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Effect of light and stocking density on performance, breast muscle yield and potential damage caused by feather pecking in two strains of commercial Pekin ducks

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ABSTRACT

Context. Minimal information is available as to the optimal stocking density and light intensity for best performance of commercial ducks. **Aims.** To investigate the effects of stocking density and light intensity on commercial Pekin duck production. **Methods.** Cherry Valley and Grimaud Freres Pekin ducks were housed at stocking densities of 4.4 (low), 5.2 (medium) and 6 (high) birds/m^2 and from 8 to 41 days of age at 6 lux (low) and 45 lux (moderate) light intensities. On Days 14, 28, and 41 of age all ducks were individually weighed, and pen feed and water intakes recorded. On Day 41, one male and female from each pen was euthanised and breast muscle weight determined. At Weeks 3 and 4 all birds were individually examined, for extent of feather and skin damage. **Key results.** In all weeks, the Grimaud Freres birds had higher liveweight than Cherry Valley birds. Only at Week 4, birds under low light had higher liveweight than those at moderate light intensity. At Week 4, birds at low densities had higher liveweight, while at Week 6 birds at low and medium stocking densities had higher liveweight than those at high stocking densities. At Week 4, the feed to gain ratio was poorer when birds were housed in moderate light intensity. The stocking density had no effect on the feed to gain ratio. Light and stocking density had no effect on any of the breast muscle measures. In Week 4, the birds housed at medium density had a higher feather and skin damage. At Week 3, more damage was directed to the wings than the thigh regions. There was a higher incidence of damage in some pens irrespective of treatments. **Conclusions.** The medium stocking density supported performance equivalent to that at low density and better than at the high density. Ideally the density recommendation should be based on 'weight density' (kg/m^2) and the current results indicate this was between 16.49 and 19.0 kg/m^2. The birds performed similarly under both light intensities. **Implications.** The suitable stocking density for efficient production is 16.5–19.0 kg/m^2 and housing at 6 or 45 lux had no influence on performance. Best performance and breast muscle yield was from the Grimaud Freres strain.

Keywords: breast muscle yield, Cherry Valley, duck performance, Grimaud Freres, light intensity, liveweight, Pekin ducks, stocking density.

Introduction

Stocking density (SD), light duration and its intensity are key elements affecting bird physiology, behaviour, and welfare (Rodenburg *et al.* 2005; Xie *et al.* 2014). While there has been extensive evaluation of light and SD effects on broiler performance it is far less comprehensive for commercial ducks.

The Federation of Animal Science Societies recommend SD in litter floor systems for ducks at 6 weeks of age as 6 birds/m^2 (FASS 2010). The maximum SD of 7-week-old Pekin ducks recommended in European production systems ranges from 6 to 8 birds/m^2 (Rodenburg *et al.* 2005). Under Australian conditions using open-sided sheds with limited environmental control the recommended SD is 5 birds/m^2 (DPI 2012). High stocking densities (8–9 birds/m^2) are detrimental to liveweight gain (LWG) (Xie *et al.* 2014). This is especially so, in conventional open-sided sheds where the adverse effects can be more prevalent in summer (Chen *et al.* 2015; Park *et al.* 2018). High stocking density enhanced the negative effects of high temperature stress on behaviour, immune responses and blood biochemical measures of stress including higher corticosterone concentrations (Park *et al.* 2018).

The effects of photoperiod duration on growth, immunity and stress have been investigated in broiler chickens (Kliger *et al.* 2000; Olanrewaju *et al.* 2006; Abbas *et al.* 2008) but again there is less of this research in ducks especially when housed on litter. In ducks, the limited lighting studies have concentrated on different light to dark (L:D) periods or by using continuous photoperiod (Renden *et al.* 1993; Lien *et al.* 2007; Erdem *et al.* 2015; House *et al.* 2021). Under continuous light and SD of 5, 6, 7, 8, and 9 ducks/m^2, the LWG was not different between 5, 6 and 7 birds/m^2 but lower at 8 compared to 5 birds/m^2 (Li *et al.* 2018). Maintaining ducks under continuous lighting at 1, 5, 10, 15, or 40 lux had no effect on LWG over a full 6 weeks of production, however, in Week 6 the LWG was better at 1 lux than at 5, 10, 15 lux (Xin *et al.* 2016). Ducks have shown a similar preference for illumination at 6, 20 and 200 lux rather than 1 lux at both 2 and 6 weeks of age (Barber *et al.* 2004).

The present experiment investigated the effects of SD and light intensity on commercial Pekin duck performance when housed in a litter-based system. Following conversations with a large commercial integrated production organisation, densities of 4.4, 5.2 and 6 birds/m^2 were investigated. The 4.4 birds/m^2 was identified as the minimum for production to be economic, that 5.2 birds/m^2 was the density used currently on their commercial farms and that 6 birds/m^2 was the maximum viable density under summer conditions using open-sided sheds as the housing option. Continuous lighting at low and moderate intensity were applied at these three stocking densities. The working hypothesis was that bird performance would be better at the lowest light intensity and stocking density combination.

