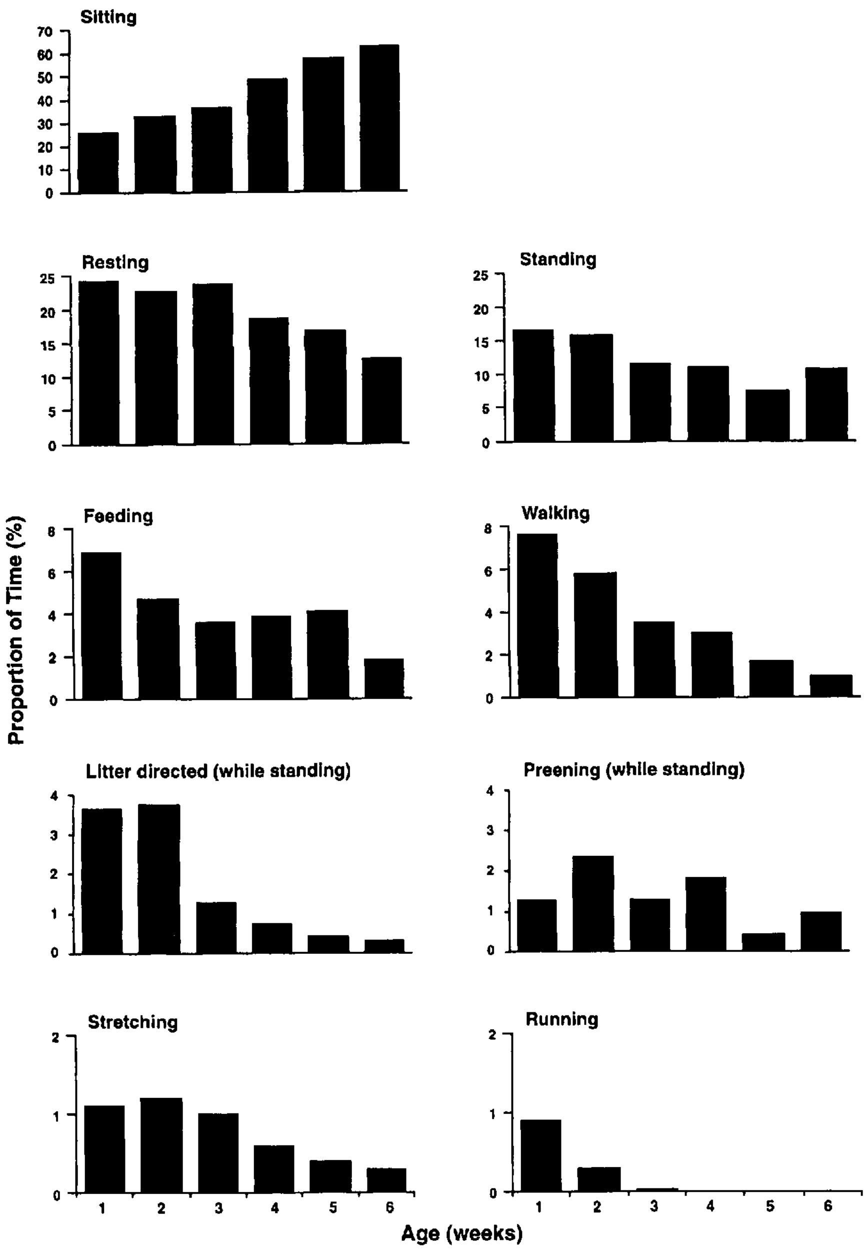

Figure 3 **Overall mean proportions of time spent performing different activities at different ages.**

Overall, birds spent 16.5 per cent of time panting, with a slightly higher proportion being shallow than deep (Table 9). Of the 9.1 per cent of time spent in shallow panting, 8.7 per cent occurred while sitting or resting, and 0.4 per cent occurred while standing. Of the 7.4 per cent of time spent panting deeply, 6.5 per cent occurred while sitting or resting and 0.9 per cent occurred while standing. Shallow panting was first seen in week two and increased thereafter (Figure 4). Deep panting only appeared in week five and increased markedly to be the main form of panting in week six (Figure 4). Only 4 per cent of all shallow panting occurred while standing, whereas 12 per cent of all deep panting occurred while standing.

