Improving the production, efficiency, welfare and processing of commercial ducks

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Improving the production efficiency, welfare and processing of commercial ducks

by J. A. Downing

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Foreword

The Australian duck industry is small compared to the broiler industry, but is worth in excess of $100 million to the domestic economy. It has continued to expand at more than 10% a year, and struggles to meet ever-increasing consumer demand. The market is very specific in its requirements for whole bird carcasses with the right amount of fat, and good skin quality. A limitation to the industry’s expansion has been the reliance on genetic strains developed overseas, and the lack of research relevant to the Australian conditions. The Rural Industries Research and Development Corporation has previously invested funds in evaluating strain differences and nutritional aspects of duck production.

Almost all ducks are reared under open-sided, conventional type broiler sheds with limited environmental control. Under Australian summer conditions, birds can suffer from heat stress, which reduces growth rates and increases time to market. Heat stress also affects birds during transport and lairage. Feather pecking in Pekin ducks, while not as severe as in laying hens, is a welfare and production issue for duck producers. The damage caused by feather pecking can result in lower production, reduced processing efficiency, and reduced animal welfare.

Like the broiler industry, the duck industry is largely vertically integrated, with over 80% of production controlled by two companies. Each of these have individual contract growers that provide housing investment, labour and management expertise to supply ducks. The research detailed in this report will be of benefit to the integrators and producers, by supporting increased production and processing efficiency and providing insights into factors influencing feather pecking and duck welfare.

While a number of strategies were evaluated to help ducks cope with heat stress, the use of water supplemented with electrolytes and betaine provided performance benefits that translated into higher processed carcass yields. The increased hydration during transport also helps to alleviate physiological stress. There are clearly two forms of feather pecking: wing-directed and back-directed. These forms occur at different times. The research reported here does provide good evidence for the causes of the wing-directed form, but not for the back-directed form. There is good circumstantial evidence given to suggest factors that might be involved, but these require further evaluation.

This project was funded from RIRDC core funds, which are provided by the Australian Government. The industry partner, PEPE’s Ducks Pty Ltd, provided financial support for this project.

This report is an addition to RIRDC’s diverse range of over 2000 research publications and it forms part of our Animal Industries RD&E program, which aims to develop new opportunities, stimulate industry partnership and adoption, and increase competitiveness, capability and capacity.

Most of RIRDC’s publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

Craig Burns
Managing Director
Rural Industries Research and Development Corporation
About the Author

Dr Jeff Downing has been employed at the Faculty of Veterinary Science, University of Sydney, since 1996. He is presently employed as a Senior Lecturer and teaches poultry and pig husbandry to students in the Veterinary Science and Animal Veterinary Bioscience degrees. Presently, his research interests include duck production, non-invasive measurement of stress in laying hens, heat stress in broilers, induction of oestrus in lactating sows, and the role of dietary fats in metabolic function. Jeff has previously provided RIRDC with research into ‘Efficient, Environmental and Bird Friendly Commercial Duck Production’, which is aligned with the current report.

Acknowledgments

Staff from The University of Sydney, Faculty of Veterinary Science and the Poultry Research Unit, are acknowledged for their contributions to this project. Special thanks to Ms Joy Gill, Ms Melinda Hayter, Ms Kate DeHon and Don Nicholson for their dedication to maintaining the animals and facilities used in these studies. Also, thanks to Ms Jo Geist for her managerial support.

Karren Williams and Amber Chen (Chapter 3), Michelle Chou (Chapter 4), Tieu Hue (Chapter 5), Shenara Somasundaram (Chapter 8) and Hamish Irvine (Chapter 9), all students of the University of Sydney Animal Veterinary Bioscience degree, were all actively involved in the project as part of their studies.

PEPE’s Ducks Pty Ltd, as the industry partners for this project, were influential in all aspects of the project and so thanks are extended to the CEO John Houston, and manager of farm operations Peter Brown, for their contributions and overall enthusiasm. Special thanks to Patrick Haddad who coordinated the data collection at the processing plant.

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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACTH</td>
<td>Adrenocorticotropic Hormone</td>
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<td>AF</td>
<td>Air flow</td>
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<td>ANOVA</td>
<td>Analysis of Variance</td>
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<td>BL</td>
<td>Blue Light</td>
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<td>BT</td>
<td>Body Temperature</td>
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<tr>
<td>CV</td>
<td>Cherry Valley</td>
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<tr>
<td>CW</td>
<td>Coloured Wings</td>
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<tr>
<td>DEB</td>
<td>Dietary Electrolyte Balance</td>
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<tr>
<td>DOA</td>
<td>Dead On Arrival</td>
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<tr>
<td>FP</td>
<td>Feather Pecking</td>
</tr>
<tr>
<td>GF</td>
<td>Grimuad Frères</td>
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<td>GFP</td>
<td>Gentle Feather Pecking</td>
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<tr>
<td>GIT</td>
<td>Gastrointestinal Tract</td>
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<tr>
<td>GLMM</td>
<td>Generalised Linear Mixed Model</td>
</tr>
<tr>
<td>HFP</td>
<td>High Feather Pecking</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
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<tr>
<td>--------------</td>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>HPA</td>
<td>Hypothalamic Pituitary Adrenal</td>
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<tr>
<td>HS</td>
<td>Heat Stress</td>
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<tr>
<td>LFP</td>
<td>Low Feather Pecking</td>
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<tr>
<td>LSD</td>
<td>Least Significant Difference</td>
</tr>
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<td>LT</td>
<td>Left Thigh</td>
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<tr>
<td>LW</td>
<td>Left Qing</td>
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<tr>
<td>LWG</td>
<td>Liveweight Gain</td>
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<tr>
<td>ME</td>
<td>Metabolisable Energy</td>
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<tr>
<td>MHA</td>
<td>Methionine Hydroxyl Analogue</td>
</tr>
<tr>
<td>PL</td>
<td>Poor Litter</td>
</tr>
<tr>
<td>REML</td>
<td>Restricted Maximum Likelihood</td>
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<td>RH</td>
<td>Relative Humidity</td>
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<tr>
<td>RIRDC</td>
<td>Rural Industries Research and Development Corporation</td>
</tr>
<tr>
<td>RT</td>
<td>Right Thigh</td>
</tr>
<tr>
<td>RW</td>
<td>Right Wing</td>
</tr>
<tr>
<td>SB</td>
<td>Straw Bundles</td>
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<tr>
<td>SED</td>
<td>Standard Error of Differences</td>
</tr>
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<td>SEM</td>
<td>Standard Error of the Mean</td>
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<tr>
<td>SFP</td>
<td>Severe Feather Pecking</td>
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<tr>
<td>SRBC</td>
<td>Sheep Red Blood cells</td>
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<tr>
<td>TI</td>
<td>Tonic Immobility</td>
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<tr>
<td>TRP</td>
<td>Tryptophan</td>
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<tr>
<td>UV</td>
<td>Ultraviolet</td>
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Executive Summary

What the report is about?

The duck industry uses genetics from overseas, and much of the knowledge used in production has been developed from research conducted overseas. Much of this is not relevant to the product specifications needed in the Australian market. A major difference between Northern Hemisphere production and production in Australia is the type of housing used, with respect to the climate. To facilitate the profitable growth of the duck industry, key husbandry factors potentially limiting bird growth and welfare on Australian farms need to be better understood. The report provides details of the results on experiments investigating:

- The husbandry, environment and bird factors that contribute to feather pecking (FP); the study proposes a model to account for one of the two forms of this behaviour
- Methods to alleviate this depressed growth of ducks during the Australian summer
- Methods to minimise dehydration during transport and lairage to improve bird welfare and carcass yields.

Who is the report targeted at?

The report targets the producers responsible for the grow-out of ducks from day olds to market age, which is normally around 42 days of age. Other aspects of the research are concerning issues associated with duck welfare, processing efficiency, such as feather removal and carcass yield in processing facilities.

Where are the relevant industries located in Australia?

The Australian duck industry has followed a similar pattern to the broiler industry, in that it is largely vertically integrated. Over 80% of the production is controlled by two companies: PEPE’s Ducks Pty Ltd, located in NSW, and Luv-a-Duck, located in Victoria. The grower farms for PEPE’s Ducks Pty Ltd are located mostly in the Sydney basin, with one producer in Young NSW. Luv-a-Duck grower farms are located in the Wimmera region of Victoria.

The remaining 20% of production comes from independent growers, each with small flocks. These are primarily located around the large population centres, and are often supplying small niche local markets.

Aims/objectives

The objectives of the project were to:

1. Describe and quantify the behaviour of growing ducks, with a specific focus on identifying the main factors associated with the occurrence of FP, and investigation of strategies that might limit FP to improve bird welfare.

2. Investigate strategies that will help alleviate the depressed growth rate and physiological stress of ducks under Australian summer conditions.

3. Develop an understanding of the on-farm and physiological factors that influence bird hydration during transport and lairage, with a view to reducing stress and improve welfare.
Methods used

A tunnel ventilated, water cooled shed with 48 individual pens was used in these studies. Ducklings were bred and hatched by PEPE’s Ducks Pty Ltd, while diets were formulated and supplied by Inghams Enterprises, Berrima, NSW.

Chapter 2: Strategies to alleviate the adverse effects of high temperature on the performance of commercial ducks

Treatments were applied to two strains of Pekin ducks: the Cherry Valley (CV) strain, and an industry strain identified as P2 that has been selected from the parent CV strain for higher growth rate and breast yield. The treatments were:

1. control diet with water alone
2. control diet and water supplemented with vitamin C
3. control diet and water supplemented with betaine
4. control diet and betaine supplemented in the diet
5. feed withdrawal during the periods of high temperature
6. control diet and water supplemented with electrolyte salts and betaine.

Treatments 1–5 were applied during Days 29–41 of age, while Treatment 6 was applied during Days 36–41 only. On Days 29–41, the shed temperature was increased to 32°C for 9 h (08:30 to 17:30h) each day, and then maintained at 24°C for the remainder of the day (17:30 to 08:30 h). Treatment days 29–35 of age (Week 5) were considered to be Heat Period 1. Treatment days 36–41 of age (Week 6) were considered to be Heat Period 2.

Liveweight, feed and water intakes were recorded on Days 14 (Week 2), 28 (Week 4), 35 (Week 5) and 41 (Week 6) of age. On Day 40 of age, one male and one female duck were removed from each pen and individually weighed and then euthanised. The total breast muscle was removed and weighed.

Chapter 3: The role of stocking density and light intensity on the performance and feather pecking activity of commercial Pekin ducks

The experimental treatments consisted of two strains of Pekin ducks: the CV strain and the Grimuad Frères (GF) strain, reared under two light intensities (high and low) and at three stocking densities. In one half of the shed, the light intensity was maintained at less than 5 lux throughout. In the other half of the shed, the light intensity was greater than 60 lux throughout. At the end of Week 3, all birds were individually examined and the extent of FP damage was determined. This was repeated at the end of Week 4.

Eight pens in the high light intensity section of the shed were used to evaluate behaviour of the two strains. The eight pens were continuously monitored by two video cameras per pen. The four treatment combinations were: the CV strain at 4.4 birds/m² and 5.2 birds/m², and the GF strain at the same densities, with each treatment combination replicated in two pens. Observations were made on each pen at 5 minute intervals for a 24 hour period at 3, 4, 5 and 6 weeks of age.

Chapter 4: The effects of electrolyte supplementation and dietary electrolyte balance on the performance of commercial ducks exposed to cyclic heat stress

CV Pekin ducks were used in the study. Two grower diets were fed: one with a low DEB, and one with a high DEB. Four different electrolyte concentrations were added to the water. These were 0% (control), 50% (E50), 100% (E100) and 150% (E150) of the electrolyte concentration used in the study, detailed in Chapter 2. A further electrolyte treatment (the 100% concentration) was supplied during the 36 hours (Days 40–41) prior to farm pick-up for processing (E100-36h). It is regular practice to add betaine to duck grower feeds, and so this was also included as a further treatment.
From Days 1–35, birds in all allocated groups were exposed to the same conditions. During Days 36–41, all birds were exposed to an ambient temperature of 30–32°C from 08:30–17:30 h, and then 22–24°C from 17:30 to 08:30 h, each day. On Days 14 (Week 2), 28 (Week 4), 35 (Week 5) and 41 (Week 6), all ducks were individually weighed. Feed intakes were determined over the same time periods, and water intakes were recorded daily. On Day 41, one male and one female duck from each pen was euthanised, and the weight of breast muscle determined. The remaining birds were processed by PEPE’s, and carcass yields were determined.

Chapter 5: The effect of transport and electrolyte provision during lairage on the carcass weight loss during processing

CV Pekin ducks were grown out on a commercial farm, operated by PEPE’s Ducks Pty Ltd. The birds were housed and reared according to commercial practices. Birds used in the study were randomly collected from the main flock at the time of farm pick-up for processing at 42–43 days of age. There were three treatments groups:

1. Ducks that were transported and then processed as soon as possible after arriving at the processing plant
2. Ducks that were transported and then held in lairage and processed at the same time as the Group 3 ducks
3. Ducks that were transported and then held in lairage and processed at the same time as the Group 2 birds, but during lairage were provided with water supplemented with electrolytes and betaine.

All birds were individually weighed at the time of farm pick-up, and then when they arrived at the processing plant. Birds were then weighed just prior to being processed. After slaughter, the carcasses were weighed before they entered the processing line chiller (dry eviscerated weight), and then again after they had gone through the chiller (wet eviscerated weight).

Chapter 6: Identifying factors that predispose commercial Pekin ducks to feather pecking damage

CV Pekin ducks were reared as either mixed sexes or as single sexes. The following treatments were applied:

1. Control: reared as mixed sexes
2. Females reared as single sex (FS)
3. Males reared as single sex (MS)
4. Poor litter quality, reared as mixed sexes (PL)
5. Wings coloured with blue spray mark reared as mixed sexes (CW)
6. Straw bunches included in the pen, reared as mixed sexes (SB)
7. Birds reared under filtered blue light, reared as mixed sexes (BL)
8. Corticosterone-treated water, reared as mixed sexes (Cort).

Treatments 1–4 were applied over the 42 days of the experiment, while Treatments 5–7 were applied from Day 21 to Day 42 of the production period. Treatment 8 was applied from Days 21–35 of the production period.

On Days 14 (Week 2), 28 (Week 4), and 41 (Week 6), all ducks were individually weighed. Feed intakes were determined over the same time periods, and water intakes were recorded daily. Liveweight was also determined at Day 35 for the control and corticosterone-treated birds only. On Day 42, the ducks were transported to PEPE’s for processing. After processing, 20–24 (equal number of males and females) carcasses for each treatment group were removed and refrigerated overnight, xvi
and then on the following day subjected to a commercial cut-up. After full dissection, the carcass parts were weighed. On Day 30 (Period 1) and Day 35 (Period 2), all birds were individually examined, and the extent of FP damage was determined.

Chapter 7: Electrolyte supplementation of commercial Pekin ducks during short periods of high ambient temperature

The strains used were the CV strain and an industry strain (P2) selected for higher growth rate from the parent CV strain. The following treatments were applied:

1. Control: water alone
2. Electrolyte supplementation in water
3. Electrolyte plus betaine supplementation in water
4. Electrolyte plus betaine supplementation provided between 08:00 to 1700 hours during Heat Period 1 (Days 30–32) and during 17:00 to 08:00 hours during Heat Period 2 (Days 40–42).

The treatments were supplied to the birds on Days 30–32, and Days 40–42. During these periods, the temperature was raised to 32°C from 08:00 to 17:00, and then reduced to 24°C from 17:00 to 08:00. Over Days 33–39, the temperature was maintained at 20°C.

Individual liveweights were recorded on Days 15, 29, 32, 39, and 42. At these same times, feed intakes were determined, and water consumption was recorded daily. On Day 43, the ducks were transported to PEPE’s Ducks Pty Ltd for processing. After processing, 20–24 (equal number of males and females) carcasses for each group were removed and refrigerated overnight, and then on the following day subjected to a commercial cut-up. Different carcass parts following the cut-up were weighed.

Chapter 8: Further evaluation of factors potentially involved in feather pecking in commercial Pekin ducks

There were essentially two studies within the one experimental framework. The FP study involved the P2 strain of CV Pekin duck with five treatments, including a control. The sixth treatment was where a new imported Grimaud Freres (GF) strain was reared as a control treatment. The growth performance of the GF control and P2 control were compared as an independent adjunct to the main FP study. The treatments were:

1. Control: GF strain reared as mixed sexes
2. Control: P2 strain reared as mixed sexes
3. Wings coloured with blue spray, P2 strain reared as mixed sexes
4. Straw bunches included in the pen, P2 strain reared as mixed sexes
5. Grower feed supplemented with tryptophan (TRP), P2 strain reared as mixed sexes
6. Increased AF in the pen, P2 strain reared as mixed sexes.

On Days 14 (Week 2), 28 (Week 4), and 42 (Week 6), all ducks were individually weighed. For the control P2 and control GF strain, a liveweight measurement was also made on Days 7, 21, and 45 just prior to processing on Day 46. Feed intakes were determined over the same time periods, and water intakes were recorded daily. On Day 46, ducks were transported to PEPE’s processing plant, and a sub-sample of birds were subjected to a commercial cut-up for determination of carcass muscle and fat content. FP damage was determined on Days 32 and 42.

Chapter 9: The use of electrolyte and betaine supplementation to alleviate weight loss during transport and lairage of commercial ducks

In this experiment, the effect of electrolyte and betaine supplementation for 32 hours prior to farm pick-up on weight loss during transport and lairage were investigated.
The study was completed on a commercial duck farm in southwestern Sydney. Birds were at the end of the grow-out period (42 days of age). On the day before farm pick-up for processing, an area of the shed was fenced off and used to house the electrolyte-supplemented birds.

Eighty electrolyte supplemented birds were transferred to transport crates with six birds per crate (Trial A). The remaining 80 supplemented birds (Trial B) were transferred to cages set up on a trailer. On the trailer, half the birds continued to be supplied with the electrolytes, while the other half had no access to the fluid. Eighty control birds were randomly selected from the shed flock, wing-tagged and individually weighed (Trial A), and then transferred to crates with six birds per crate. On arrival, birds allocated to Trial A were individually weighed and then reweighed at two hour intervals. Birds allocated to Trial B were weighed at 6 h after arrival only. Birds in both trials were processed at the same time. After feather removal and evisceration prior to entry into the chiller (dry weight) carcasses were weighed. They were then weighed after exiting the chiller (wet weight).

Results/key findings

Strategies to alleviate the depressed growth rate of ducks under Australian summer conditions

Chapter 2

During Week 5, all treatments applied increased daily liveweight gain (LWG) compared to the control birds, but this improvement was small, being around 2–4 g/d (14–28 g/week). In Week 6, the use of electrolytes and betaine-supplemented water had a positive effect on LWG and this resulted in significantly heavier liveweight at the end of the production cycle. The effect of treatment on feed to gain was marginally non-significant (P=0.06). In Week 6, birds treated with electrolytes plus betaine tended to have better feed to gain. The improved growth rate would be indicative of birds being under less physiological stress and likely better welfare.

Chapter 4

The DEB had no effect on LWG in Weeks 3–5 when the temperature was kept in the thermoneutral range. Betaine addition to the feed had no effect on LWG or final liveweight during either Weeks 3–5 or in Week 6 when the birds were exposed to cyclic high temperature. Over Weeks 3–5, betaine supplementation in feed resulted in poorer feed to gain.

During the cyclic HS period in Week 6 there was a marginal interaction between treatment and DEB (P=0.07). The trend for the control birds on the high DEB to have a higher LWG than those birds on the low DEB suggested that the increased need for electrolytes at the high temperature could be supplied in the feed. On the low DEB, birds supplemented with electrolytes tended to have higher LWG than the control birds, with this trend being stronger when the highest electrolyte concentration was used and when the standard concentration was used for 36 hours before farm pick-up for processing. This trend was not evident when birds were fed the high DEB diet. This suggests that a higher electrolyte intake during periods of high temperature will reduce the physiological stress placed on the birds.

Chapter 7

During the first period (Days 30–32), the continuous supplementation with electrolytes or electrolytes plus betaine improved LWG compared to the control birds. Supplying the electrolytes plus betaine only during the period of high temperature was not sufficient to have any effect on LWG.

In the second heat period (Days 40–42), all the electrolyte-supplemented groups had superior LWG compared to the controls but there were differences between the electrolyte groups. Birds on electrolytes alone had superior gain compared to the other electrolyte treatments, followed by those birds on the electrolytes and betaine continuously, and then by birds on this treatment when given for
the thermoneutral period only. The differences in LWG gain were sufficient for there to be significant differences in final liveweight. All electrolyte-treated groups had greater final liveweight than the controls and this ranged from 70–180 g. This significant improvement resulted in a higher carcass processing weight of 60–80 g, a 3–4% improvement in carcass yield over the controls.

**Feather pecking and the damage caused**

**Chapter 3**

The incidence of FP was relatively small, with about 8% of the birds having FP damage, and the probability of severe damage was even lower. The low incidence of FP damage could indicate that only a few individual birds are involved in this activity. While the difference was only seen at the second evaluation period, the GF birds did have a lower incidence of FP damage.

Stocking density had an effect on the degree of FP damage, but this was only seen when the evaluation was made in Period 2. The damage seen for birds housed at the medium density was greater than for birds at the low density. The difference between the damage for birds at the medium density and at high density was non-significant, but the trend was for it to worsen in the medium density treatment.

In this study we did not observe FP damage directed at the back area. This probably accounts for the much easier removal of feathers at the processing plant as relayed to the author by staff at PEPE’s Pty Ltd. This difference in processing efficiency can be identified by the need or not to wax duck carcasses to remove the pin feathers during processing. This observation is important because it suggests that the better environmental control experienced in the experimental facility might have a role in FP activity directed to the back region. Any factor that can reduce the incidence of feather pecking would improve duck welfare.

Ducks spend 65–75% of their time resting and a further 12% of their time alert but sitting, with between 15–20% of their time involved in general activity. The level of general activity is much higher in Weeks 5 and 6 (25–35% increase). This pattern might be significant in commercial duck sheds because if other environmental conditions predispose ducks to higher FP activity, the increase in general activity might help perpetuate the problem by increasing the potential for social transmission.

**Chapter 6**

Overall the extent of FP in the experiment was low, and this is an obstacle to investigating this problem in ducks. There is no way of predicting how extensive FP will be under the experimental conditions being employed. Compared to the control birds, those with coloured wings had lower damage scores than the control birds on Day 30, but not on Day 35. There was a trend for the birds reared under blue light to have lower scores than the controls, with the difference being marginally non-significant on Day 30. It should be noted that higher scores for the wings were recorded for birds on poor litter and males reared in single sex pens but these differences failed to reach significance.

The use of supplementary corticosterone certainly affected performance but had no effect on FP damage. In the study, litter quality was kept in poor condition; in fact, it was considered to be as poor as it would ever get in commercial sheds. Birds on the poor litter performed well and based on plasma corticosterone, were not stressed. The poor litter treatment had no effect on FP damage.

**Chapter 8**

This was the first study where the two different forms of FP occurred: damage directed at the wing and that directed at the back region. There was no significant effect of treatment on FP damage to the wing area. Damage directed to the back occurs towards the end of the production cycle and can result in extensive removal of feathers from the back area. The experimental facility used has much better environmental control than is possible in commercial sheds. Because this is the first time that back damage has been observed through the 3 years of these studies, there is a hint that environmental
conditions in the shed could be related to this form of FP activity. The treatment effects were not significant, although it did seem that the increased air flow causing rippling of the feathers might be involved, but this would need further evaluation. Males had more damage to the back region than did the females.