Materials and methods

All experimental protocols were approved by the University of Sydney Animal Care and Ethics Committee and complied with the Australian Code of Practice for the use of Animals for Scientific Purposes (Protocol: 1-2011/1/5454).

Birds and housing

The birds were housed during winter in an enclosed deep litter shed with controlled cross ventilation. Inlet air vents under automated control were located along one side of the shed and three exhaust fans were located towards the ends and middle of the shed on the opposite wall. Controlling temperature thermostats were suspended in three pens along the length of the shed at the level of the ducks. The concrete floor was covered with 10 cm of wood shavings. The litter material was turned, topped up and replaced when necessary to maintain a friable condition.

There were 48 individual pens separated into two equal compartments using a black plastic partition. The 24 pens in each compartment were numbered sequentially and divided evenly into four blocks of 6. Each treatment was randomly allocated to a pen in each block. The treatments were applied to Pekin ducks, reared as mixed sex groups, consisting of equal numbers of males and females. The strains were produced, by the appropriate matings at a commercial breeding farm by PEPE's Ducks Pty Ltd (Windsor, NSW, Australia) with the eggs incubated at their commercial hatchery. At hatch, the ducklings were vent sexed and transported as day-olds to the experimental facility at The University of Sydney, Camden, NSW, Australia. On arrival, ducklings were randomly allocated to pens. Supplementary heat was provided using overhead lamps with a temperature of 35°C, as measured directly beneath the brooder lamp, at Day 1. The temperature was reduced to 28°C by Day 7, to 26°C by Day 14 and then 24°C by Day 21. From Day 28 to 41 the shed temperature was maintained at 18–22°C.

Initially there were 22 ducks in each pen, but this number was reduced to 20 at the start of Week 3 to give the correct stocking density (SD) at Week 6. The excess ducks were moved to a commercial farm and grown out to market weight. The required densities were created by limiting the size of the floor area in each pen with a wooden partition fitted across one corner at the back of the pen. On Days 6–7 of age, numbered tags were inserted into the skin integument extending between the humerus and radius of the wing.

Birds had free access to feed and water *ad libitum*. A row of four nipple drinkers with a reservoir were located down one side of each pen. During the first 3 weeks, each pen had one plastic drum feeder and thereafter two feeders. A starter crumble diet, fed Days 1–14, was formulated to provide 12.45 MJ ME/kg and 22.0% protein while the pelleted grower diet, fed Days 15–41, was formulated to provide 12.58 MJ ME/kg and 19% protein.

Treatments

There were twelve experimental treatments consisting of the two Pekin duck strains, Cherry Valley Farms Ltd., (CV) and Grimuad Frères Sélection (GF), exposed to two light intensities, moderate (50 lux) and low (5 lux) and housed at one of three stocking densities, low (LSD: 4.4 birds/m^2) medium (MSD: 5.2 birds/m^2) and high (HSD: 6.0 birds/m^2).

Lighting

During the first week, ducks were exposed to fluorescent lighting at the full intensity (>60 lux) in both sections of the shed. From Weeks 2 to 6 of age, the treatment light intensities were applied. In both compartments of the shed the light was supplied separately by a circuit of fluorescent lights connected to dimmer switches. The aim was to maintain the intensity at 5 lux in one compartment and 50 lux in the other. Light intensity, temperature, and relative humidity (RH) were recorded using digital monitors strategically placed throughout both compartments of the shed.

Performance and carcass measurements

At placement, a collective pen weight was recorded. On Days 14 (Week 2), 28 (Week 4), and 41 (Week 6) all ducks were individually weighed. Pen feed intakes were determined over the same time periods while pen water intakes were recorded daily.

Feather and body damage

At the end of Weeks 3 and 4 all birds were individually examined, and the extent of feather and skin damage determined. There are principally two body areas where the feather pecking/plucking damage occurs, the wing and back, while the thigh and tail areas can be of concern in particular flocks. In the present study, plumage and skin damage were evaluated according to the scoring system detailed in Table 1. Thigh damage was assessed using the same scoring measures as for the back while the tail damage was scored using measures as for the wing. Examples of the damage scores to the wing and back are given in Fig. 1.

Breast muscle yield

On Day 41, one male and one female were removed from each pen, then weighed before being euthanised with the administration of excess sodium pentothal solution. The breast muscle was removed and weighed.

Statistical analyses

Performance and breast yield analyses

The statistical analysis was conducted using the restricted maximum likelihood linear mixed model function of Genstat® 18th edition. Data were first tested for equality of variance using residual plots. When the equality of variance could be improved using a $\log_e$ transformation, data were transformed and any extreme outliers were removed from the analysis. The fixed model included the effects of light intensity, SD, strain, and sex while the random model included the effects of block, pen, and tag. Initially all two-way interactions between fixed effects were included in the model and then any non-significant interactions removed. Significance testing of fixed effects was conducted using Wald tests with a significance threshold of $P < 0.05$. The least significant difference (l.s.d.) was used to make pairwise comparisons of means.