Table 9 **Panting behaviour. *P* values are taken from split-plot ANOVA with age, sex, density and their interactions as factors.**

	Overall mean (% time)	Age	Stocking density treatment	Sex	Age x Density	Age x Sex	Sex x Density	Age x Sex x Density
Shallow panting	9.1	<0.001	NS	NS	0.034	0.008	NS	NS
Deep panting	7.4	<0.001	0.010	NS	<0.001	0.001	NS	NS

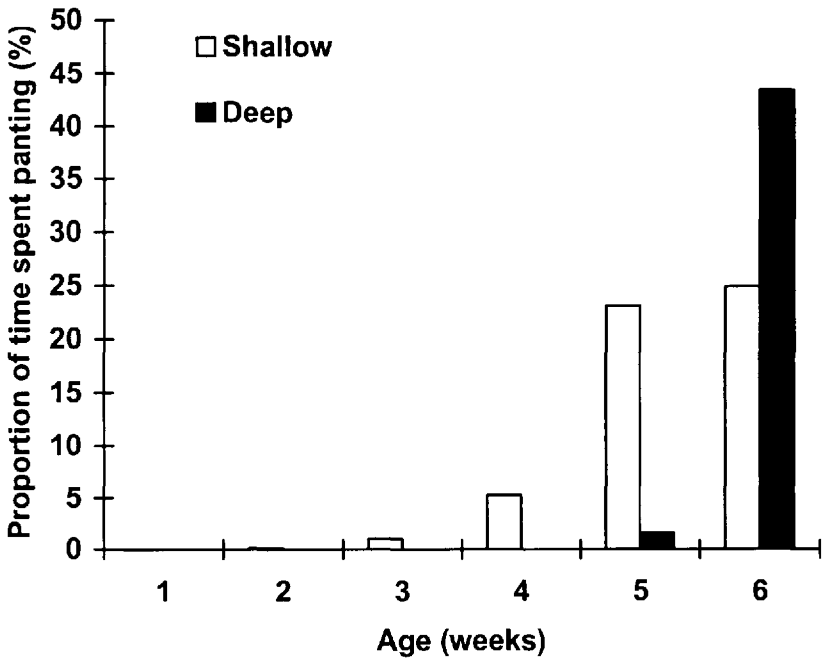

Figure 4 **Overall mean proportions of time spent panting (shallow and deep) at different ages.**

Stocking density had a significant effect on deep panting only, less being seen with the 28 kg m^{-2} treatment (overall, 5.6% of time) than with the 34 or 40 kg m^{-2} treatments (8.1% and 8.8%, respectively). The significant age x density interaction with shallow panting resulted from less being seen at the highest density in weeks three and four, while that with deep panting was because less was seen at the lowest density in weeks five and six (in week six, deep panting accounted for 33% of the time at 28 kg m^{-2}, 47% at 34 kg m^{-2}, and 51% at 40 kg m^{-2}). The significant age x sex interactions were attributable to females showing more shallow panting than males in weeks two to four, and more deep panting in week five.

Discussion

Performance

The observed levels of mortality over the whole of the present trial in males (9.7%) and females (6.6%) were higher than those expected from previous work at SAC Auchincruive (see Materials and methods section) and current overall mortality in commercial flocks in the UK (around 5%; NFU 2000). This was after the particularly high mortality in pen 20 was excluded. Most of the mortality in pen 20 occurred in the first week of life and was diagnosed as resulting from 'baby chick nephropathy', 'yolk-sac infection' or 'runt'. It is not known why early mortality was so high in that pen. There was no suggestion that stocking density had any effect on mortality at any age, as also reported previously (see eg Proudfoot *et al* 1979; Shanawany 1988; Cravener *et al* 1992; Puron *et al* 1995; but see Coenen *et al* 1996). The higher mortality observed in males, which was expected (EC Report 2000), was most marked during the final week, and was attributable mainly to ascites, sudden-death syndrome or leg weakness. Despite the higher levels of mortality, realised day 42 stocking densities were close to those predicted (Table 2).