**The effect of transport and lairage on the carcass weight loss during processing**

**Chapter 5**

All treatment groups lost similar weight during transport, with this being less than 2% of the farm weight. In lairage, delayed processing resulted in 3.5% loss of farm liveweight while supplying electrolytes limited this to 1.1% and was similar to the birds processed early, at 1.5%. When the birds were processed, the weight loss during evisceration was lower for the birds processed later without electrolytes. This suggests that the extra weight recorded for the early processed and electrolyte-supplemented birds was due to the greater gut weight which is probably fluid in the gut. While providing the electrolytes may have helped the birds cope by limiting the rate of dehydration and assist with better welfare, it had no impact on processed carcass weight.

**Chapter 9**

Working in a commercial production shed limits any control we have over many aspects of the experiment. Disappointingly, on the farm pick-up day, the ambient temperature was moderate, although persistent rain showers resulted in high relative humidity (RH).

Based on the predicted weight loss, the electrolyte-treated birds lost a higher percentage of their liveweight during transport and lairage. Most of this difference occurred early, and from 3 hours after pick-up, the rate of weight loss in lairage for the electrolyte-treated and control birds were similar. In lairage, the birds dehydrated at the same rate. While the percentage weight loss was higher in the electrolyte-treated birds they still had a higher final weight. This is even accounting for the fact that they were loaded 90 minutes earlier than the control birds at the farm. The final carcass weight was around 90 g heavier for the electrolyte-supplemented birds. The results suggest that the electrolyte-supplemented birds were more hydrated and this would help reduce the physiological stress imposed on them during transport and lairage.

**Implications for relevant stakeholders**

**Production, processing and bird welfare**

1. In the open-sided sheds used for commercial duck production a stocking density of 5.2 birds/m² at market age was the upper limit to achieve maximum performance.

2. The results from the current work indicate that the use of betaine in the feed provided no advantage under thermoneutral conditions or during cyclic heat stress.

3. Overall, formulating duck grower diets to have low DEB is not detrimental to achieving good on-farm performance under thermoneutral conditions, but a higher DEB would be beneficial during even moderate HS. This would reduce the physiological stress placed on the birds during periods of high temperature.

4. Ducks benefit from supplementing water with additional electrolytes during periods of high temperature. This is a practical option for producers as its application can be targeted to specific periods of high temperature or when heatwave conditions are anticipated. The reduction in physiological stress would benefit bird welfare.
5. Providing electrolytes during transport and lairage can reduce dehydration and reduce heat stress, it is not a practical option and similar benefits can be achieved by providing electrolytes on farm before pick-up.

6. The results of the current study provide good evidence that supplying birds with electrolytes and betaine for 32 hours before farm pick-up increased liveweight and this actually translated into higher carcass yield at processing. The improved weight is likely due to increased tissue water content which would help alleviate physiological stress. This improvement was observed under conditions of thermoneutral temperature and high RH. The benefit could be even greater at high ambient temperatures.

**Feather pecking and damage**

1. There are two distinct forms of FP damage in ducks; the wing-directed form that occurs at the time of feather emergence at the wing tip around Week 3 of age and the back-directed form, which occurs in Weeks 5 and 6 of the production cycle when the finer feather on the back are well developed.

   The results indicate that the wing-directed form is associated with ducks being attracted to the red blood that is visible in the feather shaft at the time of emergence. Disguising this did reduce the incidence of FP damage to the wing area. It is possible that individual birds with a high propensity to engage in FP activity could initiate the problem, which could then escalate by social transmission. This needs to be validated with more intensive behavioural studies.

2. The back-directed form was only detected in one of the three studies described in this report. This form is the main cause of reduced processing efficiency because of the increased difficulty of feather removal.

3. Stress does not seem to be implicated in FP but circumstantial evidence suggests that environmental conditions may be involved. While not conclusive, there was some evidence to the suggest that this form of FP might involve increased air flow in the shed acting to ripple the fine feathers on the back which attracts other ducks to peck.

   Even in the back-directed form of FP, individual birds identified as ‘high peckers’ are likely to have a major role, but this needs to be validated.

**Communities**

Improvements in feed and processing efficiency means lower inputs, which has follow-on effects for the community:

- less grain use and the resources needed for this
- lower carbon output with the reduction in resources needed.

, With the public being increasingly concerned with the way food is produced using animals, factors that influence welfare of ducks in commercial production need constant consideration FP and the damage it causes in Pekin ducks, while not as severe as is seen laying hens, does exists and remains a welfare concern. While not providing any absolute solution to the problem, the results from the current project do give an insight to some of the causes for this behaviour, and certainly add to the very sparse information available previously.

**Policymakers**

The data generated can help in the development of the revised welfare code for poultry currently in progress.
Recommendations

1. The research generated here is the first that provides information on FP in commercial ducks, under Australian conditions. There remains a need for further development of strategies that might help with this problem. The development of suitable experimental models that can be used in commercial sheds seems to be the next step in developing ways of helping producers to manage the problem.

2. The information generated will be of value to those regulators responsible for the development of a new welfare code for poultry.

3. The role of open water access needs to be investigated, both for welfare assessment and also to inform those persons developing the new poultry welfare code.

4. The use of electrolyte supplementation prior to farm pick-up would improve the economic value of duck production, reduce physiological stress on ducks and improve their welfare during transport and lairage.
Introduction

For all animal production, the ultimate goal is to meet the expectations of the products’ consumers, including their expectations for best animal welfare. In the duck meat industry the product expectations are primarily for a 2.85 kg liveweight bird at processing, with the highest possible ratio of high-value breast muscle but with the correct carcass fat content and high quality skin for the barbecue trade. There are significant losses or costs associated with handling and marketing product that does not conform to this desired market weight or quality. While these are the primary requirements of the consumer, the goal of the producer is to meet these at the least cost. Another critical aspect of the production system is the need to do all this with the welfare of the duck being paramount in the whole process.

Australian duck meat consumption is currently around 500 g per capita, markedly lower than the 44 kg per capita of chicken meat consumption. Duck meat consumption continues to increase, having doubled in the previous decade, and this expansion promises to continue if the industry remains responsive to providing a consistently high quality product, acts to expand its product range and does this while managing the birds’ welfare. The industry processes over 8 million birds annually, with an estimated value of over $100 million, and supports over 400 employees. Two large integrated companies account for about 80% of the production. If the duck meat industry is to meet its potential there needs to be a research capability established, suitable to meet the industry’s challenges, especially those relating to bird welfare, product quality, and production efficiency.

The industry has the potential to continue its expansion, but currently a major constrain is the lack of grower output to meet the demand. Until now the industry has relied on contract growers to produce sufficient birds to meet the demand. For the industry partners involved in this project, farm output is a limitation that will be difficult to rectify. The main NSW producer, PEPE’s Ducks Pty Ltd, have their headquarters located at Windsor with their growers largely located in the Sydney basin. While growers may be keen to expand, environmental and local council constraints make this difficult. The only likely solution is for the industry to move to locations further out from its present concentration around Sydney. This will increase transportation times and this could become an issue for bird welfare and processing efficiency.

While husbandry know-how is vital to maximising production efficiency and the welfare of farmed livestock, the procedures used for the production of meat ducks in Australia have predominantly developed from research conducted overseas. Much of this is not relevant to the specifications needed in the Australian market. A major difference between Northern Hemisphere production and that in Australia is the type of housing used and the climate. To facilitate the profitable growth of the duck industry, key husbandry factors potentially limiting bird growth and their welfare on Australian farms need to be better understood.

FP, predominantly a winter problem, it is a welfare concern for the bird and is estimated to account for 1–2% loss in production at the farm gate, and a further 1–2% loss during processing. A total of 2–4% loss all up is costing the industry around $2 million annually. The current project has developed knowledge of the husbandry, environment and bird factors that contribute to FP, and proposes a model to account for at least one form of this behaviour.

Under Australian climatic conditions, heat stress can affect duck welfare and the poorer performance of ducks under summer conditions means that the processing age is often extended by four to six days. An increase of one day to reach market weight equates to an increase in total feed costs of $1.1 million over 4 months. The project investigated ways to alleviate this depressed growth of ducks during the Australian summer. While this benefits production costs, it would also reduce the physiological stress on the birds and improve their welfare.
Objectives

1. To describe and quantify the behaviour of growing ducks, with a specific focus on identifying the main factors associated with the occurrence of FP and then to investigate strategies that might limit FP under commercial conditions.

2. To determine the optimal stocking density for commercial strains of growing ducks under Australian conditions.

3. To investigate the on-farm (for example, feed withdrawal and electrolyte supplementation) and transport factors that influence bird hydration and physiological stress during transport and lirage.

4. Investigate strategies that will help alleviate heat stress and the depressed growth rate of ducks during the Australian summer.

5. Develop a growth model for commercial strains of ducks grown to seven weeks of age to meet the requirements of the ‘cut-up’ market.
Methodology

Duck trials

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.

Experimental shed

The housing used was a tunnel shed with evaporative cooling (see Figures 1 and 2). The shed had 48 individual pens (1.5 x 3 m) with 24 running down each side of the building. All studies were conducted using a completely randomised design with blocking. The blocking was used to account for any inherent variation in shed conditions. Ducks were raised on deep litter, consisting of wood shavings. The wood shavings were turned regularly and replaced with new material when excreta contamination became unacceptable, unless identified differently in individual studies. The shed was lit with fluorescent lighting maintained for the full 24 hours of each day unless identified differently in individual studies.

Figure 1. The tunnel ventilated experimental shed used in the studies
Breeding and incubation

Commercial strains of Pekin ducks were used in all studies. The strains were produced at a commercial breeding farm operated by PEPE’s Ducks Pty Ltd. Eggs were incubated at their commercial hatchery. At hatch, the ducklings were vent-sexed and transported as day olds to the experimental facilities at The University of Sydney, Camden.

Brooding

Supplementary heat was provided with overhead lamps with a temperature of 35°C, as measured directly beneath the brooder lamp, at Day 1 (see Figure 3). The temperature was reduced to 28°C by Day 7, to 26°C by Day 14 and then 24°C by Day 21.

Bird identification

On Days 6–7 of age, tags were inserted into the skin integument extending between the humerus and radius of the wing. All tag numbers were recorded. If required, readjustments were made during the production phase to prevent the tags from becoming embedded in the surrounding tissues.
Diets and feeding

For all studies, diets were formulated and supplied by Inghams Pty Ltd (Inghams Feed Mill, Corner of Douglas and Berrima Rd, Berrima, 2577). In the commercial production setting, two diets are used in the six-week production period. For the first two weeks ducks are fed a crumble starter diet and the remaining four weeks a pelleted grower diet. General details of these commercial diets are shown in Table 1.

The ingredients used in preparation of the diets were: wheat, sorghum, meat and bone meal, millrun, canola meal, limestone, lysine, liquid MHA, sodium bicarbonate, enzyme mix and premix (duck concentrate). For reasons of ‘commercial-in-confidence’ details of the ingredient amounts used in the formulation of the diets in the studies reported here were not made available.

Watering

Each pen had its own water supply so the water intake could be recorded (see Figure 3.4). A row of four nipple drinkers were situated along one side in each pen. The drinkers were raised in accordance with duck growth. For the first four to seven days an additional bell waterer was also provided to ensure ducklings were adequately hydrated.

Mortalities and culls

Ducks were culled if they appeared unhealthy or lame to an extent that it affected their ability to feed, and subsequently, their ability to grow normally. Culls were euthanised with a lethal injection of phenobarbitone into the femoral vein of the leg. All culls and mortalities were recorded.
Table 1. The nutritional composition of duck starter and grower diets (Inghams Pty Ltd)

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<th>Grower (14–41 days)</th>
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<tr>
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<td>Energy (MJ/kg)</td>
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**Performance measurements**

While there were specific measurements made for individual studies, for all studies the following were regularly undertaken: at placement a group pen weight was recorded; at specified times all ducks were individually weighed; feed was weighed in and out with intake determined as the difference between feed added less that removed on a pen basis.

**Carcass measures**

For some studies breast muscle weight was determined for individual ducks selected at random from treatment pens. If the pens contained mixed sexes, one male and female was taken from each treatment pen. After selection, ducks were individually weighed and then euthanised using a lethal injection of sodium phenobarbitone.
Feather pecking damage

Several methods have been used previously to analyse FP behaviour and the associated damage:

1. Plumage condition: Birds are graded in terms of how damaged their plumage is and given a score to indicate severity of FP.
2. Physiological indicators: These include tonic immobility (TI) (how long it takes the bird to move after a fear response, usually brought about by human contact) and measures of stress hormones (e.g., corticosterone) to evaluate fear and welfare in relation to pecking.
3. Surveillance: By direct observation from video footage or personal observation. Behaviour patterns are scored and put into categories; for example, foraging, dustbathing, aggression or vocalisations. These are tallied to determine the frequency and occurrence of these behaviours. The time spent performing each of the behaviours can also be recorded.

Behavioural observations

In the current project, duck behaviour was analysed by video surveillance over a full 24 hour period in Weeks 3, 4, 5 and 6 of age. This study is detailed in Chapter 3. All birds in the pen were observed each five minutes during the 24 hour observation period.

The ethogram used was adapted from Jones et al. (2009) and Barber et al. (2004). The activities identified as being potentially relevant to FP were specific grooming activities and general activity level. Grooming activities were categorised as self-directed or directed to a flockmate, and by the perceived level of aggression exerted. More specific descriptions of FP behaviours have been made with respect to chickens; for example, stereotyped gentle FP (see Section 1.5.1). However, it can be often difficult to determine between overlapping descriptions. Three levels of grooming activities could easily be differentiated from the videos: ‘preening’, as described by Barber et al. (2004) could be performed by a duck to itself or a neighbour. ‘Vigorous grooming’ was identified when preening activities directed to another bird elicited a response perceived to be a negative reaction from the other bird, such as tail wagging or getting up and moving away. ‘FP’ was identified as a single, rapid and apparently aggressive peck, which could be performed while the pecker was stationary or while moving. The bird pecking was usually standing and the attack always elicited a response. Other activities included eating, drinking, foraging in the litter or environment-directed pecking at items in the pen such as the walls. The final categories used are detailed in Table 2.
Table 2. The behavioural categories used to identify feather pecking behaviour during the video surveillance

<table>
<thead>
<tr>
<th>Grooming activity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preening—self</td>
<td>Grooming activity directed towards itself</td>
</tr>
<tr>
<td>Preening—other</td>
<td>Grooming activity directed towards another bird with no negative response</td>
</tr>
<tr>
<td>Preening—mutual</td>
<td>Grooming activity directed to another bird and reciprocated</td>
</tr>
<tr>
<td>Vigorous grooming</td>
<td>Grooming activity directed towards another bird, with discomfort demonstrated by the recipient bird</td>
</tr>
<tr>
<td>Feather peck—stationary</td>
<td>A single attack directed towards a neighbouring bird, usually with</td>
</tr>
<tr>
<td></td>
<td>a response from the second bird</td>
</tr>
<tr>
<td>Feather peck—moving</td>
<td>A single attack involving movement towards or chasing the second bird</td>
</tr>
</tbody>
</table>

**Feather damage**

There were two distinct types of feather damage observed in these studies. There was a predominance of wing damage starting around Week 3 of production, while damage on the back occurred later in production at Weeks 5 and 6.

**Wing damage**

For studies detailed in the chapters where FP was investigated, and where the plumage condition and body damage concentrated on the wing area, the following scoring system was used:

- score 0: No damage observed
- score 1: Evidence that feathers have been pecked and damaged
- score 2: Evidence that feathers have been removed and blood drawn from the feather follicle
- score 3: Further feather loss on the wings leading to featherless patches and greater blood loss
- score 4: The feather damage warranted removing the bird from the pen and treating it in isolation.

Scores 1–4 were used in the first study, detailed in Chapter 3. In later studies, Score 4 was not used as it occurred so infrequently that Scores 3 and 4 were combined.

Plumage damage was assessed at four body areas:

- left and right wings
- left and right thighs
- head
- tail.

Damage to the thigh did not involve bleeding but removal of the fine feathers under the wing tip. Care was taken to differentiate between feather removal and when the feathers had been matted with blood but not removed.
Back damage

In the study reported in Chapter 8, feather damage to the back area was extensive. This had not been seen in the earlier FP studies. The feather damage to the back was evaluated using the following scoring system:

- Score 0: No damage observed
- Score 1: Evidence that feathers had been removed but the area affected was minimal (<2 cm in diameter)
- Score 2: Evidence that feathers had been removed with the area being 2–5 cm in diameter with no skin damage
- Score 3: The area of the back is heavily denuded but there is no skin damage
- Score 4: The area of the back is completely denuded and there is skin damage with blood
- Score 5: More extensive feather loss and greater blood loss.
Chapter 1: Background

1.1 The Australian duck industry

Ducks account for around 5% of the world’s poultry production, with >85% of this being in Asia (Michael 2004). Duck production in Australia has expanded rapidly, increasing by about 60% over 2005–2010, and was worth in excess of $100 million in 2010, with 8 million ducks produced annually (Brown 2010). It is estimated that this production level has increased by a further 10–15% since 2010 (PEPE’s Pty Ltd, personal communication). Eighty-five percent of the Australian production is controlled by two vertically integrated companies (Michael 2001): the NSW-based PEPE’S Ducks Pty Ltd, and Luv-a-Duck, located in Victoria.

In Australia, around 75% of the duck production is for the whole bird market, catering for Asian barbecue shops, restaurants and butchers (Brown 2010). While the present focus is on meeting domestic demand, there is an increasing world demand, and the opportunity exists to develop export markets in the future (Tilman et al. 2002). Most world demand is from developing South East Asian countries including China, Thailand, Vietnam and Bangladesh (Michael 2001). Recently Luv-a-Duck has started supplying a local retail supermarket chain with ‘cut-up’ portions. The consumer specification for the whole carcass market is for a bird grown to a liveweight of 2.85 kg at processing (42 days) and having a high breast muscle yield, the correct amount of fat content, and good skin roasting quality. While past emphasis has been on achieving good performance, the significance of bird welfare has gained prominence in recent years, and is now a paramount consideration for industry sustainability.

All domestic duck breeds used for commercial production have originated from the wild mallard. The Pekin duck (*Anas domesticus*) is the preferred breed for meat production in the Australian industry (Brown 2010). It has high growth rates and lower FP tendencies compared to Muscovy and Mule ducks (Rodenburg et al. 2005). The Pekin breed has low mortality and this is attributed to the high level of disease resistance (Nowland 2004). Two strains, the GF (of French origin) and CV (of English origin), predominate in the Australian industry. The selection pressure placed on each of these strains is the most likely reason for the divergence in FP behaviour.

Conventional broiler sheds are the prominent type of housing being used for growing ducks in Australia (Figures 1.1 and 1.2). These facilities were originally used for broiler production but because of the limited environmental control, the efficiency possible is not comparable to that of the modern tunnel ventilated sheds now prominent in the broiler industry. A solution has been for these producers to commit their sheds to duck production. The limited environmental control can create problems in summer under Australian conditions. The Pekin strains used in the Australian industry have been developed in Europe and this probably has not helped the birds cope during the higher summer temperatures experienced in Australia. In the warm summer months, it can take birds 4–6 days longer to reach market weight compared to production in winter (Downing 2010). This is a financial cost to the industry but also a welfare concern for the birds, as they can experience heat stress (HS) during periods of high ambient temperature.

FP is a problem in the duck industry, causing feather damage, carcass injuries and difficulties with removing the feathers at processing. FP is predominantly a winter problem, and is estimated to account for 1–2% of production loss at the farm gate, and a further 1–2% loss during processing, due to the increased difficulty of feather removal and skin damage to the carcass (PEPE’S Pty Ltd, personal communication). With an annual turnover in excess of $100 million, FP is costing the industry around $2 million each year. It also is a welfare issue for the birds themselves. There is a need to understand what are the predisposing factors causing FP, and to develop strategies to alleviate it as a welfare issue and financial constraint on the industry.
Figure 1.1. The type of conventional housing used for production of ducks in Australia (the brooding phase)

Figure 1.2. The type of conventional housing used for production of ducks in Australia (the finishing phase)

For quality control, and to prevent carcass contamination, ducks are taken off feed at least three hours before farm pick-up, and do not have access to water from the time of on-farm pick-up. Transport is stressful and this is especially so during periods of high temperature. Lack of access to water and the transport stress causes the birds to dehydrate. This water loss has important effects; it causes physiological stress, it adds to the loss in carcass weight during processing and it increases the difficulty of feather removal during processing. There is a need to investigate the rate of water loss in birds from the on-farm pick-up until processing, and identify potential ways of maximising bird hydration prior to pick-up and during transport to the processing plant and lairage.
1.2. Heat stress

Stress is a condition that places an animal in a state where its biological response mechanisms attempt to re-establish homeostasis and if these systems are inadequate, predisposes the animal to pathological states that impinge upon its wellbeing. Major perturbations in homeostasis require adjustments by the bird to re-establish normality. This is done through an integration of the nervous and endocrine systems, resulting in a combination of behavioural and physiological responses. If the changes can be made readily the process is acclimation, if they are long term and permanent, the process is acclimatisation, and when the changes are irreversible, adaptation occurs.

The conditions or factors initiating the stress response in ducks are often referred to as stressors. In the initial phase, the stressor initiates the release of adrenaline and noradrenaline from the adrenal gland, and these support the ‘fight or flight response’ which requires the rapid release of glucose. Following this, corticosterone is released from the adrenal gland and supports the synthesis of glucose from protein and energy reserves (Puron et al. 1994). The adaptation to stress requires diversion of energy and protein reserves away from growth and reproduction to the re-establishment of homeostasis (Puron et al. 1994; McKee et al. 1997).

Poultry are homeotherms and need to maintain their core body temperature (BT) within narrow limits (Etches et al. 1995). Environmental temperature can be a stressor of poultry (Wilson 1948; Reece et al. 1972; Sykes and Fataftah 1986; Geraert et al. 1996; Rosa et al. 2007).

1.2.1. The concept of the thermoneutral zone

For best performance, birds need to be in a state of zero net energy balance, where the energy input and output from the body is equal. The energy involved in metabolism and that associated with high ambient temperature are major contributing inputs, while body maintenance and low environmental temperature are major contributors to the energy output (Etches et al. 1995).

The thermal comfort zone is the range of ambient temperature where the animal can maintain its BT within the normal range. It is essentially that range of temperature where energy input into the body is equal to the energy output (Ahmad and Sarwar 2006). To maintain a nearly constant BT while being exposed to a wide range of ambient temperatures, birds use behavioural, physiological and metabolic functions in a process referred to as thermoregulation (Kadono and Besch 1978; Arieli et al. 1980; Meltzer 1983). While birds can survive outside the thermoneutral zone, this comes at a cost, because they use metabolic energy (Mitchell 2005) to increase BT when ambient temperature is low or to pant to lower BT when ambient temperature is high. While the thermal comfort zone will vary depending on age, genotype, RH and especially weight, in general terms it is 20–22°C for ducks over three weeks of age.

The effects of HS depend on the temperature and RH, the duration of exposure, genetics and age (Lin et al. 2006). At moderate temperatures (23–28°C), birds can easily dissipate heat by radiation, conduction and convection (sensible heat loss), because the difference between the surrounding air and BT (41°C) is large (Ahmad and Sarwar 2006). These behavioural modifications come at the least energy cost to the bird. They become less active (McFarlane et al. 1989), eat less feed and consume more water (Donkoh 1989; Cooper and Washburn 1998; Deeb and Cahaner 2001; Rosa et al. 2007).