Feather and skin damage analyses

The feather and skin damage analysis were conducted using an ordinal logistic regression model with a proportional odds method (Agresti 2002). The form of the method specified in the analyses was:

$$\log_e\left[\frac{P(Y \le k)}{P(Y < k)}\right] = \theta_k + \text{Density} + \text{Light} + \text{Strain} + \text{Period} + \text{Region} + \text{Density} \times \text{Period} + \text{Strain} \times \text{Period} + \text{Period} \times \text{Region} + \text{Block} + \text{Block} \times \text{Pen} + \text{Block} \times \text{Pen} \times \text{Tag} + \text{Block} \times \text{Pen} \times \text{Tag} \times \text{Period},$$

where $P(Y \le k)$ = probability of obtaining a score of k or lower, k = 0, 1, 2 and θ_k the intercept for a score of k. Period = (1: Week 3, 2: Week 4) (fixed); Region = Wing and Thigh, with Density × Period + Strain × Period + Period × Region, as the only significant interactions included. The fixed effects were Block, Block × Pen, Block × Pen × Tag, Block×Pen × Tag × Period (set of bird's measurements at a particular period).

Significance of the fixed effects were assessed using Wald Chi-squared tests, and individual treatment or other between-group comparisons were conducted using approximate z-tests; $z = \frac{\text{logit1} - \text{logit2}}{\text{SED}}$ where logit1 − logit2 = difference in

Table 1. The scoring systems used to visually evaluate feather pecking and skin damage to the wing, thigh, tail and back of the ducks at the end of Weeks 3 and 4 of age.

Feather and skin damage	Score 0	Score 1	Score 2	Score 3	Score 4
Wing and tail	No damage observed	Evidence that feathers had been pecked at and damaged	Evidence that parts of feathers had been removed and blood drawn from the feather shaft (see Fig. 1)	Further feather loss on the upper wings leading to featherless patches and greater blood loss on wing tips	The feather damage warranted removal of the bird from the pen and treatment in isolation
Back and thigh	No damage observed	Feathers removed but the area was minimal <2 cm in diameter) with no skin damage	Feathers removed with the area being 2–5 cm in diameter with no skin damage	The area is heavily denuded but no skin damage at the time	The area is denuded and there is skin damaged with blood present (see Fig. 1)

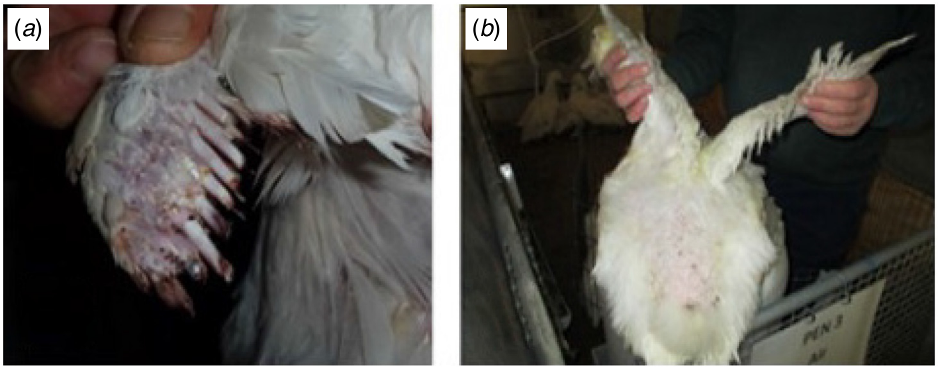

Fig. 1. Examples of the feather and back damage scoring system. (*a*) Wing damage scored as a 2; (*b*) back damage scored as 4 using the system detailed in Table 1 (photographs by J. A. Downing).

model-based logits of the two treatments, and standard error of the difference of the model-based logits. A z-statistic greater than two (absolute value) was identified as significant ($P < 0.05$). For the analysis, $\text{logit}[P(Y = 0)] = \log_e[P(Y = 0)/P(Y > 0)]$ was used to compare logits of different treatments (Gilmour *et al.* 2009).

Also, a distribution analysis was performed on the percentage of birds recording no feather or skin damage in each pen. The values were separated into categories each in a range of 10% units ranging from 0–10% to 90–100%. The coefficient of skewness and excess kurtosis were determined and then used to compute a D'Agostino–Pearson omnibus test (D'Agostino and Stephens 1986).

Results

Temperature, relative humidity, and light intensity

Over Days 28–42, the daytime (07:00–19:00 h) average temperature was 18.4 ± 0.3°C and RH was 64.9 ± 0.8%, while the overnight average temperature was 17.8 ± 0.1°C and RH was 69.8 ± 0.3% (all values are mean ± s.e.m.). These conditions are considered within the thermoneutral range (18–22°C) for meat ducks (Cherry and Morris 2008). In one compartment of the shed the average light intensity was 6 lux (low light) and in the other compartment it was 45 lux (moderate light).

Performance

The performance measures are given in Table 2.