The significant suppression of food intake observed with increasing stocking density was greatest during the final week (Tables 3 and 4). This is consistent with the findings of several previous studies (Scholtyssek 1974; Scholtyssek & Gschwindt-Ensinger 1983; Shanawany 1988; Puron *et al* 1995). There would appear to be two possible explanations for this effect. First, the birds' ability to move around freely, and hence to obtain access to feeders, may become increasingly limited because available floor space diminishes as birds grow bigger, and this effect would be greatest at the highest stocking density. However, even if this were the case, recent evidence has shown that a reduction in the frequency of visits to feeders by broilers (when apparently lame) is compensated for by the birds eating larger meals (Weeks *et al* 2000), so total daily food intake is not necessarily affected. Second, their requirement for food energy may decline as a result of a reduced ability to dissipate heat at higher densities. The increased panting seen during the final week provides evidence for this explanation (see below).

Although there was a significant linear decline in food intake with increasing density during the final week, there was no corresponding significant reduction in growth rate. This is in contrast to most previous work, which has shown a tendency for slower growth at densities greater than 30 kg m^{-2} (Proudfoot *et al* 1979; Shanawany 1988; Cravener *et al* 1992; Gordon 1992; but see Blokhuis & van der Haar 1990). Similarly, there was no significant effect of stocking density on food conversion ratio (food intake/weight gain) in the final week of the present study; any such relationship has been found to be inconsistent in previous studies (see Introduction).

Health

There was no significant effect of stocking density either on the incidence of contact dermatitis lesions or on a subjective score of leg weakness (Table 5). The only significant effect of sex was on the hock lesion score, which was greater in males, presumably reflecting their greater bodyweight. Recently, however, Sorensen *et al* (2000) found that gait scores (reflecting leg weakness) were higher in males, but that an increase in stocking density had a greater effect in increasing the gait scores of females than in increasing those of males.

Environmental monitoring

There were significant effects of both stocking density and sex on litter condition. Presumably, the higher litter scores observed with the 34 and 40 kg m^{-2} treatments compared with the 28 kg m^{-2} treatment mainly reflect the increasing litter moisture content (Table 6). However, in general, litter condition was good (mean pen scores greater than 2 were never recorded, on a 1–5 scale), and the observed differences between stocking densities were small. There were also significant differences between males and females in both litter score and litter moisture content. The higher levels of both in female pens cannot be accounted for in terms of greater food intake per m^2, thus suggesting a higher water to food intake ratio in females. Conceivably, this might reflect compensation for greater water loss by females because of their increased panting (Table 9). However, there was no significant difference between sexes in time spent drinking (Table 8), and water intake was not measured.

The observed increase in atmospheric relative humidity with age (Table 7), which led to levels exceeding 70 per cent in weeks five and six, has implications for thermoregulation, because vapour density gradients determine evaporative heat loss from birds. The true index of thermal load is "apparent equivalent temperature", which can be derived from absolute temperature, relative humidity and a psychrometric constant (Mitchell & Kettlewell 1993).

Behaviour

There were substantial age-related changes in the time budget of the broilers. In particular, the birds became more inactive as they grew older: total time spent sitting and resting increased consistently from 50 per cent in week one to 75 per cent in week six. Coincidentally, times spent walking and running decreased from 9 per cent to 1 per cent. This is consistent with previous work on broiler chickens (Newberry *et al* 1988; Blokhuis & van der Haar 1990; Bessei 1992; Reiter & Bessei 1994, 1999). There are several possible explanations for the decline in activity with age. For example, it could result from physical restriction of movement because of diminishing floor space as birds grow larger, increased difficulty in walking due to altered conformation and/or leg weakness (Kestin *et al* 1994), or a pre-disposition towards inactivity resulting from genetic selection for improved food conversion efficiency (and hence conservation of energy). The fact that neither sitting nor resting was influenced significantly by stocking density suggests that activity was not constrained by available floor space. Conversely, the greater time spent resting by males could reflect their greater food conversion efficiency and greater bodyweight.

The overall mean time spent feeding (4%) is similar to that reported in other studies (Preston *et al* 1983; Newberry *et al* 1988; Bessei 1992; Reiter & Bessei 1994, 1999). Some studies, however, have reported that growing broilers spend a higher proportion of time feeding — possibly because different methodology, food form and/or genotype were used (Savory 1975; Murphy & Preston 1988; Blokhuis & van der Haar 1990). It has been suggested that feeding behaviour has changed as a result of genetic selection for increased food conversion efficiency, resulting in broilers consuming more food in less time than layers of the same age (Savory 1975). In the present study, birds spent more time drinking (6%) than feeding, in contrast to previous work reporting more time spent feeding than drinking (Preston *et al* 1983; Murphy & Preston 1988; Blokhuis & van der Haar 1990; Bessei 1992). The most likely explanation is that nipple drinkers, as used here, limit the rate of water intake (and hence require the broilers to spend more time drinking), compared with the bell and cup drinkers used in the other studies.