At temperatures above 29°C, the difference between the surrounding air and the BT is smaller, reducing the sensible heat loss. Changes in the pattern of blood flow divert it away from internal organs to tissues involved in heat dissipation, such as unfeathered parts of the body: skin, peripheries, the trachea and the larynx (Wolfenson et al. 1981). At this point, birds start to pant in an effort to lose heat via evaporation (insensible heat loss). Under such conditions, high RH can hinder heat dissipation by impairing the process of evaporative cooling. At temperatures of 28, 32 and 35°C and RH ranging from 40–75%, maximum body weight gain and feed intake were obtained when the RH was 60–65% (Yahav et al. 1995; Yahav 2000).
1.2.2. Effect of heat stress on meat bird performance

The broiler industry has managed HS by using housing design, with ventilation and cooling systems to reduce mortality and maintain performance during summer. However, there still remain climates where the ambient temperature can rise to a level where the design of the housing facilities is not adequate to limit the temperature from rising about the critical value. Heatwave conditions are still a concern in many parts of Australia.

The thermal comfort zone for poultry declines as the bird ages and liveweight increases. HS is not a concern for broiler producers when birds are small (<four weeks of age). Heavier birds have less surface area for heat dissipation per unit weight (Teeter and Belay 1996), and need to dissipate much larger amounts of metabolic heat (Gous and Morris 2005).

In an attempt to control BT during periods of high ambient temperature, birds decrease their feed intake to reduce metabolic heat production (Donkoh 1989). Increased BT is negatively correlated with feed intake, body weight gain and feed efficiency (Cooper and Washburn 1998). When the range in temperature was 38°C maximum and 27°C minimum, there was a 23% reduction in liveweight and 15% decrease in the feed intake of broilers (Yalcin et al. 1997). The difference in feed intake when broilers were kept at 27.6°C or 21.1°C was 7–14% (Suk and Washburn 1995). Exposure to high temperature decreased feed intake by 3.4% for each degree increase in temperature from 21°C to 34°C in fast growing broilers (Lu et al. 2007). When three to seven-week-old broilers were exposed to ambient temperatures of 25°C, 30°C and 35°C, and compared to broilers reared at 20°C, the liveweight was reduced by 1.6, 21.6, and 32.4% for birds reared at the respective temperatures of 25°C, 30°C and 35°C (Donkoh 1989). Mitchell and Carlisle (1992) reported a 29% reduction in feed intake and 37% reduction in growth rate when broilers were exposed to 35°C from two to four weeks of age, compared to birds at 22°C. Exposing 28-day-old male broilers to high temperature (30°C) for two weeks reduced body weight by 13% and feed intake by 21% (Garriga et al. 2006). In a paired feeding experiment Geraert et al. (1996) found that about half of the reduction in broiler growth rate during exposure to high temperature was related to the reduction in feed intake but that there were also other factors acting to depress growth rate. Energy is needed to maintain homeostasis during HS and this limits the energy available for growth.

The adverse effects triggered by exposing broiler chickens to constant high temperature are more severe than exposing them to cyclic HS. Under cyclic HS conditions, during the cooler period of the day birds have the opportunity to dissipate heat, consume more feed and compensate for losses in body weight gain (Lagana et al. 2007; Ribeiro et al. 2001). The effects of thermoneutral temperature (22°C), a cyclic pattern of moderate temperature (28°C–22°C) and a constant high temperature of 34°C on performance from three to seven weeks of age were investigated by Aksit et al. (2006). Compared to the birds at thermoneutral temperature, birds at the constantly high temperature had decreased LWG at four to seven weeks of age. The cyclic temperature had no effect on LWG at four and five weeks of age but had an effect at later ages. At the end of the grow-out period, the loss in body weight was twice as great for the birds at 34°C compared to those experiencing the cyclic high temperature. Exposing broilers to cyclic temperatures of 24–35°C for three days before exposing them to extremely high temperature (40°C) helped improve their survivability, with mortality being reduced from 33% to zero (Reece et al. 1972). Henken et al. (1982) subjected broilers to constant temperatures of 25°C and 35°C or cyclic temperatures of 30–40°C. Feed intake was reduced by 15.9% and LWG reduced 12.9% at 35°C, and under cyclic temperature (30–40°C) feed intake was reduced 14.9% and LWG reduced by 12.5% compared to that seen at 25°C.

High ambient temperature triggers morphological and physiological changes to the gastrointestinal tract (GIT). Broilers exposed to high ambient temperature (35°C) for 14 days had reduced villus mass and dry weight per unit length of the jejunum when compared to thermoneutral control birds (Mitchell and Carlisle 1992). Reductions in villus and small intestine size decrease intestinal mucosal surface and this might negatively affect the functional capacity of the gut. These changes are not attributed to reduction in feed intake, but to other factors during HS (Garriga et al. 2006). Exposure to HS reduces
intestinal tract motility (Tur and Rial 1985) and blood flow (Wolfenson et al. 1981), decreasing nutrients and oxygen supply to the gut.

1.2.3. Acid-base homeostasis

Electrolytes are compounds that dissolve in fluids to yield cations (positive ionic charge) and anions (negation ionic charge), and are capable of conducting and electrical current. The ability of cations and anions to neutralise OH⁻ and H⁺ ions is expressed in millequivalents (mEq). In poultry, the main cations are sodium (Na⁺), potassium (K⁺), calcium (Ca²⁺) and magnesium (Mg²⁺), while the main anions are chloride (Cl⁻), phosphate (PO₄³⁻), sulphate (SO₄²⁻) and bicarbonate (HCO₃⁻). Further contributions to the electrolyte environment are made by the production of H⁺ ions derived from organic acids generated during metabolism and the reserve of body anions. Body water is the main fluid and along with these electrolytes functions to maintain the acid-base balance and osmotic pressure of the body.

In body fluids, the hydrogen ion (H⁺) concentration needs to be maintained within a narrow range. This is done by buffering systems that prevent immediate shifts in blood pH. A buffering system consists of a weak acid that provides H⁺, lowering the pH, and a base (salt of the acid) which accepts H⁺ ions, increasing the pH. While the buffer cannot remove H⁺ ions from the body, it acts to limit the concentrations of free H⁺ ions. Excess H⁺ ions need to be removed by the kidney. The bicarbonate (NaHCO₃ + carbonic acid) system is the main extracellular buffer in the body and the phosphate system, (NaH₂PO₄ + Na₂HPO₄), the main intracellular buffer. If the blood becomes acidic (low pH), the base component of the bicarbonate buffer accepts H⁺ ions and the ratio of acid to base will increase, and the pH will increase towards the normal range. When the blood pH shifts towards the alkaline range, the acid donates protons so that the ratio of the acid to base will decrease and the pH will shift back to normal (Carlson 1997). This system is described by the following equation:

\[ \text{HCO}_3^- + \text{H}^+ \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{CO}_2 + \text{H}_2\text{O} \] (Equation 1)

This equation identifies what will happen during HS when the respiration rate increases. The lungs and kidneys play a primary role in the regulation of HCO₃⁻, CO₂ and H⁺ concentrations in the blood. If the rate of CO₂ clearance from the blood increases then the partial pressure of CO₂ (pCO₂) is reduced. The influence of the relationship between HCO₃⁻ and pCO₂ on the blood pH is given by the Henderson-Hasselbach equation:

\[ \text{pH} = 6.1 + \left[ \log \frac{\text{HCO}_3^-}{0.03 \times \text{pCO}_2} \right] \] (Equation 2)

The normal ratio of HCO₃⁻:pCO₂ is around 30:1, resulting in a normal pH of 7.4. As the pCO₂ decreases, the relative concentration of HCO₃⁻ increases. The free H⁺ ions are removed (Equation 1) from the blood by the kidney, leading to a relatively higher HCO₃⁻ concentration and an increased blood pH, and eventually respiratory alkalosis (Carlson 1997; reviewed in Ahmad and Sarwar 2006). Now that the blood acid-base balance is not in equilibrium, physiological mechanisms are initiated to re-establish homeostasis. Once the blood shifts to alkalosis, the kidney excretes excess base (HCO₃⁻) to shift the blood pH back to normal (Ahmad et al. 2008). As the depletion of HCO₃⁻ increases there is renal re-absorption of chloride ions (Cl⁻) which increases blood Cl⁻ as a likely mechanism to limit H⁺ excretion (AitBoulahsen et al. 1989). Continuous depletion of HCO₃⁻ ions, along with renal Cl⁻ re-absorption as a metabolic compensation for blood alkalosis can lead to extracellular fluid acidification, because high concentrations of H⁺ are retained (Borges et al. 2007). Metabolic acidosis may result in H⁺ entering the cells and replacing K⁺, leading to increased plasma K⁺ concentrations (hyperkalemia) and then increased renal K⁺ excretion (Hoskote et al. 2008). An increase in blood Na⁺ concentrations during summer has been reported, although this increase could be due to hemodilution (AitBoulahsen et al. 1989). Others have reported a decrease in plasma Na⁺ during HS (Belay and Teeter 1993; AitBoulahsen et al. 1995; Borges et al. 2004a). There is increased excretion of the electrolytes K⁺ and Na⁺ in urine and faeces in broiler chickens exposed to high ambient temperatures (Belay et al. 1992; Belay and Teeter 1996). The changes in systemic pH in response to HS are complex, involving an
initial respiratory response phase, which can produce a systemic alkalosis and then a compensatory phase which can produce systemic acidosis. Any attempts to use dietary intervention during HS must be aware of these cascading events.

To maintain acid-base homeostasis the bird needs to balance the input and output of acid (Mongin 1981). The balance is achieved by:

\[(\text{cation-anion})_{\text{intake}} + H^+_{\text{endogenous}} (\text{cation-anion})_{\text{excretion}} + \text{BE} = \text{zero}\]

Where $H^+_{\text{endogenous}}$ is the endogenous production of acid, mainly derived from organic acids during protein metabolism, and BE is the base excess reserve in the body. The balance of cation-anion intake is equal to the mEq of $(Na^+ + K^+ + Ca^{2+} + Mg^{2+})$ less the mEq $(Cl^- + SO_4^{2-} + H_2PO_4^- + HPO_4^-)$. The explanation for this relationship is discussed and well documented in the review of Ahmad and Sarwar (2006).

1.2.4. Maintaining water balance

In addition to regulating acid-base balance, electrolytes are essential in maintaining osmotic pressure and the electrical potential of cell membranes (Borges et al. 2003a). To maintain homeostasis, growing birds need to have a positive water balance. Water consumption depends on the bird age and the $Na^+:K^+:Cl^-$ ratio in the feed (Borges 1997; Borges, 2001). Heat stressed poultry increase urine output by more than 60% (Belay and Teeter 1993). At 38°C, water intake was four times greater than at 21°C in broilers (North and Bell 1990). The higher consumption of water during HS helps the birds avoid dehydration (Zhou et al. 1999), with the increased water acting as heat sink, helping to increase the heat dissipated during respiration (Teeter and Smith 1987; Belay and Teeter 1993).

The change in blood flow away from internal organs to the periphery (Wolfenson et al. 1981) can cause dehydration, hypoxia and increased osmotic pressure in the cells of the internal organs, especially those lining the GIT (Cronje 2007). Extreme osmotic pressure can cause the cells lining the gut to contract, impairing the tight junction between them, and reducing this as a barrier against enteropathogens (Cronje 2007). This could reduce nutrient absorption and metabolism and allow the entry of pathogens and toxins (Cronje 2007). The loss of intracellular ions, especially $K^+$, will inhibit the cell’s capacity to retain water in face of the changing osmotic gradient. With water shifting to the extracellular compartment, the cells will shrink. Smith and Teeter (1987) reported a 27% increase in $K^+$ excretion when broilers were at 35°C compared to thermoneutral temperature.

In an environment of high osmotic pressure, cells use ion pumps and water channels to control the movement of ions and water (Rao 2004). However, this requires energy (Moeckel et al. 2002), and so less energy is available for growth and production. Under hypertonic conditions, cells increase their ionic strength (especially $K^+$, $Na^+$ and $Cl^-$) in an effort to prevent water movement out of the cell (Strange 2004). A high ionic concentration can be detrimental to cellular proteins and enzymes. This is why cells internalise organic osmolytes (i.e., betaine, sorbitol and inositol), to prevent water flux without harming the cellular macromolecules (Strange 2004). However, this is a slow process compared with inorganic ion uptake, as it requires up regulation of osmoprotectant genes and synthesis of organic osmolyte transporters (Strange 2004). This delay indicates that osmolytes, like betaine, need to be supplemented for a period before the birds are heat stressed if they are to be effective.

1.3. Strategies to alleviate heat stress

1.3.1. Dietary electrolyte balance

The acid and base intake, the balance between them, the environment, and the interactions between these will influence poultry performance (reviewed in Ahmad and Sarwar 2006). Diets high in $Cl^-$ will lower blood pH and cause acidosis, while those high in $Na^+$ and $K^+$ will increase pH and cause alkalemia (Cohen and Hurwitz 1974). The best growth rate is achieved in broilers when the blood pH is 7.28, and is inhibited when outside the range of 7.2–7.3 (Hurwitz 1973). As stated previously, the
Main cations are sodium (Na\(^+\)), potassium (K\(^+\)), calcium (Ca\(^{2+}\)) and magnesium (Mg\(^{2+}\)), while the main anions are chloride (Cl\(^-\)), phosphate (PO\(_4\)\(^{3-}\)), sulphate SO\(_4\)\(^{2-}\) and bicarbonate (HCO\(_3\)\(^-\)). The ionic concentrations of these cations and anions in the diet can be determined by:

\[
\text{mEq/kg} = (\% \text{ in the diet} \times 10,000) \times \text{valence} \div \text{atomic or formula weight in g}
\]

In real terms the DEB, measured in mEq, is equal to the sum of all contributing anion and cations. However, the main contribution comes from eight electrolytes and so Borges (2001) indicated that the DEB is equal to mEq (Na\(^+\) + K\(^+\) + Ca\(^{2+}\) + Mg\(^{2+}\)) – mEq (Cl\(^-\) + SO\(_4\)\(^{2-}\) + 2PO\(_4\)\(^{3-}\) + HPO\(_4\)\(^{-}\)). Early on Mongin (1981) identified the potential relationship between balancing the cations and anions in poultry diets and their effects on acid-base balance and consequent performance. This author reported that the monovalent ions (Na\(^+\), K\(^+\), and Cl\(^-\)) were the main components involved in the acid-base balance of body fluids and determined the DEB as:

\[
\text{mEq/kg} = (\text{mEq Na}^+ + \text{mEq K}^+) - \text{mEq Cl}^-
\]

Some have questioned the limitations of this equation because it neglects other cation and anion contributions (Reviewed in Ahmad and Sarwar 2006). It is accepted in diet formulation for practical reasons, and because these three ions have such an influence on acid-base homeostasis. Using this equation, it is clear that a specified DEB can be achieved with a range of Na\(^+\) + K\(^+\) and Cl\(^-\) concentrations. To maintain optimum performance there are limitations to the total concentrations of these different ions in the diet (Mongin 1981). Excesses of Na\(^+\) or Cl\(^-\) will be detrimental to performance, with birds tolerating excess K\(^+\) better than they do excess Na\(^+\) (Nesheim et al. 1964).

At moderate ambient temperatures, water intake and litter moisture tended to increase linearly when DEB increased through 40, 140, 240 and 340 mEq (Borges et al. 2004b). During cyclic HS (22.5±3.5°C for 14 h and 32±2°C for 10 h), water intake increased by 22.5% but there was no effect of the DEB (140, 240, and 360) on water intake or excreta water content (Borges et al. 2004a). For each 0.1% increase in dietary mineral content (Na, K and P), excreta moisture increased by 0.9±0.2 % for Na, 1.2±0.2% for K and 0.56±0.2% for P (Smith et al. 2000). Mongin (1981) found that litter moisture increased as dietary Na\(^+\) and K\(^+\) increased but a higher Cl\(^-\) content had no effect.

### 1.3.1.1. Dietary electrolyte balance and performance

Mongin (1981) identified that a DEB (Na\(^+\) + K\(^+\) − Cl\(^-\)) of 250 mEq/kg would maintain acid-base balance and achieve optimal performance in broilers. Borges et al. (2003a) reported that at thermoneutral temperature, broiler performance was better when the DEB was 240 mEq/kg compared to when it was 40 and 340 mEq/kg. However, in that particular study the DEB failed to influence performance when the broilers were exposed to high ambient temperature. Further work by Borges et al. (2004a) found that a DEB of 240 mEq/kg increased Na\(^+\) and K\(^+\) retention and water consumption under both thermoneutral and high temperatures better than if the DEB was 140 or 340 mEq/kg. Under summer conditions (31°C maximum, 23°C minimum and RH 75.5%), best performance was achieved at 240mEq/kg compared to 0, 120 and 360 mEq/kg (Borges et al. 2003b). Under tropical conditions, performance of broilers was poorer when fed diets with a DEB of 0 and 350 mEq/kg, compared to when the DEB was 50, 150 and 250 mEq/kg (Ahmad et al. 2008). The diet with a DEB of 350 mEq/kg was associated with metabolic alkalosis (high blood HCO\(_3\)\(^-\) concentrations) and the diet with a DEB of 0 mEq/kg was associated with metabolic acidosis (increased blood Cl\(^-\) concentrations). Johnson and Karunajeewa (1985) fed broiler diets ranging in DEB from −29 to 553 mEq/kg. Growth was depressed when the DEB was outside the range of 180–300 mEq/kg. The optimum DEB range was reported to be 250–300 mEq/kg.

At high temperatures (25–35°C), a diet with DEB of 350 mEq/kg was recommended for broilers compared to one with a DEB of 250 mEq/kg, which was found to be suitable when the temperature was 18–26°C (Fixter et al. 1987). Sodium bicarbonate (NaHCO\(_3\)) has been added to poultry diets to improve performance during periods of high temperature. Adding 0.5 and 1.0% NaHCO\(_3\) to broiler diets when they were exposed to high temperature (39–41°C and 34–36°C) increased feed intake and
LWG and lowered feed to gain (Fisher da Silvia et al. 1994). The dietary inclusion of 0.5% NaHCO₃ was found to have no effect on blood alkalosis by Teeter et al. (1985). DEBs of 140, 240 and 360 mEq/kg had no effect on feed intake and LWG or nitrogen balance when fed to colostomised broilers exposed to a cyclic temperature of 22.5±3.5°C for 14 h and 32±2°C for 10 h (Borges et al. 2004b). These workers recommended that in pre-starter diets, a suitable range for dietary sodium was 0.15–0.6%, potassium 0.98–1.21% and chloride 0.15–0.71%. The LWG was improved by increasing DEB from 180 to 344 mEq/kg using Na⁺ as the cation, while the same increase in DEB using K⁺ depressed growth. Optimum growth was obtained when the Na⁺:K⁺ ratio in the diet ranged from 0.5 to 1.8. These authors concluded that the relative amounts of Na⁺ and K⁺ in the diet are important factors determining growth (Johnson and Karunajeewa 1985). North and Bell (1990) found that compared to a temperature of 21°C, at six weeks of age, the LWG of broilers was 14.3% and 21.2% lower when the ambient temperature was 32.2°C and 37.8°C, respectively. Similarly, Cheng et al. (1997) found that LWG was 34% less at 32.2°C compared to 21°C.

Ahmad et al. (2005) investigated the effects of supplementing the starter and finisher diets with various Na⁺ and K⁺ salts (NaHCO₃, Na₂CO₃, Na₂SO₄, KHCO₃, K₂CO₃ and K₂SO₄) at an identical DEB of 250 mEq/kg on the performance of heat stressed broilers. Superior performance was recorded in broilers fed diets with Na⁺ supplements in comparison to diets supplemented with K⁺ salts. These findings demonstrate the potential effects that individual cations have on growth performance. Borges et al. (1999) manipulated the sodium and chloride concentrations in pre-starter diets and found best performance was achieved when the DEB was 199 mEq/kg. When the Na⁺ content was varied, a DEB of 250 mEq gave the best performance but when the K⁺ content was varied the ideal DEB was 315 mEq (Rondon et al. 2001). For 21–42 day old broilers, highest feed intake was achieved at a DEB of 264 mEq/kg when Na⁺ was increased in the diet but 213 mEq/kg when both Na⁺ and K⁺ were increased (Borges et al. 2004b). Gorman and Balnave (1994) were able to achieve better results by supplementing heat stressed broilers with NaHCO₃ than Na₂CO₃. Using 0.5% NaHCO₃ in broiler diets during summer reduced the time to achieve market weight by two days (Benton et al. 1998). Using NaHCO₃ in preference to KHCO₃ gave better feed to gain when birds were maintained at 31°C (Hayat et al. 1999). Hulan et al. (1987) studied the effect of different DEB and calcium concentrations in broiler diets and found best performance at a DEB of 174 mEq with 1.38% calcium and a DEB of 215 mEq at 0.95% calcium.

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**1.3.2. Electrolyte supplementation of drinking water**

Supplementation of poultry feed and/or water with electrolytes is a strategy used to combat the effects of HS. The electrolytes commonly added to broiler diets include salts of sodium and potassium such as sodium chloride (NaCl), sodium carbonate (Na₂CO₃), sodium bicarbonate (NaHCO₃), potassium chloride (KCl), potassium carbonate (K₂CO₃) and potassium bicarbonate (KHCO₃).

When supplementing drinking water with electrolytes, it should be remembered that during periods of high temperature, water intake is increased (Zhou et al. 1999; Ahmad et al. 2005). This needs to be considered when trying to determine the correct concentrations of electrolytes to use. Too high a sodium intake is associated with anorexia, and can cause high mortality in broiler chickens. Mortality rates as high as 90% have been reported when broilers were supplemented with NaHCO₃ at the rate of 10 g/L in water (Hayat et al. 1999). Similarly, high mortality rates have been reported when 7–10 g/L of NaCl are added to drinking water (Krista et al. 1961; Sibbald et al. 1962).

The addition of NaCl, K₂SO₄ and KCl to the drinking water of broilers helps to alleviate the adverse effects of HS (Smith and Teeter 1989). Intermittent (12 h daily), supplementation of water with KCl (2 g/L) during cyclic high temperature (26.8–36°C) tended to increase growth rate, but continuous supplementation gave a better response (Smith and Teeter 1992). Under cyclic high temperature conditions, the addition 3.76 g/L of NaCl to the drinking water gave better LWG than did supplementation with 4.8 g/L KCl, which was better than providing water only (Smith 1994). Under a similar range of cyclic temperature, water supplementation with KCl alone and in combination with NH₄Cl or CO₂ improved growth rate and feed intake (Smith and Teeter 1993). Ross (1979) reported a
greater effect of supplementing Na\(^+\) in the water compared to the equivalent intake when provided in the feed. Under hot (30–41°C) and humid (45–93% RH) conditions, NaHCO\(_3\) (2 g/kg) not only improved performance, but importantly, decreased mortality from the 33% seen in the control treatment to 6.6% (Khattak et al. 2012). Farfan et al. (2011) supplied 28- to 35-day-old (Phase 1) broilers with electrolytes (NaHCO\(_3\), 0.82%; NH_4Cl, 0.7%; NaCl 0.3%; DEB 240 mEq) in water and feed during cyclic HS (26–32°C) and then a high temperature challenge (36°C) on Day 36 (Phase 2). In Phase 1, performance was not improved by using electrolytes but the water intake and rectal temperature were lower when electrolytes were given in the water. In Phase 2, the electrolytes in water decreased the respiratory rate, and most importantly, mortality by 22%. During extreme HS, the electrolyte benefits are only achieved if supplied in the water, because the birds will not eat at these high temperatures.