Liveweight (LW)

There were significant effects of Week on LW that differed according to strain and light intensity (both, $P < 0.001$) and SD ($P = 0.002$) as all interactions between these and Week were significant. In all weeks, the GF birds were heavier than the CV birds ($P < 0.05$) and males were consistently heavier than females ($P < 0.05$). At the end of Weeks 4 and 6, birds exposed to low light intensity were heavier than birds exposed to the moderate light intensity ($P < 0.05$). In Week 6, birds at HSD had lower LW than those at other densities ($P < 0.05$).

Liveweight gain (LWG)

The effect of Week was significant for LWG but the interactions with strain, sex, light intensity, and SD had an influence (all, $P < 0.001$). In all weeks, the GF birds had higher LWG than CV birds ($P < 0.05$) and males had higher LWG than females ($P < 0.05$). It was only at Week 4 where birds at low light intensity had higher LWG than those at moderate light intensity ($P < 0.05$). At Week 6, housing birds at the MSD and LSD resulted in higher LWG than those at HSD ($P < 0.05$).

Feed intake

Measures of feed intake are given in Table 3. The strain effect on feed intake was influenced by Week as the interaction was significant ($P < 0.001$). As expected the heavier GF birds consumed more feed than the CV birds ($P < 0.05$). The light intensity ($P = 0.812$) and SD ($P = 0.419$) had no effect on feed intake.

Feed to gain ratio

Measures of feed to gain are given in Table 3. The CV strain (1.97 ± 0.02) had a poorer feed to gain ($P = 0.003$) compared to the GF strain (1.89 ± 0.02). The effect of light intensity on feed to gain depended on the week as the interaction between these was significant ($P = 0.021$). At Week 4, the feed to gain ratio was poorer when birds were housed in moderate light intensity compared to the low light intensity ($P < 0.05$) with no differences at other weeks. The SD had no effect on the feed to gain ratio ($P = 0.701$).

Water intake

Measures of water intake are given in Table 3. The effect of strain on water intake depended on the week as the

Table 2. The mean (± s.e.m.) liveweight (g) and liveweight gain (g) for Pekin ducks reared at three different stocking densities and at low or moderate light intensity.

Treatment	Week 2	Week 4	Week 6	s.e.m.	P value
Liveweight (g/day)					
CV	745Bc	1982Bb	3030Ba	9	W < 0.001 S < 0.001 W × S < 0.001
GF	778Ac	2124Ab	3282Aa		
Female	753Bc	2021Bb	3060Ba	8	W < 0.001 Sex < 0.001 W × Sex < 0.001
Male	771Ac	2085Ab	3252Aa		
Low light	760a	2077Ab	3175Aa	9	W < 0.001 L = 0.024 W × L < 0.001
Moderate light	763a	2030Bb	3137Ba		
HSD	762c	2049b	3130Ba	11	W < 0.001 SD = 0.386 W × SD = 0.002
MSD	766c	2061b	3176Aa		
LSD	758c	2050b	3162Aa		
Liveweight gain (g)					
CV	688Bc	1237Bb	1048Ba	6	W < 0.001 S < 0.001 W × S < 0.001
GF	721Ac	1348Ab	1171Aa		
Female	696Bc	1270Bb	1044Ba	5	W < 0.001 Sex < 0.001 W × Sex < 0.001
Male	714Ac	1315Ab	1175Aa		
Low light	703c	1318Ab	1100a	6	W < 0.001 L = 0.010 W × L < 0.001
Moderate light	706c	1267Bb	1108a		
HSD	705c	1287b	1082Ba	9	W < 0.001 SD = 0.058 W × SD < 0.001
MSD	709c	1297b	1122Aa		
LSD	701c	1294b	1125Aa		

Data represent the means and s.e.m. of four replicate pens for each treatment with 20 birds per pen (10 males and 10 females). Treatments were strain (CV and GF), light intensity (moderate and low) and stocking density (LSD – 4.4 birds/m^2, MSD – 5.0 birds/m^2 and HSD – 6.0 birds/m^2).
a–c: within treatment rows the weekly values without the same letters are different ($P < 0.05$).
A, B: within a column for Week and Treatment, values without the same letters are different ($P < 0.05$).
CV, Cherry Valley Pekin ducks; GF, Grimaud Freres Pekin ducks; HSD, 6 birds/m^2; MSD, 5.2 birds/m^2; LSD, 4.4 birds/m^2.
For *P*-values: W, week; S, strain; L, light; SD, stocking density.

interaction was significant ($P < 0.001$). The only difference was at Week 6, where CV birds had lower water intake than the GF birds ($P < 0.05$). There was a light intensity interaction with week affecting water intake ($P < 0.001$). The only difference was at Week 6 where the intake was higher under low light intensity. Stocking density had no effect on water intake ($P = 0.729$).