Apart from panting, stocking density had no significant effect on behaviour in the present study. This is similar to the conclusion of Bessei (1992), but is in contrast to previous reports of suppression of walking, litter-directed activity and preening, and increased disturbance of resting, at higher stocking densities (Blokhuis & van der Haar 1990; Lewis & Hurnik 1990; Reiter & Bessei 1994, 1999; Martrenchar *et al* 1997). Reported effects of stocking density on behavioural expression of broilers are thus inconsistent, probably at least partly because of variation in the densities and ages of birds tested. Because activity declines with age (see above), higher terminal stocking densities may have greater impact (in terms of behavioural restriction) on broilers routinely killed at five weeks of age (as is the case in some countries), rather than at six weeks or later. However, the relative inactivity of modern broilers (EC Report 2000) may mean that such an effect could well be less important in welfare terms than the association between stocking density and thermoregulatory ability (considered later; see Animal welfare implications).

The proportion of time spent panting was greatest in weeks five and six (Figure 4). The fact that deep, but not shallow, panting increased markedly from week five (<5%) to week six (>40%) suggests that deep panting may reflect a greater effort devoted to dissipating heat, and hence may be a reliable indicator of thermal discomfort and compromised welfare. The panting observed in weeks five and six coincided with an increase in mean atmospheric relative humidity (Table 7) to a level above that normally recommended in the Ross Broiler Management Manual (Ross Breeders 1999). The combination of this increased relative humidity together with the observed ambient temperature may have raised "apparent equivalent temperature" (Mitchell & Kettlewell 1993) sufficiently to have been a cause of the increased panting. On the other hand, the increased panting may itself have contributed to the increased atmospheric relative humidity because of greater evaporative water loss, and possibly consequential increased water intake through drinking to replace the water lost. Hence, it is difficult to separate cause and effect.

Stocking density affected deep but not shallow panting, and there was a highly significant age x density interaction with deep panting (Table 9). This was because of the fact that, in week six, there was less deep panting seen with the 28 kg m^{-2} treatment (33% of the time) than with the 34 kg m^{-2} (47%) or 40 kg m^{-2} (51%) treatments. This presumably reflects a reduced need to dissipate heat at the lowest density. As stocking density increases, there will be greater metabolic heat production from the birds per m^2. There will also be more heat generated in the litter per m^2, as a result of increased bacterial activity from faeces (Reiter & Bessei 2000). In addition, reduced available floor space at high densities will restrict air-flow between birds, thereby reducing their ability to dissipate heat.

There were highly significant age x sex interactions with both shallow and deep panting. Thus, females showed more shallow panting in weeks two to four, and more deep panting in week five. This was despite their reduced food intake and bodyweight at these times. Conceivably, this may reflect a higher level of insulation because of the faster feathering (Ross Breeders 1999) and greater body lipid content (Pym & Solvyns 1979; Broadbent *et al* 1981) of females. It is also worth noting that females panted significantly more while standing than males did in week five — an age when broilers normally show very little standing. Standing may be an additional form of behavioural thermoregulation, because it increases the body surface area available for heat loss and reduces any heat increment due to contact with other birds and floor litter. Hence, if thermal discomfort becomes a problem at higher stocking densities later in the growing period, it may do so earlier in females.

Reservations concerning the experimental design

As mentioned in the Introduction, a possible problem with the present results concerns the fact that all treatments were studied in a single shared environment with common climate control. Atmospheric conditions at bird level, therefore, were presumably a consequence of the average stocking density across the whole house (34 kg m^{-2}), rather than being typical of the treatment in any one pen. If so, this may have had its greatest effect on birds' thermoregulation, because of effects on ventilation rate (and hence air speed at bird level) and relative humidity (and hence apparent equivalent temperature; see above). However, it is also possible that the effects of the common air speed and relative humidity (both of which would presumably have been higher for 28 kg m^{-2} and lower for 40 kg m^{-2} than if those treatments had been in their own separate environments) might have cancelled each other out in terms of their effects on thermoregulation. This is because higher air speed facilitates heat loss, whereas higher relative humidity has the opposite effect within the normal range of house temperature.