When electrolytes are used, the alkaline or acidic nature of the salts needs to be considered. When birds experience panting-induced alkalosis, supplementation with NH_4Cl helps to reduce blood pH, but if used in excess, it will lead to acidosis (Teeter et al. 1985). Supplementing drinking water with 0.52% KCl plus 0.137% NH_4Cl improved LWG and feed efficiency in broilers exposed to cyclic high temperature (26.6–36.7°C). Increasing the NH_4Cl concentrations to 0.274% in combination with 0.52% KCl failed to have any effect on performance when compared to the control treatment (Smith and Teeter 1993). Under high ambient temperatures, providing NaHCO\(_3\) in feed or drinking water is reported to improve broiler performance and survivability (Balnave and Gorman 1993; Hayat et al. 1999; Mushtaq et al. 2005; Ahmad et al. 2006). The favourable effects of NaHCO\(_3\) supplementation on performance might be associated with increased water intake, decreased BT, and/or replenishing depleted HCO\(_3\)\(^-\) ion concentrations (Balnave and Gorman 1993). Nevertheless, the inclusion of NaHCO\(_3\) at high levels in panting broilers can result in metabolic alkalosis (Hayat et al. 1999). The use of sodium bicarbonate in combination with NH_4Cl to adjust acid-base balance during periods of high temperature could be a safer strategy for adjusting blood pH and removing any acidification which develops. Bicarbonate can combine with excess H\(^+\) to form carbonic acid which is then converted to carbon dioxide and water by the action of carbonic anhydrase. This acts to restore blood pH when acidosis occurs.

### 1.3.3. Vitamin C

Vitamin C (ascorbic acid) has a role in redox homeostasis as one of several interlinked antioxidants. It has an essential role in vitamin E regeneration (Jacob 1995). Vitamin C is not considered an essential nutrient in poultry, because poultry possess the enzyme L-gulonolactone oxidase, which supports the synthesis of ascorbic acid in the liver (Whitehead and Keller 2003). The rate of vitamin C synthesis in heart, liver and pectoral muscles increases throughout the first two months of growth, yet in some unfavourable situations this may be insufficient (Nagorna-Stasiak 2001). Vitamin C concentrations in plasma and the liver were lower in heat stressed laying hens (Sahin et al. 2002). It has been recommended that poultry be supplemented with vitamin C during periods of HS, as absorption and the rate of synthesis might not be sufficient to meet requirements (Klasing 1998; Gous and Morris 2005; Lin et al. 2006). Because feed intake is reduced during HS, the provision of vitamin C in water at this time could be beneficial to poultry (McKee et al. 1997).

Mule ducks were fed starter (0–3 weeks) and grower (4–11 weeks) diets supplemented with vitamin C, at rates ranging from 0 to 300 mg/kg (Lai et al. 2003). During Weeks 0–3, the performance of males was not affected, but there were effects on the performance of the females. In the grower period the LWG responses were inconsistent but no effects were reported for feed intake, feed to gain or carcass traits. At moderate temperatures vitamin C supplementation might not be needed. The amount of vitamin C required for the antioxidant and performance benefits might also be age-dependent. When ducks were fed vitamin C supplemented diets (0, 150, 300, 400, 800 and 1400 mg/kg), from day old for four weeks (Xie et al. 2008) the LWG, feed to gain, and oxidative capacity increased as the rate of vitamin C supplementation increased. The vitamin C concentrations resulting in highest antioxidative status was 1,400 mg/kg at Day 5 of age but were lower at Day 28, being 300–400 mg/kg. This probably reflects the greater capacity of older birds to synthesis vitamin C.
Under hot (30–41°C) and humid (45–93% RH) conditions, broilers provided feed supplemented with vitamin C had as good total LWG and feed to gain as birds given feed supplemented with vitamin E, betaine or NaHCO₃, and all supplemented feeds gave better results than the control unsupplemented diet (Khattak et al. 2012). The mortality was 33% for the control birds, but lower for vitamin E (23%) and vitamin C (16%) supplemented birds. The performance and carcass quality of quail were better during HS (32°C) when supplemented with 250 mg/kg of vitamin C in the feed (Sahin and Kucuk 2001). A similar rate of supplementation to slow-growing broilers reversed some of the negative effects HS had on feed intake, protein digestibility and feed efficiency (Attia et al. 2009). Better LWG and feed intake were reported when quail were given 200 mg/kg vitamin C during exposure to high temperature (34°C). Similar benefits were reported in heat stressed broilers given 200 mg/kg vitamin C (Njoku 1986). Broilers exposed to 36°C had better performance when provided with 250 mg/kg vitamin C in the diet (Kutlu and Forbes 1993). Benefits were also seen when broilers were exposed to 42°C using the same vitamin C supplementation rate (Elkheir et al. 2008). Supplementation of water with 20–35 mg/L of vitamin C improved feed to gain and LWG in broilers exposed to high temperature (Blaha and Kang 1997).

HS decreases nutrient digestibility and the activity of some key enzymes (Bonnet et al. 1997; Hai et al. 2000) and inhibits immunity (Lebman and Coffman 1998; Mashaly et al. 2004). Ciftci et al. (2005) inferred that for laying hens under HS, vitamin C could act to prevent oxidative denaturing of digestive enzymes. When the diet of heat stressed (34°C) quail were supplemented with dietary vitamin C the digestibility of major nutrients were improved (Sahin and Kucuk 2001). Similar improvements were seen for laying hens at low temperature (Sahin and Sahin 2001). The involvement of vitamin C in feed digestibility could be related to the fact that it is synthesis in the wall of the GIT (Lechowski and Nagorna-Stasiak 1995).

Vitamin C has a role in enhancing immune function (Bendich 1990; Wu et al. 2000). During HS, the heterophil to lymphocyte ratio (H/L) is higher, indicating changes in immune function (McFarlane and Curtis 1989; Mashaly et al. 2004). Immunological responses to purified sheep red blood cells (SRBC) have often been used as an experimental challenge to measure immune status in poultry (Khan et al. 2012). At 250 mg/kg of vitamin C in the diet, the immunological response of slow-growing broilers to SRBC were improved (Attia et al. 2006). During HS (35°C), vitamin C at1,000 mg/L in the drinking water acted in synergy with vitamin E to enhance the in vitro lymphocyte proliferative response of laying hens (Puthponsiriporn et al. 2001).

1.3.4. Feed withdrawal

The metabolic heat produced from food digestion adds significantly to the heat load of fast-growing meat birds. Feed withdrawal for part of the day decreases heat production and mortality in HS broilers (Francis et al. 1991). Feed withdrawal for two hours before exposure to high temperature improved feed to gain and decreased mortality in broilers (Yalcin et al. 2001). During the summer period, feed withdrawal between 10:00 and 16:00 h in Weeks 5 and 6 of age resulted in a lower LWG and BT in Week 5, but had no effect in Week 6 when compared to control birds (Ozkan et al. 2003). The higher feed intake in six-week-old broilers might allow these birds to consume sufficient feed during the cooler period of the day and help compensate for the absence of feed during the high temperature period. Feed withdrawal during the hottest part of the day (09:00-16:00 h) under tropical conditions (28–42°C) lowered BT but reduced growth and resulted in poorer feed to gain (Lozano et al. 2006). So the concern with feed withdrawal as a strategy to combat HS is whether the birds can compensate when the feed is available. This probably will depend on the temperature during the period when feed is available. It is a strategy that is more likely to work during periods of cyclic high temperature.
1.4. Betaine use in poultry

1.4.1. Role in metabolism

Betaine is the trimethyl derivative of glycine, capable of acting as a methyl donor and acceptor (Kidd et al. 1997). Methyl metabolism is involved in the synthesis of creatine, methyl purines, adrenaline and methylated amino acids (reviewed in Mahmoudnia and Madani 2012). Vertebrates cannot synthesis methyl groups and so choline, methionine, folic acid and betaine are used as sources (Kidd et al. 1997). Because they have other roles, the potential for these to act as methyl donors is not equal (reviewed in Metzler-Zebeli et al. 2009).

Methionine is an essential amino acid and is routinely added to poultry diets and considered to be the first limiting amino acid in poultry diets based on maize (Saunderson and Mackinlay 1990). If methionine is lacking, the synthesis of polypeptides and proteins will be limited. When diets with 800 mg/kg betaine and ranging in protein content between 15 to 24% were fed to broilers the LWG and breast yield was improved at 21 days with betaine when the protein content was 15%, but not when the protein content was higher (Rao et al. 2011). Florou-Paneri et al. (1997) reported that betaine can be used to substitute for up to 80% of methionine in broilers diets without any significant adverse effect on body weight, mortality or carcass quality. Betaine could act to partially spare methionine by providing labile methyl groups for the synthesis of methylation products (Xu and Zhan 1998).

Contrary to the previously identified roles for betaine, there are reports indicating that betaine has no part in replacing methionine in poultry diets. Betaine supplementation to broiler methionine-deficient diets had no significant effect on LWG, feed conversion and carcass quality (except for breast muscle yield), whereas adequate methionine supplementation significantly improved these performance traits (Esteve-Garcia and Mack 2000). Similarly, McDevitt and Wallis (2000) reported that betaine failed to improve performance of broilers fed a diet deficient in methionine, while addition of betaine together with methionine improved carcass quality, especially breast muscle yield. The presence of betaine at 1 g/kg in a methionine-deficient diet improved antioxidant status; decreased lipid peroxidation of breast meat and improved the meat quality (Alirezaei et al. 2012).

Choline is synthesised by methylating phosphatidylethanolamine (Dilger et al. 2007). Birds have limited capacity to synthesise choline through this methylation reaction, which increases their choline requirements (reviewed in Metzler-Zebeli et al. 2009). In order to act as a methyl group donor, choline must be converted to betaine in the mitochondria. This interrelationship has created interest in betaine as possible substitute for choline in commercial diets to meet the animal’s methyl group requirements.

1.4.1.1. Betaine as an osmolyte

In a hypertonic environment, cells accumulate inorganic ions (i.e., K⁺ and Na⁺) in an effort to prevent water efflux. Changes in cell volume can affect anabolic or catabolic directed activities (Haussinger 1998). The problem with this is that if a high intracellular concentration of inorganic ions is maintained for too long, it can denature and inhibit the function of cellular proteins. To help avoid this, cells internalise organic osmolytes via integral membrane transport proteins (Strange 2004). Accumulation of these organic osmolytes modulates the tonicity inside the cells and prevents water flux without damage to the cellular proteins (Alfieri et al. 2002). Therefore, these osmolytes have important roles under conditions of high osmotic pressure in attempting to help maintain water balance (Klasing et al. 2002). Betaine is used as an organic osmolyte in poultry diets (Kidd et al. 1997; Klasing et al. 2002). The osmoregulatory function of betaine could be significant in conditions of excessive water loss such as during HS (Cronje 2005).

1.4.1.2. Effect of betaine on performance and carcass composition

When broilers were fed a diet high in protein but low in energy, betaine supplementation increased LWG and feed efficiency (Neto et al. 2000). However, this was not the same when the protein content was low and energy was high (17% protein and 13.82 MJ/kg) with the methionine content being the
same in control and treatment diets (Neto et al. 2000). In methionine-adequate diets, betaine supplementation had no effect on broiler performance (Pillai et al. 2006). There are other reports indicating that when betaine is added to diets having adequate methyl donor capacity there are improvements in LWG, feed to gain and carcass yield (Wallis 1999; Esteve-Garcia and Mack 2000; Zhan 2000; Attia et al. 2005; Hassan et al. 2005; Zhan et al. 2006). There are contrary reports where no beneficial effect was noted (Rostagno and Pack 1996; Pillai et al. 2006; Waldroup and Fritts 2005; Waldroup et al. 2006). Under hot (30–41°C) and humid (45–93% RH) conditions betaine (1,200 mg/kg) improved performance and decreased mortality (Khattak et al. 2012). The mortality was 33% for the control birds and lower for vitamin E (23%) and vitamin C (16%) supplemented birds, but very much lower for NAHCO₃ (6.6%) and betaine (3.3%) supplemented birds.

A reduction in body fat was observed in broilers fed diets supplemented with betaine and methionine compared with birds fed diets enriched in methionine and choline but having no betaine (Saunderson and Mackinlay 1990). In laying hens, supplementing the diet with 600 mg betaine/kg decreased abdominal fat by 19.6% and 22.3% at 50 and 70 weeks of age, respectively (Zou and Lu 2002). CV ducks were fed diets supplemented with betaine at 0, 0.5, 1.0, 1.5 and 2.0 g/kg in the starter period (Weeks 1–3) and 0, 0.25, 0.5, 0.75 and 1.0 g/kg of diet in the grower period (Weeks 4–6) (Wang 2000). In the starter phase betaine added at 0.5–1.5 g/kg increased LWG and feed intake without any effect on feed to gain. At 0.75 and 1.0 g/kg, betaine significantly increased LWG, and at 1.0 g/kg significantly decreased feed to gain in the grower period. Betaine supplementation increased the percentage of breast muscle and decreased the amount of abdominal fat. At 1.0 g/kg betaine, the amount of carnitine in liver was increased. The author concluded that betaine enhancement of carnitine concentration could act to increase the beta-oxidation of long chain fatty acids, decreasing abdominal fat and supporting protein synthesis. This conclusion was supported by earlier work in similar CV ducks. During the starter phase dietary supplementation with 800 mg/kg betaine increased lipase activity, stimulated carnitine synthesis and beta-oxidation of fatty acids (Wang et al. 1999).

In a 2x2 factorial study, females Pekin ducks were supplemented with betaine at 0 and 0.5 g/kg and DL-methionine at 0 and 1.2 g/kg (Wang et al. 2004). At 21 days birds had responded to the methionine with significant increased LWG and improved feed to gain. At this age the effect of betaine on LWG was marginally non-significant (P=0.06) but feed to gain was significantly better. At 42 days, methionine supplementation improved LWG but had no effect on feed to gain. Meanwhile betaine had no effect on feed to gain and again a marginally non-significant effect on LWG (P=0.07). At the end of the production cycle betaine increased breast weight, breast yield and reduced abdominal fat. Methionine increased breast weight but has no effect on abdominal fat (Wang et al. 2004). A 0.5% betaine supplementation in the diet of Pekin ducks was found to be mildly lipotrophic, as indicated by lower liver fatty acid content (Bernard and Demers 1949).

There could be a number of explanations for the effects betaine exerts on poultry performance. Broiler diets supplemented with 1,000 mg betaine/kg significantly increased RNA content and the RNA to DNA ratio in breast muscle cells. Betaine could be acting to support an increase in muscle cell proliferation (Zhan 2000). Betaine may increase availability of methionine, making it available for protein synthesis rather than being used as a methyl donor. Betaine has been reported to stimulate growth hormone secretion (Zhan 2000; Wang et al. 2000). Zhan (2000) suggested that the improvement in growth was due to an increase in the serum concentrations of insulin-like growth factor-1 (IGF-1). IGF-1 is a potent growth promoter in animals. In laying hens fed 600 and 1,000 mg/kg betaine, IGF-1 gene expression showed significant increases while at the same time the secretion of IGF binding protein-1 decreased (Choe et al. 2010). Creswell (2012) found that a methionine-deficient diet decreased carcass yield in broilers. Betaine (1–2.5 g/kg) increased breast meat yield of birds on the methionine-deficient diet and this increase was greater than seen for the positive control birds having adequate methionine. The addition of betaine produced lower viscera weight prompting the author to suggest that the osmolytic effect of betaine help maintained water and ion balance at a lower energy cost, enabling the lighter viscera.
In laying hens, 1,000 mg/kg of betaine in the diet decreased serum low density lipoprotein cholesterol, triglycerides and uric acid and increased lipase activity (Zou and Feng 2002). These findings indicate a role for betaine in regulation of fat metabolism. As a methyl donor, betaine could be used to support carnitine synthesis (Wang et al. 1999; Wang 2000). Carnitine is responsible for the transport of fatty acids to the mitochondria where fatty acid oxidation occurs and this role reduces lipid deposition (Eklund et al. 2005). This mechanism could help explain the redistribution of fat in betaine-supplemented birds. When 56-day-old broilers were fed 0.1% betaine in the diet, the mRNA levels for fatty acid synthase and adipocyte type acid binding protein genes in abdominal fat were significantly decreased (Xing et al. 2011). Differences in CpG methylation patterns of the promoter region of the lipoprotein lipase gene were observed, suggesting this may be the mechanism linking the betaine influences on fat metabolism.

1.4.1.3. A role for betaine in gastrointestinal tract function

A role for betaine in limiting the damage caused by coccidial invasion in poultry has been reported (Allen et al. 1998; Klasing et al. 2002). Coccidial infection leads to diarrhoea and GIT wall lesions. The cells of the GIT function in a media that may be hypertonic compared to blood. While it is not totally clear how betaine exerts its effect in limiting parasite invasion, one suggestion is that it restores the intestinal epithelial water balance and thereby enhances the bird’s resistance to coccidial proliferation (Klasing et al. 2002; Eklund et al. 2005). Kettunen et al. (2001) reported that betaine supplementation helped duodenal epithelial cells to maintain water balance under hyperosmotic conditions by reducing the water flux from the cells. Challenging broiler chickens with *Eimeria acervulina* caused a decrease in intestinal villus height, which was alleviated with betaine supplementation at 1.0 g/kg feed (Klasing et al. 2002). The role of betaine in limiting the damage of coccidial infection is confused following recent research indicating that it slightly increased *Emiera tenalla* sporozite invasion of Madin-Darby bovine kidney cells in culture (Burt et al. 2013). Other phytochemicals inhibited the initial invasion of sporozites. It might be that betaine limits the damage in the gut epithelial cells once they are invaded.

1.5. General overview of heat stress

In the thermoneutral zone there is a balance in electrolytes at which digestive and metabolic processes function at maximum efficiency. Under HS conditions this electrolyte balance is likely to be much higher to maintain the same metabolic efficiency. Maintaining the acid-base balance, increasing water intake, gut integrity and absorption of water determine the birds’ survivability and productivity under high ambient temperatures. While the use of electrolytes to regulate the acid-base balance has been extensively investigated during HS, improving gut integrity and enhancing the ability to maintain water balance under a high osmotic gradient have received less attention.

Because exposure to high ambient temperature negatively affects body electrolyte balance by increasing K⁺ and Na⁺ excretion (Belay et al. 1992; Belay and Teeter 1996) it is fair to assume that increasing dietary K⁺ and Na⁺ concentrations will increase their retention and help birds maintain their electrolyte balance as well as improve performance. This can be accomplished by feeding diets with higher DEB or providing supplements in water at concentrations that avoid creating metabolic disorders. Both electrolyte and betaine supplementation could be relevant strategies to help commercial ducks deal with HS.

1.6. Feather pecking

1.6.1. Introduction

FP is a general term used to describe the damaging behaviours directed towards the feathers of other birds. There is a decided lack of research into duck behaviour in Australian production systems, so any review of FP requires investigation of what is known in other poultry species, especially laying hens. Differences in cleaning, preening, foraging and eating could influence how relevant the research from
hens is for the duck. This lack of knowledge on FP, and its causes in commercial ducks, needs to be addressed if solutions to the problem are to be identified and implemented, thereby limiting this as cause of poorer welfare.

Savory (1995) summarised the distinction between different types of FP behaviour in laying hens. The categories used were:

1. **Aggressive pecking**: This is where a dominant bird directs a peck at a subordinate. Normally this is to the head.

2. **Pecking without feather removal**: This results in little or no damage and could be directed at food particles rather than the feathers. This is often considered as gentle FP (GFP).

3. **Pecking with potential for feather removal**: This is where the feather is grasped and pulled with force and can lead to it being removed and there is the potential to denude areas. This is often referred to as severe FP (SFP).

4. **Tissue pecking**: This is the pecking at denuded skin areas that can lead to bleeding and attract other birds to start pecking.

5. **Vent pecking**: This is probably a separate behaviour from FP. It is often directed at the vent after a minor prolapse of the uterus immediately after laying.

The detrimental effects caused by this behaviour are related to the cost of production and bird welfare. The act itself can be painful to the bird in both an acute and chronic manner, and can cause an increase in stress, fear and susceptibility to disease. In addition, it is related to an increase in feed consumption, since affected birds lose heat faster and hence use more energy, as well as reduced LWG due to the hormonal alterations caused by long-term stress (Gustafson et al. 2007; Petek and McKinstry 2010; Lambton et al. 2010). Birds from a low FP line laid more eggs and had better feed efficiency than those form a high FP line of layers (Su et al. 2006).

The motivation for GFP and SFP appear to be independent from each other, with little overlap or development of one to the other (Rodenburg et al. 2008). While SFP can lead to cannibalism (McAdie and Keeling 2000), increased mortality in laying flocks (Savory and Mann 1997; Koene 1997), this is not a problem in the Pekin duck strains used in Australia for commercial production. It can be more severe and end in cannibalism in Muscovy ducks (Bilsing et al. 1992; Knierim et al. 2002). Categories iii and iv (Savory 1999) are significant issues in the duck industry as they are welfare concerns for the birds and they result in an estimated 2% loss in production at the farm gate, and a further 2% loss in efficiency on the processing line because of the increased difficulty of removing damaged feathers (PEPE’s Ducks Pty Ltd, personal communication). FP in ducks can be seen at early age and it seems to coincide with the emergence of the first feathers. This is clearly confirmed by field observations and communication with commercial farmers under Australian conditions.

FP can be described as a ‘multi-factorial’ problem with a causative mix of environmental, genetic and physiological elements (Hughes and Duncan 1972). Occurrence of FP has been attributed to genotype, physiology, nutrition, light intensity, group size/stocking density, stress, floor type and early rearing environment (Wysocki et al. 2010).

While aggressive pecking usually involves establishing dominance in the hierarchy (Sedlackova et al. 2004), the FP directed towards the rump, belly or tail tends to be more compulsive than aggressive. It has been attributed to redirected foraging behaviour and/or the ground pecking behaviour that is present in dustbathing situations. This has generated two hypotheses to account for SFP: the ‘redirected foraging behaviour’ and the ‘dustbathing’ hypotheses (Savory 1995). There has been debate about the relevance of each in laying hens. Dixon (2008) found similar fixed motor patterns between FP and foraging, leading to the proposal that they have similar motivation. Dustbathing has no relevance to the problem in ducks, but the absence of open water and preening could play a role.
While these hypotheses seem to concentrate on behavioural aspects and identify the drive to perform certain behaviours as the motivation, there is a need to also consider the genetic propensity of individuals to FP and the social learning that can escalate the problem.

While foraging, birds will peck and scratch at the ground in an exploratory manner that mirrors that of GFP. Blokhuis (1986) postulated that the relationship between FP and ground pecking depends on the incentive to perform either action. When the incentive to peck at feathers either on the ground is greater than that to peck at substrate, then FP occurs. Incentive to peck at the ground rather than a flockmate can be encouraged by providing appropriate substrate during rearing or keeping the flock at lower densities to reduce the amount of bird/feather material available to peck at (Hansen et al. 1994). Access to bedding early in life which can be used for regular dustbathing has been shown to decrease FP by encouraging ground pecking (Vestergaard and Lisborg 1993). Newberry et al. (2007) found no evidence that FP was a substitute for foraging behaviour. Birds from a high and low FP line showed no difference in feed exploration but the high line showed more activities directed to feathers (Hausler et al. 2008).

Another theory for FP is that it is associated with feather eating behaviour (McKeegan et al. 1999; Bilick and Keeling 1999; Harlander-Matauschek and Hausler 2009). This can develop in some birds when there is an abundance of feathers on the ground, with feather characteristics including taste and shape having an impact on whether a bird will consume it, and groups with higher feather eating behaviour will show more severe FP (Harlander-Matauschek et al. 2007). The theory for feather eating is that the feathers improve digestion in the crop, preventing blockages (Harlander-Matauschek and Bessei 2005). When there is low availability of feathers on the ground to peck at, there is the potential for the behaviour to be redirected towards other birds.