Breast muscle yield

The breast muscle measures are given in Table 4. Breast muscle weight was higher for the GF than for the CV strain ($P < 0.001$), while the breast weight to feed weight ratio was lower in the GF strain ($P < 0.001$). There was an interaction between strain and SD affecting the breast muscle yield as a % of the slaughter weight ($P = 0.029$). The SD had no effect on % breast muscle yield for the GF strain. However, for the CV strain the % breast muscle yield was higher at the HSD compared to the MSD ($P < 0.05$). At the LSD both strains had similar % breast muscle yield while at both the HSD and MSD the % breast muscle yield was higher for the GF strain compared to the CV strain ($P < 0.05$).

Sex influenced slaughter weight ($P < 0.001$) and % breast yield ($P < 0.001$) but not breast muscle weight ($P = 0.510$) or feed weight to breast weight ratio ($P = 0.394$). While males had the higher slaughter weight ($P < 0.001$) it was the females that had a higher % breast muscle yield ($P < 0.001$). Light intensity had no effect on breast muscle measures.

Feather and skin damage

The probabilities of feather and skin damage are given in Fig. 2. There were few instances ($N = 22$ birds) where damage to the tail or back was recorded and this level was not sufficient for statistical analysis. Light intensity had no effect on feather and skin damage ($P = 0.791$).

Table 3. The mean (± s.e.m.) feed and water intakes and feed to gain ratio for Pekin ducks reared at three different stocking densities and low or moderate light intensities.

Treatment	Week 2	Week 4	Week 6	s.e.m.	*P* value
Feed intake (g/day)					
CV	51c	170Bb	236Ba	2	W < 0.001 S < 0.001 W × S < 0.001
GF	52c	178Ab	252Aa		
Low light	50c	173b	245a	2	W < 0.001 L = 0.812 W × L = 0.069
Moderate light	52c	176b	242a		
HSD	51c	172b	243a	2	W < 0.001 SD = 0.419 W × SD = 0.599
MSD	51c	176b	242a		
LSD	52c	175b	246a		
Feed to gain					
CV	1.04c	1.93b	2.92a	0.03	W < 0.001 S = 0.003 W × S = 0.482
GF	1.01c	1.85b	2.82a		
Low light	1.01c	1.84Bb	2.89a	0.03	W < 0.001 L = 0.334 W × L = 0.021
High light	1.05c	1.94Ab	2.84a		
HSD	1.01c	1.87b	2.92a	0.04	W < 0.001 SD = 0.693 W × SD = 0.228
MSD	1.03c	1.89b	2.80a		
LSD	1.03c	1.91b	2.88a		
Water intake (mL/day)					
CV	173c	457b	720Ba	7	W < 0.001 S < 0.001 W × S < 0.001
GF	174c	465b	770Aa		
Low light	173c	461b	762Aa	8	W < 0.001 L = 0.327 W × L < 0.001
High light	174c	461b	728Ba		
HSD	173c	459b	742a	8	W < 0.001 SD = 0.756 W × SD = 0.973
MSD	172c	463b	744a		
LSD	176c	462b	749a		

Data represent the means and s.e.m. of four replicate pens for each treatment with 20 birds per pen (10 males and 10 females). Treatments were strain (CV and GF), light intensity (moderate and low) and stocking density (LSD – 4.4 birds/m^2, MSD – 5.2 birds/m^2 and HSD – 6 birds/m^2).
a–c: within treatment row the weekly values without a common letter are different ($P < 0.05$).
A, B: within a column for Week and Treatment values without a common letter are different ($P < 0.05$).
CV, Cherry Valley Pekin ducks; GF, Grimaud Freres Pekin ducks. HSD, 6 birds/m^2; MSD, 5.2 birds/m^2; LSD, 4.4 birds/m^2.
For *P*-values: W, week; S, strain; L, light; SD, stocking density.

There was a significant strain by week interaction ($P = 0.003$). At Week 3, the CV and GF birds had similar damage scores. At Week 4, more GF birds had no damage ($P < 0.05$) and less birds had a damage score of 1 ($P < 0.05$). At Week 4, birds at MSD tended to have more damage those at HSD ($P = 0.063$).

The body region affected depended on the week ($P < 0.001$). At Week 4, there were no differences in recording a specific damage score for the wings or thigh. At Week 3, there was more damage recorded to the wings than to the thigh region ($P < 0.05$).

The histogram plots for the distribution of the percentage birds observed with no feather or skin damage in individual pens in Weeks 3 and 4 are given in Fig. 3. At Weeks 3 and 4, the coefficient of skewness was −1.4335 and −1.6033 and the excess kurtosis was 1.6076 and 2.1361, respectively. Using the measures of skewness and kurtosis the D'Agostino–Pearson values identified the distributions as being significantly not normal ($P < 0.05$).

Discussion

The GF birds grew faster and were more efficient at doing so than the CV birds. The GF strain had an 8.3% higher LWG at the end of Week 6, a persistently higher LWG at all weeks, a

Table 4. The mean (± s.e.m.) slaughter weight and breast muscle (BM) weight (g), BM yield as a percentage of the slaughter weight and the feed to breast weight ratio for CV and GF Pekin ducks reared at three stocking densities and either low or moderate light intensity.