Another possible confounding factor is that group sizes were varied from 130 to 208 birds per pen in order to achieve predicted terminal stocking densities with the (six) different treatments. This was necessary because the alternative — keeping group size constant and varying pen size — was impracticable. In one study, which compared group sizes of 10–60 broilers at the same stocking density, there was no evidence of any consistent effect on behaviour (Reiter & Bessei 1999). It seems likely that any effects resulting from group size *per se* would be greatest when group sizes are considerably smaller than they were here.

Animal welfare implications

In conclusion, the main effects of stocking density in this study were on food intake, which was greater for the 28 kg m^{-2} treatment group than for the 40 kg m^{-2} group in (the final) week six, and on time spent panting deeply, which was reduced at the lowest density in weeks five and six (it was not seen in weeks one to four). Presumably, both of these effects reflect a greater thermal load at the higher densities at that time. The increased panting shown by females in weeks two to five suggests that they start to experience thermal discomfort earlier than do males. There is no conclusive evidence from this study that broiler welfare is compromised any more at 40 (in fact 38.5) than at 34 kg m^{-2}. However, the fact that time spent panting deeply during weeks five and six was significantly reduced at 28 kg m^{-2} suggests that thermal comfort then (and hence welfare) may be improved at densities of less than 34 kg m^{-2}. Also, the fact that there were highly significant effects on deep panting both of age and of age x density interaction suggests that any future recommendation concerning maximum terminal stocking density should take the age at slaughter into account. This is because the challenge to birds' thermoregulatory ability increases independently with both age (because of increases in food intake/heat production and body insulation) and stocking density (because of decreasing space between birds). Hence, it should be the case that birds that are due to be slaughtered at five weeks of age could be stocked at a higher density than those slaughtered at six weeks. In addition, as females spend significantly more time in deep panting than males in week five, perhaps females should be stocked at a lower density than males when the slaughter age is five weeks.

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References

Andrews S M, Omed H M and Phillips C J C 1997 The effect of a single repeated period of high stocking density on the behaviour and response to stimuli in broiler chickens. *Poultry Science 76*: 1655-1660

Arad Z 1983 Thermoregulation and acid–base status in the panting dehydrated fowl. *Journal of Applied Physiology 54*: 234-243

Arad Z and Marder J 1983 Acid–base regulation during thermal panting in the fowl (*Gallus domesticus*) — comparison between breeds. *Comparative Biochemistry and Physiology (A) 74*: 125-130

Bessei W 1992 The behaviour of broilers under intensive management conditions. *Archiv fur Geflugelkunde 56*: 1-7

Blokhuis H J and van der Haar J W 1990 The effect of stocking density on the behaviour of broilers. *Archiv fur Geflugelkunde 54*: 74-77

Broadbent L A, Wilson B J and Fisher C 1981 The composition of the broiler chicken at 56 days of age: output, components and chemical composition. *British Poultry Science 22*: 385-390

Cahaner A, Deeb N, Yunis R and Lavi Y 1998 Reduced stress tolerance in fast growing broilers. *Proceedings of the 10th European Poultry Conference, 21–26 June, Jerusalem, Israel* pp 113-117. World's Poultry Science Association: Israel

Classen H L, Riddell C, Robinson F E, Shand P J and McCurdy A R 1994 Effect of lighting treatment on the productivity, health and behaviour and sexual maturity of heavy male turkeys. *British Poultry Science 35*: 215-225

Coenen M, Schulze-Kersting I, Zentek J and Kamphues J 1996 Effects of different housing conditions (stocking density) on performance of broilers and the composition of litter. *Deutsch Tieraerztliche Wochenschrift 103*: 79-83

Cravener T L, Roush W B and Mashaly M M 1992 Broiler production under varying population densities. *Poultry Science 71*: 427-433

Cunningham D L, Buhr R J and Mamputu M 1992 Beak trimming and sex effects on behaviour and performance traits of large white turkeys. *Poultry Science 71*: 1606-1614

Ekstrand C 1993 *Effects of stocking density on the health, behaviour and productivity of broilers. A literature review.* Report 32. Swedish University of Agricultural Sciences, Faculty of Veterinary Medicine, Department of Animal Hygiene, Skara, Sweden