1.6.2. Factors influencing feather pecking

1.6.2.1. Genetic selection

Strains differ in the degree to which they engage in FP (Reviewed in Sedlackova et al. 2004). Hocking et al. (2004) indicated that the breed variation in FP was not strongly correlated with other behavioural measures. The heritability for FP has been stated to be as low as 0.007 by Bessei (1986) and as high as 0.38 by Kjaer and Sorensen (1997). Selection in laying hens over 10 generations based on the bouts of GFP and SFP resulted in a high feather pecking strain (HFP) and low feather pecking strain (LFP) (Kjaer et al. 2001). Birds of the HFP line have an active coping (fight/flight response to stress) style and the LFP a reactive (withdrawal/freeze response) style (Koolhass et al. 1999; Jensen et al. 2005). The differences in coping strategy could be linked to the FP behaviour. When De Haas et al. (2010) used a maze designed to assess fear responses and foraging behaviour of LFP and HFP hens, the HFP birds walked longer distances and vocalised earlier and pecked at the maze surface more than the LFP hens. While their results suggested differences in responses to the novel environment and maybe fear levels, this was not supported by the similar results reported from the TI test made on a sub-sample of birds. The HFP birds had a stronger pecking motivation but no clear preference for eating feathers. Bilick and Keeling (2000) found that only 8.3% of the flock were involved in SFP, while Wechsler et al. (1998), categorised 12% of the flock as ‘high peckers’. Birds with high levels of FP activity (‘super-peckers’) were found to have a gene transcription profile different from birds having low FP activities (Labouriau et al. 2009).

Muscovy ducks show more FP and cannibalism than Pekin ducks (Gustafson et al. 2007). To help control the condition, ducks can be bill-trimmed, but this has welfare implication because it is painful, at least in the short-term (Gustafson et al. 2007). Bill-trimming is not used under Australian conditions as the Pekin strains predominate in the industry. Genetic selection for low propensity to FP is not going to be a major priority in the Pekin strains used locally.
1.6.2.2. Nutrition

The role of nutrition in FP has been reviewed by Hughes (1982), Sedlackova et al. (2004) and Van Krimpen et al. (2005). Lee et al. (2001) found that decreasing the energy density of the feed improved feather condition of layer hens. This is attributed to the increased time and pecking needed to consume enough feed to meet their energy needs. A relationship between the non-starch polysaccharide content of the diet and the level of FP was established by Hetland et al. (2004). It was proposed that feed spent an increased time in the gizzard, and rate of passage through the gut left birds feeling satiated between eating bouts but hungrier at meals (Krimpen et al. 2007).

The incidence of FP is related to the way feathers develop (McAdie and Keeling 2000). A low protein diet fed to different laying hen strains resulted in high levels (17.6 vs 2.5%) of cannibalistic mortality (Ambrosen and Petersen 1997). Deficiencies of amino acids, especially methionine, will result in poor feather development (Siren 1963; Röbel 1977; Kjaer and Sørensen 2002; reviewed in Van Krimpen et al. 2005). Because of the effects deficiencies have on growth performance, commercial duck diets are unlikely to be deficient in key nutrients.

The use of yeast extract addition to the diet can also decrease FP behaviour, although the exact physiological mechanisms are unknown (Mathlouthi et al. 2011). Feed form can have an influence on the extent of FP, with pellets being worse than mash feeding (Hughes 1982; Savory et al. 1999; reviewed in Van Krimpen et al. 2005). A coarsely ground diet may increase FP due to the decreased amount of time spent feeding. Walser and Pfirter (2001) found that rate of FP was different when 33–55% of the feed particles were under 2 mm in diameter compared to 0–13%. Feeding Muscovy ducks mash compared to a pelleted diet decreased cannibalistic behaviour, although the diets differed in composition and fibre, and so may not be a realistic measure of the true influence (Rauch et al. 1995). Irrespective of these observations, it will not be a real consideration in meat ducks. Because of their eating mannerisms they will only be fed pelleted diets in commercial production and poor pellet quality (high fines) results in poorer performance in the field (PEPE’s Ducks Pty Ltd, personal communication).

L-tryptophan is the precursor for serotonin and dietary supplementation results in increased brain turnover of serotonin (Van Hierden et al. 2004b). Increased rates of FP were associated with low serotonergic neurotransmission (Van Hierden et al. 2002, 2004a). The role of serotonin in FP activity was supported by the work of Dennis et al. (2008) in birds selected for high and low group productivity and survival. Feeding White Leghorn pullets 21.6 g/kg TRP compared to 1.6 g/kg improved plumage condition (Van Hierden et al. 2004a). Savory et al. (1999) found a similar effect in bantams fed 22.6 g/kg of TRP compared to 2.6 g/kg. Early studies by Shea et al. (1990) in broiler breeder males on skip-a-day feeding found that dietary TRP supplementation at 0.38, 0.75 or 1.5% decreased aggressive pecking in both developing and mature flocks. In their first experiment, the Week 20 mortality in TRP treated birds was nil at 0.75% supplementation, 4.8% at 1.5% supplementation, but 23.8% in the control birds (0.19% TRP in the base diet).

1.6.2.3. Stress and fear

Fear and stress is a welfare concern for all animal production systems, and for poultry both could be a causative agent for SFP. Several stressors have been implicated in accelerating the development of FP behaviour in laying hens (Vestergaard et al. 1997; Riedstra and Goothuis 2002). Fear has been described appropriately as the ‘adaptive psycho-physiological (emotional) response to real or perceived danger’ (Jones 1996). Fear can inhibit all other emotional states (Jones 1996) and can be expressed as an acute or chronic state. Like some other emotions it is inevitable in an animal’s life (Fraser 1993). Signs of fear and stress documented in animals are focused on vocalisations and behavioural responses to a stressor such as the TI test in hens. This is a state of immobilisation induced by mild restraint in which the bird has reduced responsiveness to external stimuli (Jones 1996). Feather condition is regularly used as a measure of fearfulness and wellbeing.
An association between FP and fear has been reported by a number of researchers (Jones et al. 1995; Keeling and Jensen 1995; Albentosa et al. 2003). Better feathered hens are considered to be less fearful (Hughes and Duncan 1972; Na-Lampang and Craig 1990). The TI duration is reported to be related to the extent of FP (Jones et al. 1995). Contrary to this, for five strains of hens, those with the shortest TI had the poorest feather condition, suggesting they were less fearful (Campo et al. 2001). In that study, hens with the poorest feather condition had a significantly higher H/L ratio even though the increase in heterophil number and decrease in lymphocyte number were separate and not different. When force moulted, hens having the greatest feather loss also have the greatest H/L ratio (Alodan and Mashaly 1999).

Physiological responses such as blood corticosterone concentrations may be an indication of stress associated with the environment or behaviour. As behavioural measures of fear increase, so do plasma corticosterone concentrations and the H/L ratio (Davis et al. 2000). Mini-osmotic pumps implanted subcutaneously to deliver corticosterone at 15 µg/h, significantly increased plasma corticosterone concentration in hens from 0.15–0.48 ng/mL to 1.1–2.9 ng/mL. The increase in plasma corticosterone significantly increased the TI duration and H/L ratio (Jones et al. 1988). This gives strong support to the proposal that the chronic hypothalamic-pituitary-adrenal axis (HPA) activity and fear are related in laying hens. Chickens selected for high activity in a novel environment were found to have lower basal and stress-induced corticosterone concentrations (Faure 1980). Stress-induced increases in corticosteroids affect emotion, cognitive processes and motivation (McEwen 2007). The low affinity brain glucocorticoid receptor is only activated following stress-induced surges of corticosterone or at the peak of the circadian rhythm (Conway-Campbell 2007). In rodents, changes to glucocorticoid receptor occupancy lead to altered interpretation of the environment and may determine an animal’s emotional state and its adoption of a coping strategy to stress (Korte et al. 1995, 1996). Changes in receptor occupancy may be related to how animals cope with changes in their environment (Korte et al. 1995). This seems very important, because it has relevance in animal welfare, making a connection between behaviour, feelings and stress physiology.

When FP activity was compared between hens housed on slats and litter, the extent of FP was greater for the hens on the slats (El-Lethey et al. 2001). Foraging activity was higher for the litter-housed birds. These workers tried to mimic the effects of stress by feeding dietary corticosterone. When dietary corticosterone was used to mimic the effects of stress by increasing serum concentrations of corticosterone, the incidence of FP was increased in hens kept on litter but not those on the slats (El-Lethey et al. 2001). The basal plasma corticosterone concentration of the control hens was relatively high, at around 5 ng/mL, and the feed supplemented with corticosterone increased this to around 7.5 ng/mL in treated birds. While the corticosterone treatment decreased liveweight and feed intake, there was no interaction with housing type for these measures. For the litter-housed birds, corticosterone supplementation had no effect on foraging activity even though the plasma corticosterone concentrations in supplemented birds were similar to the control birds on the slats. Control hens on the slats had longer TI and when the birds on litter were treated with corticosterone their TI was longer and similar to that of the control hens on slats. The corticosterone treatment in litter birds increased the incidence of FP but no more than was seen for the control birds on slats. As the authors indicate, of interest was the similar FP, egg production, TI and H/L ratio for the control and corticosterone-supplemented hens on slats. For these two treatment groups there was a significant difference in plasma corticosterone. Stressors can influence adrenal function by operating through the HPA or SMS pathways to influence behaviour, and may account for some of the differences observed.

Rodenburg et al (2004) have shown that the level and severity of FP increases with fear. It is suggested that certain animals may be predisposed to fearfulness through their breeding, and selection for less fearful animals has resulted in less FP. There is strong evidence that genetic selection can reduce fearfulness in different strains of duck and layers. Testing for fearfulness in ducks could be advantageous to the future selection of breeding stock. Pekin ducks were shown to be more fearful of human contact than Muscovy ducks using plasma corticosterone concentrations as the measure (Faure et al. 2003). Muscovy ducks have a higher rate of SFP than Pekins ducks (Rodenburg et al. 2005).
1.6.2.4. Stocking density

Stocking density can influence the behaviour of poultry and becomes a consideration when intensively housed poultry are kept in groups. Under experimental conditions the distinction between density and group size effects needs to be identified, as density is often modified in these studies by changing group size. Also, the differences in experimental group sizes and those in commercial flocks make extrapolation between the two difficult.

An increase in flock size increases the occurrence of FP, possibly due to increased encounters with unknown individuals, or an increase in the number of potential feather peckers in the larger group (Bilcik and Keeling 2000, Nicol et al. 1999). Nicol et al. (1999) reported that increasing flock size within a given area increased FP, but decreasing the area allocated to a given flock size did not. They concluded that flock size may be more important than stocking density. However, in these studies low numbers of birds were used and extrapolations made to commercial flocks. Using much larger group sizes Zimmerman et al. (2006) found that FP was greater in lower flock sizes. In commercial operations the average density may not be the critical measure; it may be the effective group size and density in common areas such as around feed and water points and nests that is important. The plumage condition of hens has been reported to be worse as stocking density increases (Hughes and Duncan 1972; Savory et al. 1999).

There is evidence that large group size increases fear and stress in farm animals. FP was found to be worse when laying hens were stocked at high densities of up to 30 birds/m², compared to a density of 6 birds/m² (Nicol et al. 1999). Although the sizes of the treatment groups were moderately large (from 72–368 birds in a pen), the density was mediated by changing group size. Pekin ducks had higher feather damage and poorer performance and product quality when housed at 8 birds/m² compared to 5, 6 or 7 birds/m², again by using group sizes of 225–360 birds to change density (De Buisonje 2001). Since model code of practice recommendations for housing are currently based on space per bird, group size should be taken into account as a contributor to the overall effect of FP and welfare. Baeza et al. (2003) reported on a study with Muscovy ducks where the birds were kept in small groups of 29 ducks and were allocated different space allowances. Using densities of 7, 9 and 11 birds/m², FP and welfare was best at 9 birds/m². This result neither supports or negates the hypothesis, that a higher density predisposes birds to increased FP. The behavioural and production criteria used to compare the treatments also showed that the birds housed at the highest density exhibited the highest production performance. The higher production may indicate better welfare despite the potential for increased social interactions. Nicol et al. (1999) identified that close proximity between birds (<30 cm) was needed for the establishment of social recognition. Perhaps having too large a space available to the animal may affect this proximity requirement for social recognition and result in more aggressive interactions.

Zimmerman et al. (2006) investigated the effects of density and group size on FP and other measures in laying hens in small (n=2,450 at 7 and 12 birds/m²), moderate (n=3,150 at 9 birds/m²) and large (n=4,200 at 12 birds/m²) flocks. The effect of 12 birds/m² compared to 7 birds/m² varied depending on age. The extent of FP increased with density, but this was not apparent until 48 weeks of age. At 32 weeks of age, FP was higher in the low density group. This may suggest that until 48 weeks the effect of higher densities is negligible. Conditions during the early rearing stage have been shown to influence FP behaviour later in the production stage. When layer chicks were reared at 6.5 birds/m² or at 13 birds/m² in pens containing 195 to 390 chicks, and FP assessed at 36 weeks of age, FP was lower for birds reared at the lower density (Hansen et al. 1994). Again, in the experimental design the density effects were achieved by changing group size. These kinds of study are of limited relevance to meat ducks as the processing age is six weeks. The density of ducks needs to be studied in terms of FP without increasing flock size. Area availability needs to be manipulated to change the distance between individual ducks.
1.6.2.5. Light intensity

Light is probably the most important environmental stimulus for poultry having an effect on physiology and behaviour (Perry and Lewis 1993; reviewed in Manser 1996). While there are a number of reports identifying light preferences for hens, turkeys and broilers (Appleby et al. 1984; Sherwin et al. 1998; Widowski et al. 1992; Kristensen et al. 2007) there is little information on the preferences of ducks.

Birds detect light in a much broader spectrum of colour than humans, and since sight is the primary foraging cue it is important for survival and should be considered when housing poultry (Jane and Bowmaker 1988; Rajchard 2009). The duck’s eye contains cone types that are indicative of tetrachromatic vision, with light perception at wavelength peaks of between 544 and 577 nm. The spectral range includes that of the UVA region of colour that humans cannot perceive (Parrish et al. 1981; Barber et al. 2006). Poultry being reared in indoor shelters are regularly illuminated using artificial light. The type is often determined by the price of power and ease of maintenance rather the bird’s perception of light.

Feathers often reflect UV light, while the wattles or crests rely on their UV colour to convey social cues. Both herbivorous and carnivorous birds rely on UV reflection from their food sources as a foraging cue. Ducks are thought to be able to have full dark adaptation of the eye to low light intensity (Wells et al. 1975) as well as full daytime luminance, which can reach levels as high as 120,000 lux. Deprivation of light stimuli by changing the colour or luminance could influence the redirection of foraging behaviour to the feathers. Lack of visual information may impair movements and co-ordination. It has been observed that variation in light intensity and contrast, such as beams through windows, can contribute to the occurrence of FP (Petek and McKinstry 2010). Using light intensities of 0.8–40 lux and perches placed over distances of 1 and 0.5 m, Taylor et al. (2003) found that there was a positive correlation between light intensity and a hen’s ability to navigate her way from perch to perch.

The relationship between light intensity and activity (Boshouwers and Nicaise 1987) is used to help improve feed efficiency and limit injurious FP in turkeys (Hester et al. 1987). Results from light intensity studies are complicated by the fact that it is difficult to control, and have given mixed results. There is evidence that higher light intensities may increase FP behaviour and cannibalism (Taylor et al. 2003). While low light intensities might help with some behavioural issues, low light intensities during rearing could result in developmental abnormalities of the eye (Prescott et al. 2003), the legs and brain morphology (Thompson and Forbes 1999; Patzke et al. 2009).

When exposed to various light intensities, laying hens displayed higher aggressive pecking and increased mortality when the intensity was high (30 lux), and higher GFP when the intensity was low (<3 lux), with this being mainly exploratory in nature (Kjaer et al. 1999). Broilers at six weeks of age showed a clear preference for Biolux and warm-white light and so the light intensity may not be as important as the source (Kristensen et al. 2007). The pattern of light can also affect performance. Broilers under intermittent light displayed better growth rates and feed conversion compared to those reared under continuous light (Buysse 1996).

Dimming lights to 1 lux is effective in reducing FP damage in Muscovy ducks (Heil and Torgest 1990). A survey of UK duck houses indicated that incandescent and fluorescent lighting was the common luminance used, with no coloured or filtered lighting installed (Barber et al. 2004). Different light sources provide a specific range of spectral power outputs and colour balance (Prescott and Wathes 1999).

Barber et al. (2004) reported on the effects of different incandescent light intensities (<1, 6, 20, 200 lux) in CV Pekin ducks using an experimental model to determined bird preference. Luminance was found to have a significant effect on the partition of behaviours in the different light environments. At two weeks of age, birds spent less time moving and in environment-directed pecking in the dim light (>1 lux) and most of their time in the luminance <6 lux. At six weeks of age they spent less time
preening, feeding and moving in the lowest light and most time performing these activities in the higher light intensities. The fact that ducks had no clear preference for light intensity above 6 lux might suggest that there was no preference, although as the authors identify, care is needed when trying to interpret results from preference tests, for reasons described by Duncan (1978). The ducks spent on average 240 min/day in dim light (<1 lux). This might indicate that ducks have a preference for a dark period at least for part of the day. This might account for the lower level of activity in the dim light. The results of Davis et al. (1999) tend to support this idea. At two weeks of age, eating, drinking and litter-directed activity and rest were preferred in high light intensity (200 lux). At six weeks of age ducks preferred to spend their rest time in dim light (6 lux). Duck behaviour in different light intensities needs to be further tested in terms of FP and production.

1.6.2.6. Early rearing and learned behaviours

Pecking behaviour develops very early in the life of layer chicks (Hogan 1971; Reidstra and Groothuis 2002). Food preferences early in life are associated with nutritive rewards or stress and it is possible that these influence the behaviour of older birds through learned associations. The availability of litter at a young age can have an effect on the development of FP. Blokhuis and Vanderhaar (1989) found that birds reared on wire floors demonstrated a much higher frequency of FP than those on litter. The presence of litter in early rearing seems to be more influential in preventing FP later than if litter is supplied later in production (Huber-Eicher and Wechsler 1997). High foraging activity in young chickens has been associated with severe FP at later ages (Newberry et al. 2007). Even the environment during embryogenesis can have an effect, as demonstrated by (Janczak et al. 2007). When hens were stressed during lay, the hatch chicks were more fearful and less unwilling to compete with other chicks. Riedstra and Groothuis (2002) proposed that FP may be an extension of social behaviour rather than a redirection of foraging.

Harlander-Matauschek and Rodenburg (2011) demonstrated that young and adult birds exposed to a bitter tasting substance on feathers have a lower FP rate than those of the control treatment. However, if the substance was not regularly applied, the FP behaviour reappeared at higher rates. The use of quinine for taste aversion has been associated with digestive distress such as nausea. The aversion to FP could be a learned behaviour linking it to an unpleasant taste causing physiological disruption. Skelhorn et al. (2008) found that in chicks quinine elicited a bias against coloured treated food, but that a similarly bitter tasting but non-toxic chemical did not. In addition, the numerous chemical and natural options used by Harlander-Matauschek and Rodenburg (2011), including garlic oil, clove oil, quinine, almond oil and commercial chemicals, would all have some kind of physical effect as well as olfactory. Hence it may be difficult to distinguish what is limiting the FP behaviour. Frustration caused by limiting the pecking drive stimulus can cause an increase in the amount of FP (Rodenburg et al. 2002).

Mixing Muscovy and Pekin ducks and providing access to open water decreased the extent of injuries seen in Muscovy ducks (Klemm et al. 1995). While there is considerable research interest in the role of early rearing effects on later FP activity in laying hens, this is not going to be relevant to commercial meat ducks that are processed at six weeks of age. An area that could be relevant is the role social transmission could be playing. FP occurs in groups and has social elements attached to it (Craig 1992). Appleby et al. (1992) made the point that it spreads in the flock and this alone suggests that it starts with a few birds and others follow on with the behaviour. This pattern would suggest a role for social transmission (Weschler et al. 1998; Zeltner et al. 2000).

Zeltner et al. (2000) used White Leghorn chickens before the establishment of a dominance hierarchy (<six weeks of age), to test the concept that social transmission has a role in development of FP. The researchers used poor housing conditions to generate high and low perpetrators (referred to as tutors) of FP. Tutors of both extremes of FP behaviour (high and low) were then introduced to groups of naive controls. Introducing high FP tutors to groups started FP in these groups and the frequency was much higher than for the groups where the low FP tutors were introduced. The behavioural observations indicated that the increase in FP was not caused by the pecked birds retaliating to being pecked. It was also not due to the extent of damaged feathers, as the plumage condition was the same.
in both treatment groups. The authors witnessed group members observing the tutor birds FP behaviour and then imitating it on the target bird. The pattern of transmission in the group appeared to be by imitation. While the time spent foraging and FP have been related in this study, the amount of time spent foraging was lower in the high FP groups even though the foraging options were the same. The authors believed that this supported the hypothesis that the motivation of foraging and FP were the same, as indicated by others. Of interest was the relevance of the poor housing conditions used to generate the different tutor birds. The effect of housing appeared to be greater than that of social transmission. McAdie and Keeling (2002) provided some support for the social transmission of FP behaviour but only in cages and only for GFP.

1.6.2.7. Feather pigmentation

Keeling et al. (2004) demonstrated that higher levels of FP were directed towards brown birds compared to white birds. They suggested that this may be due to the contrast that pieces of food or litter create within the darker feathers. The pale coloured litter and pellets would not contrast as much with white feathers than with brown. Other reports support the high incidence of FP in brown hen strains compared to white strains (Savory and Mann 1997; Oden et al. 2002). When white and brown hen strains were housed in a system where they had access to an outside run, no correlation could be found between feather damage and time spent in the outdoor area (Mahboub et al. 2004). Birds from the white strain moved outside more frequently but spent less time there and were considered more fearful based on a TI test. The TI time suggested white hens were more fearful, but they had lower H/L ratio suggesting that they were less stressed. The authors commented that this relationship was contrary to that portrayed by others (Jones et al. 1988; Beuving et al. 1989) but was supported by Campo and Redondo (1996, 1997). In relation to Pekin ducks, it is possible that contrast with the white feathers may have some effect on development of FP. When their feathers are growing, they initially begin as ‘blood feathers’, with a noticeable red vein at the base of the shaft, and this may provide greater contrast and a target for other birds.

1.6.2.8. Litter

Most flocks show some degree of FP (Bright et al. 2006). A comprehensive evaluation of FP in different floor-based production systems over 2004–2007 revealed that 65% of producers identified FP to some degree (Lambton et al. 2010). Behavioural observations during two farm visits by the researchers identified evidence of GFP and SFP at rates of 89.2% and 68.5% on Visit 1, respectively, and 73% and 85.6% on Visit 2. The rate of GFP increased with the number of birds in the observation area and was higher around nests and on slatted areas. The incidence of GFP decreased with an increase in birds using the range area and at lower shed temperatures. There were higher rates in non-trimmed flocks but also in retrospectively beak-trimmed flocks. Feeding pellets increased the incidence of FP, as did the scattering of feed on the floor. Birds showing increased feather damage had higher rates of SFP. The rate of SFP was related to lower production and increased mortality.