Treatment	Slaughter weight (g)	BM weight (g)	BM yield (%)	Feed weight to breast weight ratio
CV	3046 ± 34b	259 ± 5b	8.51 ± 0.12	24.3 ± 0.5b
GF	3280 ± 34a	307 ± 5a	9.38 ± 0.12	21.5 ± 0.5a
CV-HSD	2995 ± 9	265 ± 9	8.87 ± 0.22Ba	23.5 ± 0.9
CV-MSD	3074 ± 9	248 ± 9	8.07 ± 0.22Db	25.6 ± 0.9
CV-LSD	3071 ± 9	263 ± 9	8.60 ± 0.21ab	23.7 ± 0.9
GF-HSD	3238 ± 9	308 ± 9	9.51 ± 0.22A	21.1 ± 0.9
GF-MSD	3284 ± 9	295 ± 9	9.61 ± 0.22C	22.5 ± 0.9
GF-LSD	3318 ± 9	297 ± 9	9.01 ± 0.20	20.8 ± 0.9
Female	3064 ± 34b	285 ± 5	9.31 ± 0.12a	22.6 ± 0.5
Male	3262 ± 34a	281 ± 5	8.58 ± 0.12b	23.1 ± 0.5
Low light	3140 ± 34	280 ± 5	8.94 ± 0.12	23.1 ± 0.5
High light	3195 ± 34	285 ± 5	8.95 ± 0.12	22.6 ± 0.5
HSD	3116 ± 44	286 ± 6	9.19 ± 0.15	22.3 ± 0.6
MSD	3179 ± 44	282 ± 6	8.84 ± 0.15	23.1 ± 0.6
LSD	3195 ± 44	280 ± 6	8.81 ± 0.15	23.14 ± 0.6
P-values	S < 0.001 Sex < 0.001 L = 0.330 SD = 0.390	S < 0.001 Sex = 0.510 L = 0.540 SD = 0.771	S < 0.001 Sex < 0.001 L = 0.847 SD = 0.145 S × SD = 0.029	S < 0.001 Sex = 0.394 L = 0.480 SD = 0.507

Data represent the means and s.e.m. of four replicate pens for each treatment with 20 birds per pen (10 males and 10 females). Treatments were strains (CV and GF), light intensity (moderate and low) and stocking density (LSD – 4.4 birds/m^2, MSD – 5.0 birds/m^2 and HSD – 6.0 birds/m^2).
a, b: within a column for strain and sex values without a common letter are different ($P < 0.05$).
A, B: within strain the HSD values without a common letter are different ($P < 0.05$).
C, D: within strain the MSD values without a common letter are different ($P < 0.05$).
CV, Cherry Valley Pekin ducks; GF, Grimaud Freres Pekin ducks.
P-values: S, strain; L, light; SD, stocking density; S × SD, strain × stocking density interaction.

4.7% and 6.8% higher feed intake and a 4.1% and 3.5% better feed to gain ratio at Weeks 4 and 6, respectively. The higher growth and performance efficiency of the GF strain extended into differences in breast muscle weight and yields. The BM weight was 18.5% heavier with a 11.5% better feed weight to breast weight ratio for the GF birds. Males were heavier than females at all weeks, and this is consistent with other reports in ducks (Onbaşılar *et al.* 2011; Erdem *et al.* 2015). The sex differences in LW had no effect on breast muscle weight but the yield based on final slaughter weight was higher in females, however with no influence on the efficiency of converting feed to breast muscle.

Lighting and stocking density are environmental factors controlling many physiological and behavioural processes in meat birds (Rodenburg *et al.* 2005; Xie *et al.* 2014). The results of photoperiod and lighting studies for meat chickens should not be automatically adapted for ducks without adequate evaluation because ducks and meat chickens have distinctly different growth curves. Duck weight increases rapidly early in life and declines quickly thereafter, with the inflection point between these stages, reported to be 25.5 days for ducks compared to 47.7 days for meat chickens (Knížetoá *et al.* 1995).

When 13 partially open-sided UK duck houses were surveyed (Barber *et al.* 2004), the majority had mean light intensities ranging between 7 and 32 lux ($N = 11$). The light intensities in the current study, at 6 and 45 lux fitted reasonably well into this range. In the present study, birds exposed to the lower light intensity had a 2.1% higher LW at Week 4 and 1.2% at Week 6. It was only at Week 4, that the LWG was superior for birds under the low light intensity, and this probably accounts for the minimal difference in LW seen at the end of Week 6. Improved LW under continuous or near continuous light has been related to increased feed intake (Gordon 1994; Erdem *et al.* 2015). The LW differences observed in the current study were not associated with higher feed intake. The better feed to gain ratio at Week 4 under the low light intensity would suggest improved growth efficiency but this was not carried forward to Week 6 and likely related to the pattern of the duck growth curve mentioned previously (Knížetoá *et al.* 1995).