El Hadi H and Sykes A H 1982 Thermal panting and respiratory alkalosis in the laying hen. *British Poultry Science 23*: 49-57

Elson A 1993 Housing systems for broilers. In: Savory C J and Hughes B O (eds) *Fourth European Symposium on Poultry Welfare, 18–21 September, Edinburgh, UK* pp 177-184. Universities Federation for Animal Welfare: Hertfordshire, UK

Elwinger K 1995 Broiler production under varying population densities — a field study. *Archiv fur Geflugelkunde 59*: 209-215

European Commission Report 2000 *The welfare of chickens kept for meat production (broilers).* Report of the Scientific Committee on Animal Health and Animal Welfare

Farm Animal Welfare Council 1992 *Report on the welfare of broiler chickens.* FAWC: Surbiton, UK

Farm Animal Welfare Council 1995 *Report on the welfare of turkeys.* FAWC: Surbiton, UK

Gaardbo Thomsen M 1993 Influence of increasing stocking rates on performance and carcass quality of broilers. In: Savory C J and Hughes B O (eds) *Fourth European Symposium on Poultry Welfare, 18–21 September, Edinburgh, UK* pp 285-287. Universities Federation for Animal Welfare: Hertfordshire, UK

Gleeson M and Brackenbury J H 1983 Ventilation, gaseous exchange and airsac gases during thermal panting in domestic fowl. *Quarterly Journal of Experimental Physiology and Cognate Medical Sciences 68*: 591-602

Gordon S H 1992 The effect of broiler stocking density on bird welfare and performance. *British Poultry Science 5*: 1120-1121

Grashorn M A 1992 High stocking densities and incidences of leg disorders in broiler chickens. In: Whitehead C C (ed) *Bone Biology and Skeletal Disorders in Poultry* p 352. Carfax Publishing Company: Oxford, UK

Grashorn M and Kutritz B 1991 Effect of stocking density on performance of modern broiler breeds. *Archiv fur Geflugelkunde 55*: 84-90

Kestin S C, Knowles T G, Tinch A E and Gregory N G 1992 Prevalence of leg weakness in broilers and its relationship with genotype. *Veterinary Record 131*: 190-194

Kestin S C, Adams S J M and Gregory N G 1994 Leg weakness in broiler chickens, a review of studies using gait scoring. *Proceedings of the 9th European Poultry Conference, Vol II, 7–12 August, Glasgow, UK* pp 203-206. World's Poultry Science Association: UK

Lewis N J and Hurnik F J 1990 Locomotion of broiler chickens in floor pens. *Poultry Science 69*: 1087-1093

Martrenchar A, Morisse J P, Huonnic D and Cotte J P 1997 The influence of stocking density on some behavioural, physiological and productivity traits of broilers. *Veterinary Research 28*: 473-480

Ministry of Agriculture, Fisheries and Food 1987 Codes of recommendation for the welfare of livestock: domestic fowls. MAFF: London, UK

Mitchell M A and Kettlewell P J 1993 Catching and transport of broiler chickens. In: Savory C J and Hughes B O (eds) *Fourth European Symposium on Poultry Welfare, 18–21 September, Edinburgh, UK* pp 219-229. Universities Federation for Animal Welfare: Hertfordshire, UK

Mitchell M A and Kettlewell P J 1994 Road transportation of broiler chickens — induction of physiological stress. *World's Poultry Science Journal 50*: 57-59

Mitchell M A and Kettlewell P J 1998 Physiological stress and welfare of broiler chickens in transit: solutions not problems! *Poultry Science 77*: 1803-1814

Murphy L B and Preston A P 1988 Time-budgeting in meat chickens grown commercially. *British Poultry Science 29*: 571-580

NFU Poultry Bulletin 2000 *Chicken Market Quarterly* (July)

Newberry R C, Hunt J R and Gardiner E E 1988 Influence of light intensity on behaviour and performance of broiler chickens. *Poultry Science 67*: 1020-1025

Preston A P, Pamment P, McBride G and Foenander F 1983 Some activity patterns of meat chickens. *Fifth Australasian Poultry and Stock Feed Convention, 19–22 September, Adelaide, Australia* pp 203-207