The effects of water and feed enrichment on activity and cannibalism in beak-intact Muscovy ducks were investigated by Riber and Mench (2008). The water enrichment included water troughs with plastic string attached to the base of the trough, plastic objects too large to swallow placed in the trough and water with a grain mixture. The feed enrichments included corn silage in a trough, lucerne in a hayrack, grain and gravel mixture in a trough, and astroturf onto which a grain mixture was scattered and occasionally meal worms. The feed and water enrichments increased the time spent foraging but had no effect on the extent of injury associated with FP, which totalled 56.4%. The incidence of cannibalism was low with most injuries being minor in nature, with any bleeding mostly due to feather removal. This might not really be cannibalism but SFP, as the feather shaft rather than the skin is damaged. The FP started at around the time primary feathers started to emerge but overall the level of FP was low. There was evidence of a treatment and age interaction. At Day 14, FP was greater in the controls than the enrichment groups, while at Day 18 it was only higher in the controls compared to the feed enrichment group. LWG or total liveweight had no influence on FP. As indicated by the authors their data did not support the hypothesis that FP was the result of redirected foraging behaviour. As discussed by Riber and Mench (2008), the results of a large-scale trial by
Knierim (2005) provided some evidence that water and feed enrichment reduced damaged due to FP. However, due to the inconsistent results, foraging motivation might not be the critical element driving ducks to FP.

In general, it is agreed that the provision of litter reduces the prevalence of FP, although the reasons behind this are disputed. Birds housed on slatted floors feather peck at a greater rate than those on litter (Blokhuis and Arkes 1984). Birds that were transferred from litter to slats also demonstrated an increase in FP behaviour. The increase in FP seen when birds were moved from the litter to the slats may be the result of the highly active litter birds, remaining active in a foraging limiting environment and re-directing this towards other birds. Huber-Eicher and Wechsler (1997) found that FP within a group increased with a decrease in foraging activity, but there was no relation to dustbathing activity. Their results also indicated that providing sand for dustbathing had no effect, whereas the provision of straw for foraging did affect FP activity. Since ducks do not demonstrate dustbathing behaviour but do forage, providing litter may have a positive effect on FP incidence in this species. However, the differences in foraging methods must be taken into account and it is less likely that litter will have the same relevance for ducks.

1.6.2.9. Access to open water

In commercial production, drinking water is provided using nipple drinkers. The reasons for this include good litter management, shed hygiene and sustainability of water usage. While these are economic and health considerations, the failure to provide open water access has been suggested to be a welfare concern (Reviewed in Rodenburg et al. 2005). O’Driscoll and Broom (2011) demonstrated that despite the increase in damp bedding associated with the provision of open water, there were limited detrimental effects such as skin infections or poor hygiene. Their results actually indicated an increase in hygiene of the birds, in particular their plumage condition. They also saw an increase in natural preening, head dipping and other natural behaviours. This study also established a relationship between an increase in liveweight and access to water, and suggested this could be related to a decrease in stress.

Waitt et al. (2009) indicated that there was little difference in bathing behaviour when ducks were provided with baths, troughs or showers. This suggests that as long as there is water available to dip the head, bathing behaviours can be performed adequately. This means that showers or troughs may be the most suitable because of the associated hygiene benefits. These results are also supported by Jones et al. (2009). In terms of preference, day old ducklings spend more time interacting with a bell drinker, which provides a small surface area of open water, than with a nipple drinker (Cronin et al. 2010).

On the contrary, Riber and Mench (2008) found that providing water-based enrichment to Muscovy ducklings did not reduce the number of injuries due to FP and cannibalism. It is clear that more research is needed to determine the role of water access to duck welfare.

1.7. Transport and processing

Transport to processing involves feed withdrawal for a period before pick-up, handling and loading into transport crates, transport from farm to the processing plate, holding in lairage and finally processing, all potentially adding to the stress levels in ducks (Yalcin and Guler 2012).

1.7.1. Transport stress

The main stressors during transportation and processing include the thermal environment, water and feed deprivation, the changing microclimate of the transport crate, transit and lairage times (Zulkifli et al. 2009). It has been recognised that HS constitutes the major threat to animal wellbeing and productivity, and is the main cause of death during transit. HS can affect duck dehydration, physiological stress, processing efficiency, meat quality and welfare. The extent of the problems can be confounded by longer transport and lairage times and overcrowding in transport crates. During stress an animal will utilise its energy stores and other body functions to deal with the specific stressor
present. It is the degree and length of time that an animal remains distressed that will determine the severity of impact upon the health, well-being and productivity of the animal (Moberg and Mench 2000).

1.7.2. Loading density

The loading density of birds within transport crates can have an effect on HS and dehydration during transport. The ideal number of birds per crate changes with the ambient temperatures and humidity, and these can frequently change throughout the duration of transport, making it difficult to manage (Knezacek et al. 2010). At high ambient temperatures, higher loading densities have been associated with higher mortality (Warriss et al. 2005).

1.7.3. Time in transit

The length of time that poultry spend in transit can also influence the degree of stress and dehydration. There are conflicting studies about the effect of the time of transport on birds. The majority of studies have shown that long-term transportation is associated with higher mortality rates (Nijdam et al. 2004; Vecerek et al. 2006; Whiting et al. 2007). A 6% increase in dead on arrival (DOA) rates with every 15 minute increase in transport time when conditions of high humidity and temperature are experienced has been reported by Nijdam et al. (2004). Other studies have shown that short-distance transport or the first period of long-term transport is the most stressful (Vosmerova et al. 2010). The authors suggested that an increase of DOA rates in short-term transport could be due to birds not having sufficient time to recover from the stressors incurred during the catching and loading of birds.

1.7.4. Time of feed withdrawal

In most situations, feed is withdrawn a couple of hours before farm pick-up. This is done for two different reasons: to reduce faecal contamination at the time of processing, and to reduce heat produced from metabolic and digestion functions, which would exacerbate the problems of HS (Zulkifli et al. 2007). The time of feed withdrawal can significantly impact upon the degree of stress and dehydration during transport.

1.7.5. Catching and loading

The catching and loading of birds has been shown to impact upon their stress levels before and during transport. If injury occurs during this process it will exacerbate the level of stress during the rest of the transport process (Whiting et al. 2007). The catching and loading of birds prior to transport has been shown to be more stressful than the actual transport itself (Ritz et al. 2005).

1.7.6. Effect of different microenvironments during transport types

The effect of the microclimate around the crates in which the birds are kept during transport may be the single biggest contributor to HS and subsequent dehydration during transport. The effect of HS during transport is the major contributor to mortality rates and decreased meat quality during poultry transport (Vieira et al. 2011). Mitchell and Kettlewell (1998) showed that 40% of deaths during transport are associated with thermal stress due to poor distribution of ventilation throughout the transport crates. It was also shown that there is an increase in mortality rates with increasing humidity in the transport crates (Hunter et al. 1999). It has also been shown that the effect of microclimate is not only important during transport but also during the loading and lairage of birds (Ritz et al. 2005).

There have been several studies that have associated high temperatures to increased shrink (dehydration) and higher core BTs. High temperatures in the crates during transport have been shown to increase in dehydration levels by 3–5% due to panting and increased urine output (Mitchell et al. 2003).
1.7.7. Dehydration—meat quality and processing

Dehydration may be a result of factors such as increased respiration rates, urinary water loss, and excessive panting during transit and this affects the size of the water pool in the interstitial space and is likely to affect meat quality (Gortel et al. 1992). An increased respiration rate results in the movement of free water from the intercellular spaces to the extracellular space, from where it can then be lost. Extracellular fluid decreases as a result, leading to a drop in blood pressure and volume and subsequently an increase in plasma osmolarity (Tortoe et al. 2007). Maintenance of intercellular water is of benefit to the bird and so any strategy that helps to promote this would be beneficial to maintaining homeostasis. As discussed in previous sections, the loss of water also results in the excretion of electrolytes and so replacing these will also assist the bird.

Dehydration during transport and lairage can affect meat quality and the ease of processing. Dehydration increases the difficulty of removing feathers on the processing line (Bianchi et al. 2006). Schaefer et al. (1997) lists the meat quality attributes that are primarily affected by stress and handling, and these include pH, texture, colour and moisture, which may result in undesirable palatability and an increase in toughness and hence poorer overall meat quality. The meat quality of poultry is ultimately affected by the duration of transportation as a result of the stress experienced, especially prior to slaughter (Schaefer et al. 1997; Scott and Schaefer 1999). Meat quality and composition is dependent on the muscle fibre number, size and fibre type composition (Rybarczyk et al. 2011) and is affected by glycolysis elicited by stress and water loss. Zhang et al. (2009) investigated the effects of transport stress on the meat quality of broilers. The results indicated that transportation initiates the release of corticosterone, which subsequently may change the area and density of the muscle fibres and furthermore, enhance glycolysis and lipolysis. This will also have negative effects on pH, colour, thawing and cooking loss and texture (Bianchi et al. 2006, 2007).

1.7.8. Ventilation during transport

The use of ventilation systems could have beneficial effects in reducing HS during transport (Yahav et al. 2008). Transport trailers that incorporate ventilation systems that distribute air evenly throughout transport crates could be used to reduce the impact of HS during transport. In an enclosed transport vehicle the air would have to be evenly distributed and controlled to guarantee even temperature distribution (Schwartzkopf-Genswein et al. 2006).

1.7.9. Strategies to reduce stress and water loss during transport

Studies have established a link between transportation, stress and meat quality (Scott and Schaefer 1999; Zhang et al. 2009) and hence we need devise interventions that can help minimise stress and water loss. Nutritional modulation such as the addition of electrolytes to water or establishing amino acid requirements after or during transportation can be implemented as a means of combat stress effects on birds (Gortel et al. 1992; Virden and Kidd 2009). However, there are limitations. For example, the improper administration of electrolyte treatment can be counterproductive resulting in a depletion of potassium and diarrhoea (Schaefer et al. 1997). Nevertheless, electrolyte therapy has been shown to be efficacious in combating stress if administered properly (Gortel et al. 1992; Scott 2007). Zhang et al. (2009) suggested that increasing the recovery time after transportation could be used to lower the plasma corticosterone concentration and to reduce muscle glycolysis, which may allow birds to re-establish homeostasis and improve meat quality.

The use of electrolytes to alleviate some of the problems associated with HS has been considered in other sections. Supplementation of electrolytes has shown to be an effective way to help alleviate the negative effects of HS and dehydration in poultry (Yahav 2009). The most common commercial electrolytes that are used in production to minimise the effects of HS are salts providing Na⁺ and K⁺. Common feed electrolyte additives are sodium chloride (NaCl), sodium carbonate (Na₂CO₃), sodium bicarbonate (NaHCO₃), potassium chloride (KCl), potassium carbonate (K₂CO₃) and potassium bicarbonate (KHCO₃) (Majekodunmi et al. 2012). Ahmad et al. (2005) showed that with the use of electrolyte salts there was a reduction in mortality rates by 50% in high ambient temperatures (29–
Potassium-based salts combined with NaCl in drinking water significantly reduced the negative impacts of HS on performance (Smith and Teeter 1989). These positive results gained from the supplementation of electrolytes have been attributed to increased water retention, caused by the maintenance of the acid-base balance (Nienaber and Hahn 2007), factors that would reduce physiological stress.

Betaine is associated with the synthesis of creatine and carnitine, which are involved with water retention in muscle and reduced water loss under high osmotic pressure (Klasing et al. 2002). Betaine supplementation decreased water movement through the intestinal epithelium, identifying a role for it in osmoregulation (Kettunen et al. 2001). Metzler-Zebeli et al. (2009) showed that due to its osmoregulatory functions, betaine improves digestibility, water retention and feed conversion in meat ducks.

A strategy of supplying ducks with electrolytes and betaine prior to transport, especially during periods of high temperature, could help water retention and have positive effects on their welfare, carcass weight and meat quality in ducks.
Chapter 2: Strategies to alleviate the adverse effects of high temperature on the performance of commercial ducks

2.1. Introduction

Under Australian conditions, most commercial meat ducks are housed in facilities with minimal environmental control. This means that ducks are subjected to large ranges in ambient temperature. This can be a problem during summer when they can experience periods of high ambient temperature outside their thermal comfort zone. A consequence for performance is that it can take four to six days longer for birds to reach market weight, and during the HS, the welfare of the birds will be compromised. Similar problems are experienced by broilers reared in conventional housing in hot, humid climatic areas. Extensive research efforts have attempted to find strategies to alleviate the problems associated with HS in broilers. The same effort has not been directed to the problem in ducks. In this study, some of the strategies identified in broiler research have been evaluated in commercial Pekin ducks.

2.2. Objective

The objective of the study was to assess the effects of nutritional modifications on the growth performance of Pekin ducks exposed to cyclic high ambient temperature. It is hypothesised that the beneficial effects seen in broilers can be duplicated for commercial Pekin ducks.

2.3. Material and methods

2.3.1. Experimental design

There were 48 pens in the tunnel ventilated shed used in this study. The pens were numbered sequentially and divided evenly into four blocks (see Methodology).

2.3.2. Birds and husbandry

The treatments were applied to two strains of Pekin ducks reared as mixed sex groups, consisting of equal numbers of males and females. The strains used were CV and an industry strain identified as P2 that had been selected for higher growth rate and breast yield from the parent CV strain. The strains were produced by the appropriate matings at a commercial breeding farm owned by PEPE’s Ducks Pty Ltd (Windsor, NSW) 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.

On arrival, 36 ducklings were placed randomly in each pen. Surrounds were used for the first five days, restricting the ducklings to half the pen area. This helped to keep them within close proximity of the brooding lamps. Birds were identified individually with wing tags at Day 7 of age. By Week 6 of age the number of birds in each pen was reduced to 24 with a floor space of 1,875 cm²/bird.

Birds had access to feed and water ad libitum. The starter and grower feeds were provided by Ingham’s Pty Ltd. The starter diet was formulated to provide 12.45 MJ ME/kg and 22.2% protein while the grower diet was formulated to provide 12.54 MJ ME/kg and 18.8% protein. The starter diet was in crumble form and was fed from Day 1 to Day 14. The finisher diet was in pellet form and was provided from Day 15 to Day 41.
2.3.3. Treatments

Six treatments were applied to both duck strains:

1. Control diet with water alone
2. Control diet with water supplemented with vitamin C at 125 mg/L
3. Control diet with water supplemented with betaine at 400 mg/L
4. Control diet with betaine supplemented in the diet at 950 mg/kg
5. Feed withdrawal during the period of high temperature (08:30–17:30 daily)
6. Control diet with water supplemented with electrolyte salts (sodium chloride 1.57 g/L, sodium bicarbonate 1.71 g/L and potassium chloride 0.884 g/L and betaine at 400 mg/L).

Betaine was provided by Feedworks Pty Ltd. It contained 96% betaine and for addition to water treatments it was dissolved in warm water and the dissolved betaine was removed from the precipitated calcium by suction and then added to the drinking water. As an additive to the feed, betaine was included as a dry powder.

Treatments 1–5 were applied during Days 29–41 of age, while Treatment 6 was applied during Days 36–41 only. On Days 29–41, the shed temperature was increased to 32°C for 9 hours (08:30 to 17:30 h) each day and then maintained at 24°C for the remainder of the day (17:30 to 08:30 h). Treatment days 29–35 of age (Week 5) were considered as Heat Period 1 and then Days 36–41 of age (Week 6) as Heat Period 2.

The shed was divided into four blocks of 12 pens. Each treatment was randomly allocated to one pen in each block. This gave two strains and six treatments, with four replicate pens, for each treatment.

2.3.4. Performance and carcass measurements

At placement, a collective pen weight was recorded. Individual liveweights were recorded on Days 14 (Week 2), 28 (Week 4), 35 (Week 5) and 41 (Week 6) of age. At these same times, feed intake was determined as the difference between weights of feed added less the weights of feed refusals removed. Water consumption was recorded daily. On Day 40 of age, one males and one female duck were removed from each pen and individually weighed and then euthanised. The total breast muscle was removed and weighed.

2.3.5. Statistical analysis

Data were stored in Microsoft Excel® and unless stated otherwise, the statistical analysis was conducted using the REML linear mixed model function of Genstat® 11th edition. The data were first tested for equality of variance using residual plots. When the equality of variance could be improved by using a loge transformation, the data were transformed.

The fixed model included the effects of treatments, strain, sex and week, and the random model included the effects of block, pen and tag. Initially, all two-way interactions between fixed effects were included in the model. Significance testing of fixed effects was conducted using Wald tests with a significance threshold of P <0.05. Any non-significant interactions were removed from the model. The predicted means for all significant fixed effects were copied to Microsoft Excel®, as well as the standard errors, which were used to calculate the standard error of the mean (SEM). The least significant difference (LSD), which is equal to two times the standard error of differences (SED), was used to make pairwise comparisons between means. Microsoft Excel® was used to create graphical summaries of the back-transformed means.
2.4. Results

2.4.1. Liveweight

The effect of treatment on mean (±SEM) liveweight is given in Table 2.1. Treatment had a significant effect on liveweight, but this changed with time as the treatment x week interaction was significant (P<0.001). In Weeks 1–4 when birds were under the same conditions there were no differences between allocated treatment groups. During the first heat period (Week 5) ducks supplemented with betaine in the water had higher liveweight than did the control ducks (P<0.05). During the second heat period (Week 6), supplying birds with electrolytes plus betaine in the water supported significantly higher liveweight than control birds and those provided with vitamin C or having feed withdrawn during the heat period ( <0.05), but was no different to those with betaine in the feed or water.

Table 2.1. The effect of treatment on mean (±SEM) liveweight (g) of ducks exposed to periods of cyclic high ambient temperature in Weeks 5 and 6

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>735±10</td>
<td>1,828±24</td>
<td>2,197±29^ab</td>
<td>2,579±34^b</td>
</tr>
<tr>
<td>Vitamin C</td>
<td>731±10</td>
<td>1,832±24</td>
<td>2,224±29^ab</td>
<td>2,581±34^b</td>
</tr>
<tr>
<td>Betaine in water</td>
<td>740±10</td>
<td>1,850±24</td>
<td>2,239±29^b</td>
<td>2,599±34^ab</td>
</tr>
<tr>
<td>Betaine in feed</td>
<td>730±9</td>
<td>1,832±24</td>
<td>2,222±29^ab</td>
<td>2,612±34^ab</td>
</tr>
<tr>
<td>Feed withdrawal</td>
<td>746±10</td>
<td>1,830±24</td>
<td>2,222±29^ab</td>
<td>2,581±34^b</td>
</tr>
<tr>
<td>Electrolytes + betaine in water</td>
<td>732±10</td>
<td>1,835±24</td>
<td>2,202±29^ab</td>
<td>2,644±34^a</td>
</tr>
</tbody>
</table>

Note: Values within a column with different superscripts are significantly different (P<0.05)

While strain had a significant effect on liveweight (see Figure 2.1), there was a significant interaction with week (P=0.01). The SEMs are small and for this reason they are not included on the graph. In all weeks, the liveweight of Strain P2 was significantly greater than strain CV (P<0.05), but this difference increased as that birds aged.

The effect of sex on liveweight weight is shown in Figure 2.2. The sex x week interaction was significant (P<0.001) with males being heavier than females at all weeks (P<0.05) and this difference increased as the birds aged. The effect of sex was also influenced by the strain as the sex x strain interaction was significant (P=0.01). The difference between males and females was greater for strain CV (1,586±19 v 1,675±20 g) than strain P2 (1,681±20 v 1,742±20 g).
2.4.2 Average daily liveweight gain

Treatment had a significant effect on LWG (see Table 2.2), but this changed with time as the treatment x week interaction was significant (P<0.001). In Week 5, the control birds and those allocated to the electrolyte treatment had significantly lower LWG than did other treatments (P<0.05). In Week 6, birds supplied with electrolytes and betaine in the water had superior daily LWG compared to other treatments (P<0.05). The birds supplied with vitamin C had lower LWG than control birds and those supplied with betaine in feed (P<0.05). The LWG for birds with feed withdrawal and betaine in the feed or water was similar to the control birds. The treatment x sex interaction was marginally non-significant (P=0.06). For all treatments males had better LWG, but this difference tended to be greatest when the betaine was supplied in water alone and when electrolytes and betaine were supplied. However, this is complicated because the electrolytes were only supplied in Week 6.
Table 2.2. The effect of treatment on the mean (±SEM) average daily LWG (g/d) of ducks exposed to periods of cyclic high ambient temperature in Weeks 5 and 6 of age

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>48.9±1.5</td>
<td>78.4±1.5</td>
<td>52.9±1.5</td>
<td>53.2±1.5</td>
</tr>
<tr>
<td>Vitamin C</td>
<td>48.7±1.5</td>
<td>78.8±1.5</td>
<td>56.9±1.5</td>
<td>50.4±1.6</td>
</tr>
<tr>
<td>Betaine in water</td>
<td>49.3±1.5</td>
<td>79.8±1.5</td>
<td>55.7±1.5</td>
<td>51.7±1.5</td>
</tr>
<tr>
<td>Betaine in feed</td>
<td>48.6±1.5</td>
<td>79.0±1.5</td>
<td>55.9±1.5</td>
<td>54.3±1.6</td>
</tr>
<tr>
<td>Feed withdrawal</td>
<td>50.1±1.5</td>
<td>78.1±1.5</td>
<td>55.9±1.5</td>
<td>51.7±1.6</td>
</tr>
<tr>
<td>Electrolytes + betaine in water</td>
<td>48.9±1.5</td>
<td>79.0±1.5</td>
<td>52.7±1.5</td>
<td>62.1±1.5</td>
</tr>
</tbody>
</table>

Note: Values within a column with different superscripts are significantly different (P<0.05)

Strain had a significant effect on average daily LWG but this changed with time (see Figure 2.3) and sex, as the strain x week interaction was significant (P<0.001) as was the strain x sex interaction (P<0.05). At all weeks except Week 6, the P2 strain had a significantly higher LWG than the CV strain (P<0.05). For both strains males were heavier than females (P<0.05), but the difference was greater for strain P2 (57.4±1.3 v 64.3±1.3 g/d) than strain CV (54.7±1.3 v 60.3±1.3 g/d).

The effect of sex on average LWG is given in Figure 2.4. The interaction between sex and week was significant (P<0.001). At two weeks of age, sexes have similar average LWG but thereafter, males had higher LWG than females (P<0.05), and the difference increased as the birds aged.

Figure 2.3. The effect of strain on the mean average daily LWG (g/d) of ducks exposed to periods of cyclic high ambient temperature in Weeks 5 and 6 of age
2.4.3. Feed intake

The effect of treatment on feed intake in the different phases of the production cycle is given in Table 2.3. Treatment had no effect on feed intake at different ages (P=0.33). There was no difference in total feed intake between the different treatment groups (P=0.02).

Table 2.3. The effect of treatment on the mean (±SEM) feed intake (g) of ducks exposed to periods of cyclic high ambient temperature in Weeks 5 and 6 of age

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5</th>
<th>Week 6</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>866±19</td>
<td>2,122±47</td>
<td>1,168±26</td>
<td>1,114±25</td>
<td>5,277±84</td>
</tr>
<tr>
<td>Vitamin C</td>
<td>867±19</td>
<td>2,193±48</td>
<td>1,233±27</td>
<td>1,118±25</td>
<td>5,424±84</td>
</tr>
<tr>
<td>Betaine in water</td>
<td>877±19</td>
<td>2,162±48</td>
<td>1,216±27</td>
<td>1,113±24</td>
<td>5,377±84</td>
</tr>
<tr>
<td>Betaine in feed</td>
<td>863±19</td>
<td>2,145±47</td>
<td>1,162±26</td>
<td>1,123±25</td>
<td>5,304±84</td>
</tr>
<tr>
<td>Feed withdrawal</td>
<td>862±19</td>
<td>2,141±47</td>
<td>1,174±26</td>
<td>1,054±23</td>
<td>5,234±84</td>
</tr>
<tr>
<td>Electrolytes + betaine in water</td>
<td>861±19</td>
<td>2,122±47</td>
<td>1,151±25</td>
<td>1,135±25</td>
<td>5,275±84</td>
</tr>
</tbody>
</table>

Strain had a significant effect on feed intake (Table 2.4) but this changed with time as the strain x week interaction was significant (P<0.001). In Weeks 5 and 6 when the birds were exposed to high temperature those of the P2 strain had significantly higher feed intake than birds of the CV strain (P<0.05). Strain had a significant effect on total feed intake (P<0.001), with it being higher for strain P21 than strain CV (P<0.05).
Table 2.4. The effect of strain on the mean (±SEM) feed intake (g) of ducks exposed to periods of cyclic high ambient temperature in Weeks 5 and 6 of age

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5</th>
<th>Week 6</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>P21</td>
<td>872±14</td>
<td>2,156±34</td>
<td>1,229±20&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1,152±18&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5,417±69&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>CV</td>
<td>859±14</td>
<td>2,139±34</td>
<td>1,139±18&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1,068±17&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5,213±69&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Note: Within columns values with different superscripts are significantly different (P<0.05)

2.4.4. Water intake

The effect of treatment on water intake is given in Table 2.5. Treatment had no effect on water intake during the different production phases (P=0.57). There was a significant effect of week on water intake (P<0.001). The difference in water intake between Weeks 5 and 6 was significant for all treatment groups (P<0.05). There were no differences in the total amount of water consumed during the full production phase (P=0.58). Strain had no effect on water intake (P=0.27) during the different production phases. The effect of strain on total water intake was not significant (P=0.40), with it being 19.69±0.36 L for Strain P21 and 19.38±0.36 L for Strain CV.