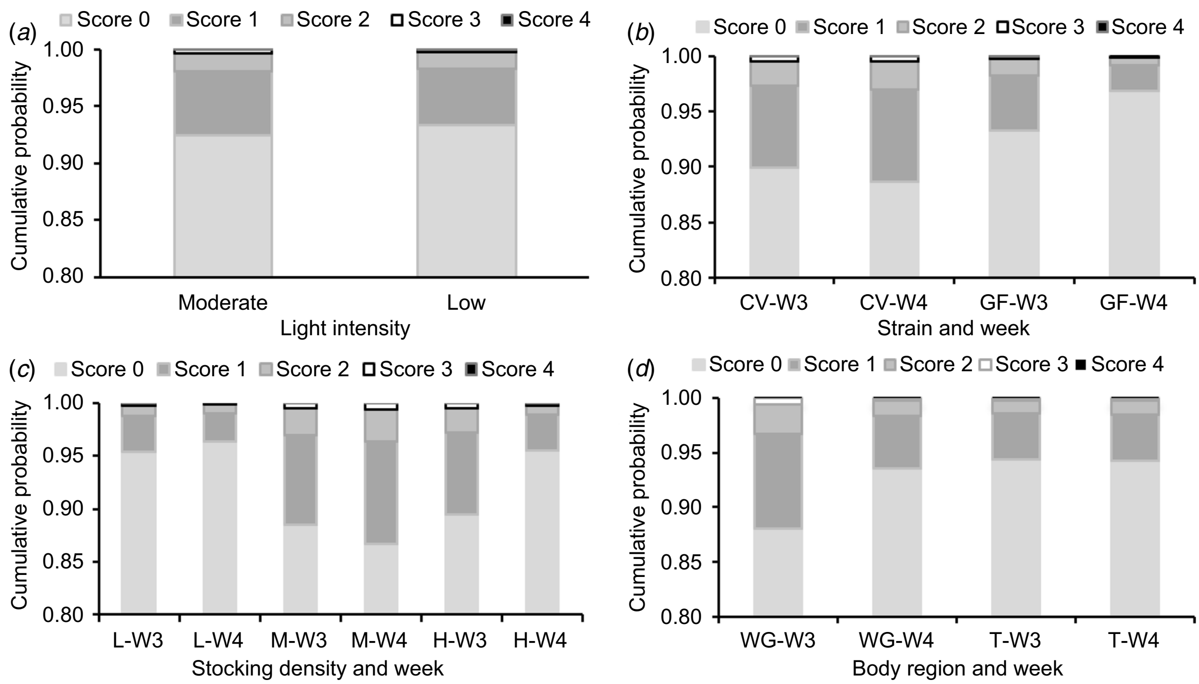

Fig. 2. The cumulative probability of recording feather and skin damage for CV and GF Pekin ducks exposed to moderate or low light intensity and at high (H), medium (M) and low (L) stocking densities. The scoring assessments were made at the end of Week 3 (W3) and Week 4 (W4) with observations made on the wings (WG) and the thigh (T) body regions. The damage was based on a score of 0–4, with zero being no damage and 4 the most severe.

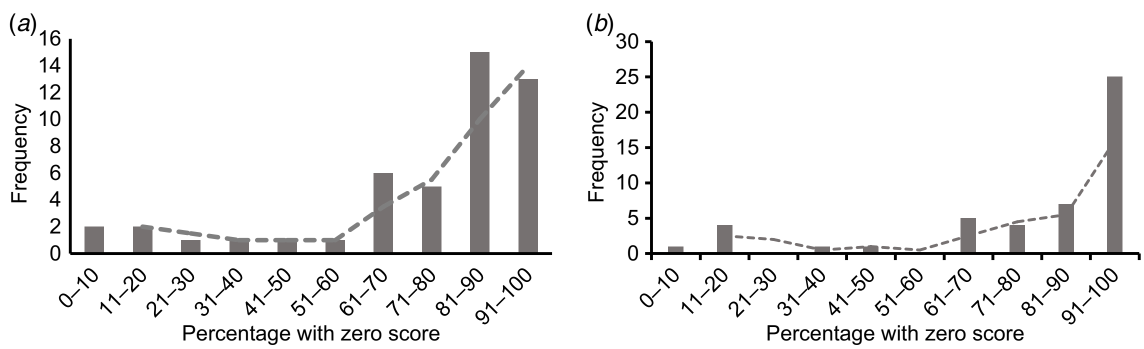

Fig. 3. The distribution for the total percentage of birds in individual pens recording no feather or skin damage in Weeks 3 and 4. The total percentage in pens were separated into categories of 10% units ranging from 0–10% to 90–100%. The frequency was the number of pens in each category.