Proudfoot F G, Hulan H W and Ramey D R 1979 The effect of four stocking densities on broiler carcass grade, the incidence of breast blisters, and other performance traits. *Poultry Science 58*: 791-793

Puron D, Santamaria R, Segura J C and Alamilla J L 1995 Broiler performance at different stocking densities. *Journal of Applied Poultry Research 4*: 55-60

Pym R A E and Solvyns A J 1979 Selection for food conversion in broilers: body composition of birds selected for increased body weight gain, food consumption and food conversion ratio. *British Poultry Science 20*: 87-97

Quinn A D, Kettlewell P J, Mitchell M A and Knowles T 1998 Air movement and the thermal microclimates observed in poultry lairages. *British Poultry Science 39*: 469-476

Reiter K and Bessei W 1994 Behaviour of broilers in dependence on group size and stocking density. *Proceedings of the 9th European Poultry Conference, Vol 1, 7–12 August, Glasgow, UK* pp 294-295. World's Poultry Science Association: UK

Reiter K and Bessei W 1998 Possibilities to reduce leg disorders in broilers and turkeys (review). *Archiv fur Geflugelkunde 62*: 145-149

Reiter K and Bessei W 1999 The behaviour of broilers in response to group size and stocking density. *Archiv fur Geflugelkunde 64*: 93-98

Reiter K and Bessei W 2000 Effect of stocking density of broilers on temperature in the litter and at bird level. *Archiv fur Geflugelkunde 64*: 204-206

Richards S A 1970 The biology and comparative physiology of thermal panting. *Biological Reviews 45*: 223-264

Ross Breeders 1999 *Ross Broiler Management Manual.* Ross Breeders Limited: Midlothian, UK

Royal Society for the Prevention of Cruelty to Animals 1999 *Freedom Food: The RSPCA Welfare Standards for Broiler Chickens.* RSPCA: Horsham, UK

Sanotra G S, Vestergaard K S and Thomsen M G 1995 The effect of stocking density on walking ability, tonic immobility and the development of tibial dyschondroplasia in broiler chicks. *Proceedings of the 29th International Congress of the International Society for Applied Ethology, 3–5 August, Exeter, UK* pp 221-222. Universities Federation for Animal Welfare: Hertfordshire, UK

Savory C J 1975 A growth study of broiler and layer chicks reared in single-strain and mixed-strain groups. *British Poultry Science 16*: 315-318

Scholtyssek S 1971 Zur Frage der Besatzdichtein Broilcrherden. *Archiv fur Geflugelkunde 35*: 235-239 [Title translation: The question of size and density in broiler flocks]

Scholtyssek S 1974 Die Bedeutung des Futterplatzes in unterschiedlich besetzen Mastabteilen. *Archiv fur Geflugelkunde 38*: 41-45 [Title translation: The importance of the feed place in broiler boxes with different density]

Scholtyssek S and Gschwindt B 1980 Untersuchungen zu Besatzdichte und Futterplatz in der Bodenmast von Broilern. *Archiv fur Geflugelkunde 44*: 220-224 [Title translation: Investigations about density and feed space for broilers on deep litter]

Scholtyssek S and Gschwindt-Ensinger B 1983 Leistungsvermogen einschliesslich Befiederung und Belastbarkeit von Broilern bei unterschiedlicher Besatzdichte in Bodenhaltung. *Archiv fur Geflugelkunde 47*: 3-8 [Title translation: Performance including feathering and stress situation of broilers in different densities on floor]

Shanawany M M 1988 Broiler performance under high stocking densities. *British Poultry Science 29*: 43-52

Sokal R R and Rohlf F J 1981 *Biometry.* Freeman & Co: New York, USA

Sorensen P, Su G and Kestin S C 2000 Effects of age and stocking density on leg weakness in broiler chickens. *Poultry Science 79*: 864-870

Webster A J F, Tuddenham A, Saville C A and Scott G B 1993 Thermal stress on chickens in transit. *British Poultry Science 34*: 267-277

Weeks C A, Danbury T D, Davies H C, Hunt P and Kestin S C 2000 Effect of lameness on feeding behaviour of broilers. *Applied Animal Behaviour Science 67*: 111-125

Zhou W T, Fujita M and Yamamoto S 1999 Thermoregulatory responses and blood viscosity in dehydrated heat-exposed broilers (*Gallus domesticus*). *Journal of Thermal Biology 24*: 185-192