Table 2.5. The effect of treatment on the mean (±SEM) water intake (L) of ducks exposed to periods of cyclic high ambient temperature in Weeks 5 and 6 of age

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5</th>
<th>Week 6</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>2.27±0.07</td>
<td>6.25±0.20</td>
<td>4.87±0.16</td>
<td>6.35±0.20</td>
<td>19.79±0.51</td>
</tr>
<tr>
<td>Vitamin C</td>
<td>2.23±0.07</td>
<td>6.16±0.20</td>
<td>4.76±0.15</td>
<td>5.95±0.19</td>
<td>19.53±0.51</td>
</tr>
<tr>
<td>Betaine in water</td>
<td>2.23±0.07</td>
<td>6.06±0.20</td>
<td>4.79±0.15</td>
<td>6.11±0.20</td>
<td>19.46±0.51</td>
</tr>
<tr>
<td>Betaine in feed</td>
<td>2.28±0.07</td>
<td>6.20±0.20</td>
<td>4.48±0.14</td>
<td>5.95±0.19</td>
<td>19.01±0.51</td>
</tr>
<tr>
<td>Feed withdrawal</td>
<td>2.27±0.07</td>
<td>6.21±0.20</td>
<td>4.88±0.16</td>
<td>6.41±0.21</td>
<td>19.79±0.51</td>
</tr>
<tr>
<td>Electrolytes + betaine in water</td>
<td>2.31±0.07</td>
<td>6.37±0.20</td>
<td>4.74±0.15</td>
<td>6.52±0.21</td>
<td>20.00±0.51</td>
</tr>
</tbody>
</table>

2.4.5. Feed to gain

Treatment had a marginally non-significant effect (P=0.07) on feed to gain (see Table 2.6). The treatment x week (P=0.50) and treatment x strain (P=0.93) interactions were not significant. In Week 6 there tended to be a treatment effect, with the feed to gain for the electrolyte plus betaine supplementation appearing to be better. Treatment had a significant effect on the total feed to gain (P=0.02). The feed to gain was significantly poorer in birds provided with vitamin C than those given electrolytes and betaine, betaine in the feed or feed withdrawal (P<0.05).
Table 2.6. The effect of treatment on the mean (±SEM) feed to gain of ducks exposed to periods of cyclic high ambient temperature in Weeks 5 and 6 of age

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5</th>
<th>Week 6</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.26±0.01</td>
<td>1.93±0.03</td>
<td>3.15±0.14</td>
<td>2.95±0.11</td>
<td>2.09±0.02abc</td>
</tr>
<tr>
<td>Vitamin C</td>
<td>1.27±0.01</td>
<td>1.99±0.03</td>
<td>3.14±0.14</td>
<td>3.13±0.13</td>
<td>2.14±0.02a</td>
</tr>
<tr>
<td>Betaine in water</td>
<td>1.27±0.01</td>
<td>1.93±0.03</td>
<td>3.10±0.13</td>
<td>3.04±0.12</td>
<td>2.10±0.02ab</td>
</tr>
<tr>
<td>Betaine in feed</td>
<td>1.27±0.01</td>
<td>1.94±0.03</td>
<td>2.98±0.12</td>
<td>2.92±0.11</td>
<td>2.07±0.02bc</td>
</tr>
<tr>
<td>Feed withdrawal</td>
<td>1.24±0.01</td>
<td>1.97±0.03</td>
<td>3.00±0.12</td>
<td>2.94±0.11</td>
<td>2.07±0.02bc</td>
</tr>
<tr>
<td>Electrolytes + betaine in water</td>
<td>1.26±0.01</td>
<td>1.92±0.03</td>
<td>3.13±0.13</td>
<td>2.67±0.08</td>
<td>2.04±0.02c</td>
</tr>
</tbody>
</table>

Strain had an effect on feed to gain (see Table 2.7) but this changed with the stage of production cycle, as the strain x week interaction was significant (P<0.001). During Weeks 1–2 and 3–4 strain P2 had a better feed to gain than strain CV (P<0.05). During the high temperature treatment periods of Weeks 5 and 6 this difference was not evident. The strain effect on the total feed to gain was significant (P=0.045) and was poorer for strain CV (P<0.05).

Table 2.7. The effect of strain on the mean (±SEM) feed to gain for the different phases of the production cycle

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5</th>
<th>Week 6</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>P21</td>
<td>1.24±0.01b</td>
<td>1.91±0.01b</td>
<td>3.04±0.08</td>
<td>3.00±0.07</td>
<td>2.07±0.01b</td>
</tr>
<tr>
<td>CV</td>
<td>1.28±0.01a</td>
<td>1.99±0.01a</td>
<td>3.13±0.08</td>
<td>2.87±0.06</td>
<td>2.10±0.01a</td>
</tr>
</tbody>
</table>

Note: Within columns, values with different superscripts are significantly different (P<0.05)

2.4.6. Water to feed

The effect of treatment on the water to feed ratio is given in Table 2.8. Treatment had no effect on the water to feed ratio (P=0.19). The week effect was significant (P<0.001), with this ratio being higher in Weeks 5 and 6 (P=0.05).
Table 2.8. The effect of treatment on the mean (±SEM) water to feed ratio of ducks exposed to periods of cyclic high ambient temperature in Weeks 5 and 6 of age

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>2.62±0.11</td>
<td>2.94±0.13</td>
<td>4.17±0.18</td>
<td>5.70±0.24</td>
</tr>
<tr>
<td>Vitamin C</td>
<td>2.57±0.11</td>
<td>2.81±0.12</td>
<td>3.86±0.17</td>
<td>5.32±0.23</td>
</tr>
<tr>
<td>Betaine in water</td>
<td>2.59±0.11</td>
<td>2.85±0.12</td>
<td>3.93±0.17</td>
<td>5.49±0.24</td>
</tr>
<tr>
<td>Betaine in feed</td>
<td>2.64±0.11</td>
<td>2.89±0.12</td>
<td>3.86±0.17</td>
<td>5.30±0.23</td>
</tr>
<tr>
<td>Feed withdrawal</td>
<td>2.63±0.11</td>
<td>2.90±0.12</td>
<td>4.16±0.18</td>
<td>6.08±0.26</td>
</tr>
<tr>
<td>Electrolytes + betaine in water</td>
<td>2.68±0.11</td>
<td>3.00±0.13</td>
<td>4.12±0.18</td>
<td>5.74±0.25</td>
</tr>
</tbody>
</table>

The effect of strain on water to feed ratio is given in Table 2.9. The strain x week interaction was significant (P=0.03). In Week 5, strain CV had a higher water to feed ratio than strain P21.

Table 2.9. The effect of strain on the mean (±SEM) water to feed ratio of ducks exposed to periods of cyclic high ambient temperature in Weeks 5 and 6 of age

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>P21</td>
<td>2.64±0.01</td>
<td>2.91±0.01</td>
<td>3.88±0.02</td>
<td>5.47±0.03</td>
</tr>
<tr>
<td>CV</td>
<td>2.60±0.01</td>
<td>2.89±0.01</td>
<td>4.16±0.02</td>
<td>5.74±0.03</td>
</tr>
</tbody>
</table>

Note: Within columns, values with different superscripts are significantly different (P < 0.05)

2.4.7. Breast yield

The effects of treatment, strain and sex on breast weight, breast weight expressed as a percentage of liveweight and the ratio of feed to breast weight is given in Table 2.10. Treatment had no effect on breast weight (P=0.63), breast percentage (P=0.50) or ratio of feed weight to breast weight (P=0.63). Sex had no effect on breast weight (P=0.87) or ratio of feed weight to breast weight (P=0.87). Strain had an effect on breast weight, breast as a percentage of liveweight and the ratio of feed to breast weight (all P<0.001). Strain P21 had greater breast weight, breast percentage and better ratio of feed to breast weight (P<0.05). Sex had no effect on breast weight (P=0.87) and the ratio of feed to breast weight (P=0.87), but had an effect on breast as a percentage of liveweight (P<0.001). Females had a higher breast percentage than males (P<0.05).
Table 2.10. The effects of treatment, strain and sex on breast weight, breast weight as a percentage of liveweight and the ratio of feed weight to breast weight

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Breast weight (g)</th>
<th>Breast as % of liveweight</th>
<th>Ratio of feed to breast weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>246±12</td>
<td>9.18±0.32</td>
<td>22.3±1.2</td>
</tr>
<tr>
<td>Vitamin C</td>
<td>253±11</td>
<td>9.29±0.29</td>
<td>22.7±1.1</td>
</tr>
<tr>
<td>Betaine in water</td>
<td>264±11</td>
<td>9.77±0.29</td>
<td>21.8±1.1</td>
</tr>
<tr>
<td>Betaine in feed</td>
<td>254±11</td>
<td>9.56±0.30</td>
<td>23.4±1.1</td>
</tr>
<tr>
<td>Feed withdrawal</td>
<td>243±11</td>
<td>9.14±0.29</td>
<td>23.1±1.1</td>
</tr>
<tr>
<td>Electrolytes + betaine in water</td>
<td>266±11</td>
<td>9.73±0.30</td>
<td>20.6±1.1</td>
</tr>
<tr>
<td>Strain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P21</td>
<td>301±6a</td>
<td>10.18±0.17a</td>
<td>18.4±0.6b</td>
</tr>
<tr>
<td>CV</td>
<td>208±7b</td>
<td>8.08±0.17b</td>
<td>25.9±0.7a</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>255±6</td>
<td>9.92±0.16a</td>
<td>22.1±0.6</td>
</tr>
<tr>
<td>Male</td>
<td>254±6</td>
<td>8.97±0.16b</td>
<td>22.2±0.6</td>
</tr>
</tbody>
</table>

Note: For strain and sex, values within a column without common superscripts are different (P<0.05)

2.5. Discussion

In Week 5, when birds weighted around 1.8 kg at the start of Heat Period 1, all treatments applied increased daily LWG compared to the control birds. The power of the analysis identified subtle differences in LWG of around 2–4 g/d (14–28 g/week) and realistically, this is not going to be readily measured as differences in final liveweight.

In the second heat period, the supplementation with electrolytes and betaine in the water improved average daily gain and the improvement transcended into heavier final liveweight compared to the control birds given water alone. All the treatments applied have been reported to improve LWG in broilers, but in many cases this has been under continuous high temperature and often at very high temperatures (see Section 1.3). The starting hypothesis is correct in part, as the electrolyte plus betaine supplementation improved performance but the other treatments had limited effect. The pattern of cyclic high temperature used here with the maximum of 32°C might be expected to cause moderate HS. The lengthy period of lower temperature could provide these birds with sufficient time to compensate for any effects the high temperature had on performance. This is supported by the fact that there were no differences in feed intake between treatments.
Under high ambient temperature, reduction in feed intake is associated with reduced performance (Mitchell and Carlisle 1992; Yalcin et al. 1997). During the period of high temperature ducks are likely to limit feed consumption to reduce metabolic heat load (Donkoh 1989), but then compensate for this during the period when the temperature was at 24°C. The effect of treatment on feed to gain was marginally non-significant (P=0.06). In Week 6, birds treated with electrolytes plus betaine tended to have better feed to gain. This trend may have helped to account for the significantly improved total feed to gain seen for these birds compared to some other treatments. The poor performance in LWG in Week 6 for birds supplemented with vitamin C, betaine in water and with feed withdrawal needs to be viewed with caution as the differences, while identified as significant, remain small. No treatment differences in water intake were observed, but for all treatments this was greater in the second heat period than the first. Part of this increase is probably a result of the birds being heavier in the second heat period and their need to dissipate a greater heat load. During Weeks 5 and 6, the water to feed ratio was higher than in earlier weeks. This is a response to the high temperature, with the birds consuming more water in an attempt to assist in heat dissipation. There were no treatments effects on the water to feed ratio and this was to be expected as there were no differences in feed or water intakes attributed to the treatments.

Up until Week 2, male and female ducks had a similar daily LWG. After this, the LWG of the males was greater than that of the females but this difference was larger for the P2 strain than the CV strain. The P2 strain has been selected from the parent CV strain for increased liveweight and breast muscle development. This selection is an obvious reason for the differences observed between these strains. Interestingly, the difference between these strains is not seen in Week 6 where the LWG is similar. The effect of high temperature or HS is dependent on liveweight (Teeter and Belay 1996; Gous and Morris 2005). The P2 ducks are heavier in Week 6 and the effects of the high temperature could be more severe for these birds.

Using the same reasoning, it could be expected that the difference in liveweight between males and females would see the males more severely affected by the heat, especially in Week 6. In the current study, the LWG of females in Week 6 actually decreased compared to Week 5 whereas that of the males remained similar to Week 5. There is a confounding issue here. Females reached maximum daily LWG earlier than males as has reported previously to the RIRDC (Downing 2010). The sex differences seen in the normal pattern of growth would naturally see females with a lower LWG in Week 6 than males. The sex x treatment interaction for LWG was marginally non-significant (P=0.06). There was a trend for males to benefit from the betaine added to the water and the electrolyte plus betaine in the water. Any benefit for males would likely be related to their heavier weight.

During the two heat periods, the P2 strain had a higher total feed intake than the CV strain. While there are reported genotype effects on responses to HS (Reviewed in Lin et al. 2006), the differences in feed intake are most likely due to the liveweight differences between these two strains rather than any direct effect of genotype on feed intake. While the strain weight differences might have effects during the high temperature period each day, the time spent at the lower temperature is most probably sufficient for birds to compensate for any differences occurring during the daily period of high temperature. Strain CV had a poorer feed to gain over the full production cycle. So, while the P2 strain consumes more feed, it is more efficient in converting this to LWG.

Strain had no effect on water intake. While the heavier P2 strain might need to dissipate more heat during the high temperature period and consume more water, the lengthy period at the lower temperature each day might help to even out water consumption. The only strain effect on water to feed ratio was seen in Week 5 where it was higher for the CV strain.

While feed efficiency is routinely determined as the feed weight to LWG, a better measure would be the feed consumed to produce consumable meat, especially the high quality breast meat. Treatment had no effect on efficiency of feed use to produce breast meat. Strain had an effect, with the P2 strain producing more breast muscle and doing this with increased efficiency. This difference in yield is to be expected as the P2 strain has been selected for increased breast yield, but it is an economic advantage that it is done with improved efficiency.
There is evidence that in Week 5, all treatments provided the birds with some advantage over the control group. This was not as evident in Week 6; in fact, the continued supplementation with vitamin C had a negative effect. The supplementation with electrolytes and betaine in water during Week 6 had a positive effect on the rate of LWG. It is possible that the improved LWG is related to increased water retention as no increase in breast weight was observed between the treatment groups. However, there was a large variation in breast yields and the sampling size may not have been sufficient to detect small improvements in breast yield.

The use of electrolytes and betaine supplementation during periods of high temperature warrants further evaluation and any economic improvements should be considered by analysis of carcass yield following a commercial cut-up after processing. Improvements in LWG would be reflective of less physiological stress, and this would potentially improve the ducks ability to handle periods of HS.
Chapter 3: The role of stocking density and light intensity on the performance and feather pecking activity of commercial Pekin ducks

3.1. Introduction

FP causes feather damage, carcass injuries and increased difficulty with the removal of feathers during processing. In commercial poultry, the factors thought to predispose birds to FP are wide ranging (see Section 1.5.1). Both stocking density (see Section 1.5.2.4) and light intensity (see Section 1.5.2.5) have been implicated in affecting FP behaviour. Observation made during a previous project: ‘Efficient, environment and bird friendly duck production’ (Downing 2010) suggested that there are genetic (CV more prone to FP than the GF Pekin ducks), seasonal (incidence greater in winter than summer) and age (beginning at around 3–4 weeks of age) components to this behaviour. What is clearly lacking in the literature is any detailed long-term study of duck behaviour in intensive housing systems. There is limited research on FP in ducks and there is little understanding as to what factors predispose ducks to FP. Obviously if this is unknown, the solutions remain obscure. Areas needing consideration are the effects that light intensity and stocking density have on the incidence of FP but also production performance in commercial ducks.

3.2. Objective

The objective of the study was to assess the effects of stocking density and light intensity on the growth performance and extent of FP in CV and the GF Pekin ducks. A further objective was to identify if there were differences in behaviour that might help account for the strain effects on FP seen in commercial sheds. The working hypothesis is that FP would be increased at high light intensity and at higher stocking density and performance would not be affected.

3.3. Material and methods

3.3.1. Experimental design

There were 48 pens allocated to the study, with the shed being divided into halves separated by a partition allowing different light intensities to be maintained in each compartments. The 24 pens in each compartment were numbered sequentially and divided evenly into four blocks. Each treatment was randomly allocated a pen in each block. 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. The group sizes remained the same and 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.

3.3.2. Birds and husbandry

The treatments were applied to two strains of Pekin ducks reared as mixed sex groups, consisting of equal numbers of males and females. The strains used were the CV and GF. The strains were produced by the appropriate matings at a commercial breeding farm owned by PEPE’s Ducks Pty Ltd (Windsor, NSW), 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. On arrival, ducklings were placed in their allocated pens.

Birds had access to feed and water ad libitum. The starter and grower feeds were provided by Ingham’s Pty Ltd. The starter diet was formulated to provide 12.45 MJ ME/kg and 22.0% protein,
while the grower diet was formulated to provide 12.58 MJ ME/kg and 19% protein. The starter diet was in crumble form and was fed from Day 1 to Day 14. The finisher diet was in pellet form and was provided from Days 15–41.

3.3.3. Treatments

The experimental treatments consisted of two strains (CV and GF), two light intensities (high and low) and three stocking densities, low density (4.4 birds/m²), medium density (5.2 birds/m²) and high density (6.0 birds/m²). The 12 treatments were:

1. Strain CV in high light at 4.4 birds/m²
2. Strain CV in high light at 5.2 birds/m²
3. Strain CV in high light at 6.0 birds/m²
4. Strain GF in high light at 4.4 birds/m²
5. Strain GF in high light at 5.2 birds/m²
6. Strain GF in high light at 6.0 birds/m²
7. Strain CV in low light at 4.4 birds/m²
8. Strain CV in low light at 5.2 birds/m²
9. Strain CV in low light at 6.0 birds/m²
10. Strain GF in low light at 4.4 birds/m²
11. Strain GF in low light at 5.2 birds/m²
12. Strain GF in low light at 6.0 birds/m²

3.3.4. Stocking density

The stocking densities used were determined from discussions with PEPE’s Ducks Pty Ltd. Under their farming management system, ducks are housed at a density of 5.2 birds/m². The density of 4.4 birds/m² was chosen on the basis that it would be the minimum density that would be economically viable for the production system. The density of 6.0 birds/m² was chosen on the basis that this would be the maximum that could be sustained under summer conditions using the conventional housing type currently used in production.

3.3.5. Lighting

During the first week, ducks were supplied with full fluorescent lighting at the same intensity throughout the shed. From Weeks 2 to 6 of age, the treatment light intensities were applied. In one half of the shed, the light was supplied by a circuit of globes connected to a dimmer switch and light intensity was maintained at less than 5 lux. In the other half of the shed, the light was supplied from a different circuit and the light intensity was maintained at greater than 60 lux.

3.3.6. Performance and carcass measurements

At placement, a collective pen weight was recorded. On Days 14 (Week 2), 28 (Week 4), 35 and 41 (Week 6) all ducks were individually weighed. Feed intakes were determined over the same time periods and water intakes were recorded daily. On Day 41, one male and one female duck from each pen was euthanised and the weight of breast muscle determined.

3.3.7. Behavioural measures

Eight pens in the high light intensity section of the shed were used to evaluate behaviour of the two strains. The number of pens observed was determined by resource constraints. The eight pens were continuously monitored by two video cameras per pen. One camera with a 3.6 mm lens covered the entire floor area of the pen (3 m x 1.5 m). The second camera, with a 6.0 mm lens, covered the front half of the pen to provide clearer detail of ducks in this area. The observation experiment was of a 2 x 2 factorial design with the main effects being strain and stocking density. The four treatment combinations were the CV strain at 4.4 birds/m² and 5.2 birds/m², and the GF strain at the same
densities with each treatment combination replicated in two pens. Observations were made on each pen at five minute intervals for a 24 hour period at 3, 4, 5 and 6 weeks of age. The sampling frequency was determined after initial observations of the videos indicated that bouts of activity by the ducks occurred in very brief bursts. This is supported by sampling methods using similar observation periods (Riber and Mench 2008).

The ethogram used was adapted from Jones et al. (2009) and Barber et al. (2004). The activities identified as being potentially relevant to FP were specific grooming activities and general activity level. The grooming activities were categorised as self-directed or directed to a flockmate and by the perceived level of aggression exerted. More specific descriptions of FP behaviours have been made with respect to chickens (see Section 1.5.1). However, it can be often difficult to determine between overlapping descriptions. Three levels of grooming activities could easily be differentiated. ‘Preening’, as described by Barber et al. (2004), could be performed by a duck to itself or a neighbour. ‘Vigorous grooming’ was identified when preening activities directed to another bird elicited a response perceived to be a negative reaction from the other bird, such as tail wagging or getting up and moving away. FP was identified as a single, rapid and apparently aggressive peck, which could be performed while the pecker was stationary or moving. The bird pecking was usually standing and the attack always elicited a response. Other activities included eating, drinking, foraging in the litter or environment-directed pecking at items in the pen such as the walls. The categories evaluated are described in Table 3.1.

### Table 3.1. The behavioural categories used to identify feather pecking behaviour during video surveillance

<table>
<thead>
<tr>
<th>Grooming activity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preening—self</td>
<td>Grooming activity directed towards itself</td>
</tr>
<tr>
<td>Preening—other</td>
<td>Grooming activity directed towards another bird with no negative response</td>
</tr>
<tr>
<td>Preening—mutual</td>
<td>Grooming activity directed to another bird and reciprocated</td>
</tr>
<tr>
<td>Vigorous grooming</td>
<td>Grooming activity directed towards another bird, with discomfort demonstrated by the second bird</td>
</tr>
<tr>
<td>Feather peck</td>
<td>A single attack directed towards a neighbouring bird, usually with a response from the second bird</td>
</tr>
</tbody>
</table>

### 3.3.8. Feather damage

At the end of Week 3, all birds were individually examined and the extent of FP and damage was determined and then this was repeated at the end of Week 4. Details of the feather damage evaluation are given in the Methods section.