At the end of Week 6, the birds housed at the MSD and LSD had a 1–1.5 % higher LW than those birds at the highest stocking density and this was due to higher LWG in Weeks 5–6. Stocking density had no effects on feed intake or feed to gain ratio. Most studies have reported SD as birds/m^2 but in practical terms the real measure of density should account for body size and for this reason a more practical measure of SD would be the 'weight density' recorded as kg/m^2. Abo Ghanima *et al.* (2020) housed Pekin ducks from 8 to 42 days of age in an open-sided shed and on wood shavings at 3, 5 and 7 birds/m^2. The LW was lowered by 3.1% as SD increased from 3 to 7 birds/m^2 and by 2.0% when the density increased from 3 to 5 birds/m^2. In their study, based on 'weight density' the transition from 10.15 to 16.57 kg/m^2 was sufficient to affect LW. Pekin ducks over 21–42 days of age, were housed at 5, 8 and 11 birds/m^2 with final 'weight densities' of 13.5, 20.6 and 27.9 kg/m^2 (Zhang *et al.* 2018). The SD depressed LW by 5.0% and 6.3% when comparing 5 birds/m^2 to the 8 and 11 birds/m^2, respectively. While the authors proposed 8 birds/m^2 as the optimum SD, based on their reported LW data, the optimum lay somewhere between 5 and 8 birds/m^2 and this equated to a 'weight density' of between 13.5 and 20.6 kg/m^2. In the current study, the upper limit for best performance could potentially lie between 5.2 and 6 birds/m^2 and this equated to a weight density range of 16.5–19.0 kg/m^2 and is in alignment with the observations discussed above.

Light intensity had no effect on breast muscle weight or yield as % of the slaughter weight. For the GF birds, the stocking density had no effect on breast muscle weight or % yield while for the CV birds the breast weight was unaffected by the stocking density but as % of the slaughter weight the yield was lower at MSD. The stocking density and light effects on final Week 6 LW were significant but not of a large magnitude (32–46 g), and so it is unreasonable to expect measurable changes in breast muscle weight considering the breast muscle yield as % of liveweight was only 8–9%. Using densities ranging from 5 to 9 birds/m^2 and continuous lighting of ducks, no effect on breast muscle yields or abdominal fat level were recorded by Xie *et al.* (2014). With only 84 g difference in final LW between the 5 and 9 birds/m^2 and a 13.5% breast muscle to slaughter weight yield, again, it's not reasonable to expect measurable changes in breast yield under the experimental conditions. Similarly, for Pekin ducks housed at 3, 5, 7 birds/m^2 there was a no effect on % breast yield or abdominal fat % (Abo Ghanima *et al.* 2020).

There were some strain and stocking density effects on feather pecking and skin damage and the prevalence at some body regions. The highest probability of damage was seen in birds housed at 5.2 birds/m^2. It's difficult to propose the reason for this considering there is a consensus that the higher the stocking density the more detrimental it is to performance, behaviour, and welfare (Xie *et al.* 2014) especially in summer (Chen *et al.* 2015).

Specific effects within individual pens may have had an overriding effect on the feather and skin damage. The distribution of the percentage of birds with no feather or skin damage in pens was negatively skewed with an extended tail identifying some pens with a higher % of birds affected with damage. The reasons for the asymmetrical distribution are not clear as there was no focal scanning of birds undertaken in the present study. Based on casual observations of bird activity in Weeks 3 and 4, and the subjective view of the author, there appeared to be individual birds identified as prevalent 'feather peckers' in some pens.

Dong *et al.* (2021), using focal scanning, recorded that 83.3% of birds in large commercial flocks engaged in gentle feather pecking and 16.7% in aggressive feather pecking with most actions directed to the wings, the same region most affected in the current study. Using meat chicken growers, Wechsler *et al.* (1998) found that 12% of individual birds accounted for 39.4% of all feather pecking interactions. The authors nominated some birds as 'high peckers' and that these birds had a higher percentage of their actions designated as 'plucking' at feathers rather than 'pecking' at feathers and they caused relatively high rates of damage. They proposed that these birds were in a motivational state that prompted them to initiate a series of pecking interactions in a short period of time. Using layer chicks, Huber-Eicher and Wechsler (1997) observed that once blood was present there were more feather pecks directed at the bloody feathers. Casual observations in the current study also suggested that once the damage resulted in blood loss, other birds were attracted to participate in the aggressive feather pecking activity. The role of individual bird motivation to 'feather peck', its imitation and social learning by conspecifics could escalate the problem and needs to be considered and evaluated along with other environmental, genetic and age influences in further studies.

Conclusions

The stocking density of 5.2 birds/m^2 (16.5 kg/m^2) supported performance equivalent to that at 4.4 birds/m^2 (13.9/kg/m^2) and better than birds housed at 6 birds/m^2 (19.0 kg/m^2). The SD supporting best performance likely lies somewhere between 5.2 and 6 birds/m^2. Ideally the stocking density recommendation should be based on 'weight density' (kg/m^2) and the current results indicate this is between 16.5 and 19.0 kg/m^2 under thermoneutral conditions and using litter-based housing. The birds performed similarly under both light intensities. Best performance and breast muscle yield was from the GF strain. The role of individual bird motivation to 'feather pluck', the imitation and social learning could be escalating the damage of this adverse behaviour and warrants further consideration.

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