### 3.3.9. Statistical analysis

#### 3.3.9.1. Production performance

Data were stored in Microsoft Excel® and, unless stated otherwise, statistical analysis was conducted using the REML linear mixed model function of Genstat® 11th edition. The data were first tested for equality of variance using residual plots. When the equality of variance could be improved using a loge transformation the data was transformed.
The fixed model included the effects of light intensity, stocking density, strain, sex and week and the random model included the effects of block, pen and tag. Initially all two-way interactions between fixed effects were included in the model. Significance testing of fixed effects was conducted using Wald tests with a significance threshold of P<0.05. Any non-significant interactions were removed from the model. The predicted means for all significant fixed effects were copied to Microsoft Excel® as well as the standard errors which were used to calculate the SEM. The LSD, which is equal to two times the SED, was used to make pairwise comparisons of means. Microsoft Excel® was used to create graphical summaries of the back-transformed means. All carcass measurements were analysed as a proportion of liveweight.

3.3.9.2. Feather damage

The FP analysis was conducted using an ordinal logistic regression model with a proportional odds method (Agresti, 2002). The form of the method specified in the analyses is:

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

Where:

\[P(Y \leq k) = \text{probability of obtaining a score of } k \text{ or lower, } k=0, 1, 2\]

\[\theta_k = \text{intercept for a score of } k;\]

The fixed effects of the model are:

- Density = effect of 4.4, 5.2 or 6.0 birds/m² (fixed)
- Light: effect of low or high (fixed)
- Strain= effect CV and GF (fixed)
- Period = effect of ‘replicate’ (1: Weeks 3, 2: Weeks 4) (fixed)
- Region = effect of body region (left wing (LW), right wing (RW), left thigh (LT), right thigh (RT) and tail) (fixed);

with Density.Period + Strain.Period + Period.Region being the interactions between these factors. (Other interactions were tested, but were excluded because of non-significance). The random effects of the model were:

- Block , assumed \(N(0, \sigma_B^2)\)
- Block Pen (pen effect nested within block), assumed \(N(0, \sigma_P^2)\)
- Block Pen.Tag (bird effect nested within pen), assumed \(N(0, \sigma_T^2)\)
- Block Pen.Tag.Period (set of bird’s measurements at a particular period, assumed \(N(0, \sigma_M^2)\).

This is a model for the cumulative log odds (logit) of obtaining a score of \(k\) or lower. Note that the log odds assumption implies that difference in score probabilities is entirely accounted for by the separate intercepts for each score (\(\theta_k\), i.e., the fixed (and random) effects of interest apply across all scores.

The significance of the fixed effects was assessed using Wald Chi-square tests, and individual treatment or other between-group comparisons were conducted using approximate \(z\)-tests:
\[ z = \frac{\logit_1 - \logit_2}{\text{SED}} \]

Where:

\[ \logit_1 - \logit_2 = \text{difference in model-based logits of the two treatments} \]

\[ \text{SED} = \text{standard error of the difference of the model-based logits.} \]

A \( z \)-statistic greater than 2.0 (in absolute value) was identified as significant (\( P < 0.05 \), approximately). For the current analysis, \( \logit[P(Y = 0)] = \log[P(Y = 0)/P(Y > 0)] \) was used to compare logits of different treatments, but any score cut-off could be used with identical results.

While the model fitting returns cumulative probabilities, \( P(Y \leq k) \), individual event probabilities can then be calculated by difference to allow visualisation; for example:

\[ P(Y = k) = \begin{cases} P(Y \leq 0) & k = 0 \\ P(Y \leq k) - P(Y \leq k - 1) & k = 1, 2 \\ 1 - P(Y \leq 2) & k = 3 \end{cases} \]

The models were fitted using the stand-alone version of ASReml 3 (Gilmour et al. 2009). Note that in this package, it was required to recode scores from 0–3 to 1–4, but the results are unchanged.

### 3.3.9.3. Behavioural analysis

Each of the behavioural analyses was considered a binomial trait, in the sense that the observation was the number of birds in a pen of 20 that exhibited the particular behaviour. Consequently, logistic regression was used to analyse the data. To allow for the clustering effects of pens, and week effect within a pen, random effects were included in the model and hence a generalised linear mixed model (GLMM) was fitted to each of the behaviour traits. The form of the model fitted for each trait was:

\[ \log_e \left( \frac{\pi}{1 - \pi} \right) = \text{constant} + \text{Treatment} + \text{Week} + \text{Treatment.Week} + \beta_S S_t + \beta_C C_t + \text{Pen} + \text{Pen.Week} + f_S(S_t) + f_C(C_t) \]

Where:

\[ S_t = \sin \left( \frac{2\pi t}{1440} \right) \quad \text{and} \quad C_t = \cos \left( \frac{2\pi t}{1440} \right) \]

with \( t \) being the time of observation in the day in minutes (0:00 to 24:00, in five minute intervals). The purpose of the sine-cosine pair of terms is to accommodate any 24 hour cycle of behaviour in the model. The terms \( f_S(\cdot) \) and \( f_C(\cdot) \) are smoothing splines to allow for any further cyclic pattern not accounted for by the simple sine-cosine pair. Note that the spline terms, along with Pen and Pen.Week are specified as random effect in the model. The analysis was conducted using ASReml-R.

### 3.4. Results

#### 3.4.1. Liveweight

The effects of stocking density, light intensity, strain and sex on mean (±SEM) liveweight are given in Table 3.2. Stocking density had a significant effect on liveweight but this changed with time as the stocking density x week interaction was significant (\( P = 0.004 \)). At the end of Week 6, birds at the
highest stocking density had lower liveweight than birds held at the lowest stocking density (P<0.05) but no difference was seen at other times. At the end of Week 6, the low and medium density treatments had similar liveweight. The interaction between light intensity and week was significant (P<0.001). There was no difference at the end of the starter period (Week 2). However, at the end of Week 4, birds in the low light intensity had higher liveweight (P<0.05), but this difference was not observed at the end of Week 6. The interaction between strain and week was significant (P<0.001). At all times Strain GF was heavier than Strain CV (P<0.05). The interaction between sex and week was significant (P<0.001). Males were heavier than females at all times (P<0.05), but the difference was greater as the birds aged.

Table 3.2. The effects of stocking density, light intensity, strain and sex on mean (±SEM) liveweight (g) of ducks during different phases of the production cycle

<table>
<thead>
<tr>
<th>Stocking density</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>754±5</td>
<td>2,028±12</td>
<td>3,106±19b</td>
</tr>
<tr>
<td>Medium</td>
<td>755±5</td>
<td>2,030±12</td>
<td>3,150±19b</td>
</tr>
<tr>
<td>Low</td>
<td>753±5</td>
<td>2,049±12</td>
<td>3,153±19a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Light intensity</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>751±5</td>
<td>2,057±12a</td>
<td>3,153±19</td>
</tr>
<tr>
<td>High</td>
<td>755±5</td>
<td>2,016±12b</td>
<td>3,118±19</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strain</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV</td>
<td>739±4b</td>
<td>1968±10b</td>
<td>3,014±15b</td>
</tr>
<tr>
<td>GF</td>
<td>770±4a</td>
<td>2107±10a</td>
<td>3,265±16a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sex</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>744±4b</td>
<td>2,002±10b</td>
<td>3,038±15b</td>
</tr>
<tr>
<td>Male</td>
<td>764±4a</td>
<td>2,069±10a</td>
<td>3,236±16a</td>
</tr>
</tbody>
</table>

Note: The different measures values within a column without common superscripts are significantly different (P<0.05)

3.4.2. Liveweight gain

The effects of stocking density, light intensity, strain and sex on mean (±SEM) LWG are given in Table 3.3. Stocking density had a significant effect on LWG but this changed with time as the stocking density x week interaction was significant (P=0.002). Until the end of Week 4, stocking density had no effect on LWG. During Weeks 5–6, birds at the highest density had a lower LWG than birds at the lower densities (P<0.05). Light intensity, strain and sex all had significant effects on LWG but these changed with time as all interactions with week were significant (all P<0.001). Light intensity had no effect on LWG at the end of the starter period. During Weeks 3–4 birds in the low light intensity group
had greater LWG (P<0.05), but the difference in Weeks 5–6 was not significant. Strain GF had greater LWG at all weeks (P<0.05). Males had better gain than females at all weeks (P<0.05).

Table 3.3. The effects of stocking density, light intensity, strain and sex on mean (±SEM) LWG (g) of ducks during different phases of the production cycle

<table>
<thead>
<tr>
<th>Stocking density</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>697±5</td>
<td>1,273±9</td>
<td>1,071±7b</td>
</tr>
<tr>
<td>Medium</td>
<td>698±5</td>
<td>1,279±9</td>
<td>1,115±8a</td>
</tr>
<tr>
<td>Low</td>
<td>696±5</td>
<td>1,293±9</td>
<td>1,098±8a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Light intensity</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>694±4</td>
<td>1,308±8a</td>
<td>1,091±7</td>
</tr>
<tr>
<td>High</td>
<td>700±4</td>
<td>1,258±8b</td>
<td>1,097±7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strain</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV</td>
<td>682±4b</td>
<td>1,228±7b</td>
<td>1,040±6b</td>
</tr>
<tr>
<td>GF</td>
<td>713±4a</td>
<td>1,338±8a</td>
<td>1,151±7a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sex</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>687±3b</td>
<td>1,259±6b</td>
<td>1,029±6b</td>
</tr>
<tr>
<td>Male</td>
<td>700±3a</td>
<td>1,305±8a</td>
<td>1,163±7a</td>
</tr>
</tbody>
</table>

Note: The different measures values within a column without common superscripts are significantly different (P<0.05)

3.4.3. Feed intake

The effects of stocking density, light intensity and strain on mean (±SEM) feed intake are given in Table 3.4. Stocking density had no effect on feed intake (P=0.31). Light intensity had an effect, but this changed with time as the light intensity x week interaction was significant (P<0.001). The only difference was in Weeks 1–2 where the birds in the high light intensity group had higher intake than those in the low intensity group (P<0.05). It needs to be noted that in Week 1 both groups of birds were exposed to the same light intensity. The strain x week interaction was significant (P<0.001). Over Weeks 3–4 and Weeks 5–6 the GF strain had a higher feed intake than the CV strain (P<0.05). Strain had an effect on total feed intake (P<0.001), with it being lower for the CV (6,170±47 g) strain compared to the GF (6,493±47) strain (P<0.05). The total feed intake for the high (6,273±58 g), medium (6,336±58 g) and low (6,385±58 g) stocking densities were similar (P=0.41). The total feed intake for the low (6,322±48 g) and high light intensity (6,341±48 g) groups was similar (P=0.79).
Table 3.4. The effects of stocking density, light intensity and strain on mean (±SEM) feed intake (g) of ducks during different phases of the production cycle

<table>
<thead>
<tr>
<th>Stocking density</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>711±9</td>
<td>2,407±29</td>
<td>3,149±38</td>
</tr>
<tr>
<td>Medium</td>
<td>724±9</td>
<td>2,455±29</td>
<td>3,197±38</td>
</tr>
<tr>
<td>Low</td>
<td>722±9</td>
<td>2,458±29</td>
<td>3,413±38</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Light intensity</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>703±7b</td>
<td>2,421±24</td>
<td>3,188±32</td>
</tr>
<tr>
<td>High</td>
<td>735±7a</td>
<td>2,455±25</td>
<td>3,140±31</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strain</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV</td>
<td>716±6</td>
<td>2,383±21b</td>
<td>3,059±27b</td>
</tr>
<tr>
<td>GF</td>
<td>723±7</td>
<td>2,495±23a</td>
<td>3,268±29a</td>
</tr>
</tbody>
</table>

Note: The different measures values within a column without common superscripts are significantly different (P<0.05)

3.4.4. Water intakes

The effects of stocking density, light intensity and strain on mean (±SEM) water intake is given in Table 3.5. Stocking density had no effect on water intake (P=0.78). Light intensity had an effect, but this changed with time as the light intensity x week interaction was significant (P<0.001). The only difference was during Weeks 5–6 with the birds in the high light intensity group having a higher water intake than those in the low intensity group (P<0.05). The strain x week interaction was significant (P<0.001). During Weeks 5–6, the GF strain had a higher water intake than the CV strain (P<0.05).

Strain had an effect on total water intake (P<0.001), with it being lower for the CV strain (18.18±0.22 L) compared to the GF strain (18.94±0.23 L) (P<0.05). The total water intake for the high (18.47±0.24 L), medium (18.56±0.24 L) and low (18.62±0.24 L) stocking densities were similar (P=0.83). The total water intake for the low (18.77±0.28 L) and high light intensity (18.34±0.27 L) were also similar (P=0.33).
Table 3.5. The effects of stocking density, light intensity and strain on mean (±SEM) water intake (L) of ducks during different phases of the production cycle

<table>
<thead>
<tr>
<th>Stocking density</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>2.41±0.03</td>
<td>6.42±0.09</td>
<td>9.64±0.13</td>
</tr>
<tr>
<td>Medium</td>
<td>2.42±0.03</td>
<td>6.47±0.09</td>
<td>9.66±0.13</td>
</tr>
<tr>
<td>Low</td>
<td>2.44±0.03</td>
<td>6.46±0.09</td>
<td>9.70±0.13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Light intensity</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>2.43±0.03</td>
<td>6.45±0.10</td>
<td>9.45±0.14b</td>
</tr>
<tr>
<td>High</td>
<td>2.42±0.04</td>
<td>6.45±0.10</td>
<td>9.88±0.15a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strain</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV</td>
<td>2.41±0.03</td>
<td>6.39±0.08</td>
<td>9.35±0.11b</td>
</tr>
<tr>
<td>GF</td>
<td>2.43±0.03</td>
<td>6.50±0.08</td>
<td>9.99±0.12a</td>
</tr>
</tbody>
</table>

Note: The different measures values within a column without common superscripts are significantly different (P<0.05)

3.4.5. Feed to gain

The effects of stocking density, light intensity and strain on the mean (±SEM) feed to gain are given in Table 3.6. Stocking density had no effect on feed to gain (P=0.70). Light intensity had an effect, but this changed with time as the light intensity x week interaction was significant (P=0.003). During Weeks 1–2 and 3–4, the birds in the low light intensity group had better feed to gain. Strain had a significant effect on the feed to gain (P<.001), with birds of the GF strain having better feed to gain than those of the CV strain at all weeks (P<0.05).

Strain had an effect on the total feed to gain for the 41 day production cycle (P=0.004). The total feed to gain was worse for the CV (2.07±0.01) strain compared to the GF strain (2.01±0.01) (P<0.05). The total feed to gain ratio for the high (2.03±0.02), medium (2.05±0.02) and low (2.04±0.02) stocking rates were similar (P=0.78). The total feed to gain ratio for the low (2.02±0.02) and high light intensity groups (2.06±0.02) was similar (P=0.15).
Table 3.6. The effects of stocking density, light intensity and strain on mean (±SEM) feed to gain of ducks during different phases of the production cycle

<table>
<thead>
<tr>
<th>Stocking density</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>1.01±0.01</td>
<td>1.89±0.03</td>
<td>2.89±0.04</td>
</tr>
<tr>
<td>Medium</td>
<td>1.03±0.01</td>
<td>1.91±0.03</td>
<td>2.79±0.04</td>
</tr>
<tr>
<td>Low</td>
<td>1.03±0.01</td>
<td>1.89±0.03</td>
<td>2.89±0.04</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Light intensity</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>1.01±0.01</td>
<td>1.84±0.02</td>
<td>2.89±0.03</td>
</tr>
<tr>
<td>High</td>
<td>1.04±0.01</td>
<td>1.94±0.02</td>
<td>2.84±0.03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strain</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV</td>
<td>1.04±0.01</td>
<td>1.93±0.02</td>
<td>2.91±0.03</td>
</tr>
<tr>
<td>GF</td>
<td>1.01±0.01</td>
<td>1.85±0.02</td>
<td>2.81±0.03</td>
</tr>
</tbody>
</table>

Note: The different measures values within a column without common superscripts are significantly different (P<0.05)

### 3.4.6. Water to feed

The effects of stocking density, light intensity and strain on mean (±SEM) water to feed ratio are given in Table 3.7. Stocking density (P=0.79), light intensity (P=0.27) or strain (P=0.39) had no effects on water to feed ratio. Week had a significant effect on water to feed ratio (P<0.001), with the differences between all weeks being different (P<0.05).

The total water to feed ratio for the CV strain (2.95±0.04) and GF strain (2.92±0.04) were similar (P=0.47). The total water to feed ratio for the high (2.95±0.04), medium (2.92±0.04) and low (2.94±0.04) stocking rates were similar (P=0.84). The total water to feed ratio for the low (2.97±0.05) and high light intensity (2.90±0.05) groups was similar (P=0.32).
Table 3.7. The effects of stocking density, light intensity and strain on mean (±SEM) water to feed ratio of ducks during different phases of the production cycle

<table>
<thead>
<tr>
<th>Stocking density</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>3.39±0.05</td>
<td>2.67±0.04</td>
<td>3.06±0.05</td>
</tr>
<tr>
<td>Medium</td>
<td>3.35±0.05</td>
<td>2.64±0.04</td>
<td>3.07±0.05</td>
</tr>
<tr>
<td>Low</td>
<td>3.37±0.05</td>
<td>2.63±0.04</td>
<td>3.03±0.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Light intensity</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>3.44±0.05</td>
<td>2.66±0.04</td>
<td>3.10±0.05</td>
</tr>
<tr>
<td>High</td>
<td>3.31±0.05</td>
<td>2.64±0.04</td>
<td>3.06±0.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strain</th>
<th>Weeks 1–2</th>
<th>Weeks 3–4</th>
<th>Week 5–6</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV</td>
<td>3.38±0.05</td>
<td>2.68±0.04</td>
<td>3.05±0.04</td>
</tr>
<tr>
<td>GF</td>
<td>3.37±0.05</td>
<td>2.61±0.04</td>
<td>3.06±0.04</td>
</tr>
</tbody>
</table>

Note: The different measures values within a column without common superscripts are significantly different (P<0.05)

3.4.7. Breast yield

The effects of stocking density, light intensity and strain on mean (±SEM) breast weight, breast weight as a percentage of liveweight and the ratio of feed weight to breast weight are given in Table 3.8. Light intensity had no effect on breast weight (P=0.51), breast as a percentage (P=0.84) or the ratio of feed weight to breast weight (P=0.49). Sex had no effect on breast weight (P=0.50), or the ratio of feed weight to breast weight (P=0.39), but a significant effect on the breast weight as a percentage of liveweight (P<0.001). Females had a better percentage than did males (P<0.05). Stocking density had no effect on breast weight (P=0.77) or the ratio of feed weight to breast weight (P=0.50). Strain had a significant effect on breast weight (P<0.001) and the ratio of feed weight to breast weight (P<0.001), with weight being higher and the ratio of feed weight to breast weight better for the GF strain (P<0.05). For breast percentage, there was a significant interaction between strain and the stocking density (see Table 3.9). At the high and medium stocking densities, the GF strain had higher breast percentage than the CV strain (P<0.05), but not at the lowest stocking density.
Table 3.8. The effects of stocking density, light intensity and strain on mean (±SEM) breast weight, breast as a percentage of liveweight and the ratio of feed to breast weight of ducks at the end of the 41 day production cycle

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Breast weight (g)</th>
<th>Breast as % of liveweight</th>
<th>Ratio of feed to breast weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stocking density</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>280±7</td>
<td>-</td>
<td>22.3±0.6</td>
</tr>
<tr>
<td>Medium</td>
<td>283±7</td>
<td>-</td>
<td>23.2±0.6</td>
</tr>
<tr>
<td>Low</td>
<td>285±7</td>
<td>-</td>
<td>23.1±0.6</td>
</tr>
<tr>
<td>Light intensity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>280±5</td>
<td>8.91±0.12</td>
<td>23.1±0.5</td>
</tr>
<tr>
<td>High</td>
<td>285±5</td>
<td>8.95±0.12</td>
<td>22.6±0.5</td>
</tr>
<tr>
<td>Strain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>259±5</td>
<td>-</td>
<td>24.3±0.5&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>GF</td>
<td>307±</td>
<td>-</td>
<td>21.5±0.5&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>285±5</td>
<td>9.29±0.12&lt;sup&gt;a&lt;/sup&gt;</td>
<td>22.6±0.5</td>
</tr>
<tr>
<td>Male</td>
<td>280±5</td>
<td>8.57±0.12&lt;sup&gt;b&lt;/sup&gt;</td>
<td>23.1±0.5</td>
</tr>
</tbody>
</table>

Note: The different measures values within a column without common superscripts are significantly different (P<0.05)

Table 3.9. The effects of stocking density and strain on the mean (±SEM) breast weight as percentage of liveweight of ducks at the end of the 41 day production cycle

<table>
<thead>
<tr>
<th>Strain</th>
<th>Stocking density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td>CV</td>
<td>8.87±0.21&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>GF</td>
<td>9.51±0.21&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Note: Within a column values with different superscripts are significantly different (P<0.05)
3.4.8. Feather pecking behaviours

3.4.8.1. Self-preening

The pattern of self-preening during the day is given in Figure 3.1. The probability that birds would be preening themselves was lowest at midday and highest in the evening.

Figure 3.1. The pattern of probability (±SEM: dotted lines) that ducks would be self-preening during the 24 h monitoring period

The probability that the birds of the CV and GF strains would be self-preening was the same, at 0.054±0.002 (P=0.84). The effect of stocking density and week on the probability of self-preening is shown in Figure 3.2. Stocking density had no effect (P=0.93), but week did (P = 0.02).

Figure 3.2. The effect of stocking density (low=4.4 birds/m$^2$, medium=5.2 birds/m$^2$) and week (W3=Week 3; W4=Week 4; W5=Week 5; W6=Week 6) on the probability that ducks would be self-preening

3.4.8.2. Preening directed to another duck

There was only a low probability that ducks would be preening other birds. The pattern of preening directed at penmates during the day is given in Figure 3.3. The probability that ducks would be preening other birds was highest in the morning.
The probability of preening penmates for strain CV (0.006±0.001) was similar to that for strain GF (0.005±0.001) \( (P=0.25) \). The density and week effects on the probability ducks would be preening penmates are given in Table 3.10. Density had no effect \( (P=0.32) \), but week did \( (P=0.015) \).

**Table 3.10. The probability that ducks would be preening penmates in the different light intensities**

<table>
<thead>
<tr>
<th>Density</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (4.4 birds/m²)</td>
<td>0.004</td>
<td>0.007</td>
<td>0.007</td>
<td>0.006</td>
<td>0.001</td>
</tr>
<tr>
<td>Medium (5.2 birds/m²)</td>
<td>0.003</td>
<td>0.005</td>
<td>0.005</td>
<td>0.006</td>
<td>0.001</td>
</tr>
</tbody>
</table>

### 3.4.8.3. Mutual preening

The probability that birds would be engaging in mutual preening was very low. There was no strain effect \( (P=0.82) \), with it being less than 0.001 for both stains. The density and week effects on the probability ducks would be preening penmates are given in Figure 3.4. Density had a marginally non-significant effect \( (P=0.07) \), but week did \( (P=0.048) \). Over the 24 hour monitoring period the mutual preening activity was higher during the middle of the day.
3.4.8.4. Aggressive grooming

The probability that birds would be engaged in aggressive grooming was low. Over the 24 hour monitoring period the aggressive grooming activity was highest during the early morning (see Figure 3.5). There was no strain effect (P=0.20), with it being less than 0.12% for both strains. The density and week effects on the probability ducks would be involved in aggressive grooming are given in Figure 3.6. Density had no effect (P=0.16), while week had a highly significant effect (P<0.0001).

Figure 3.5. The pattern of probability (±SEM: dotted lines) that ducks would be involved in aggressive grooming during the 24 h monitoring period.
3.4.8.5. Feather pecking

The probability that birds would be engaging in FP was very low. Over the 24 hour monitoring period the FP activity was highest during the morning (see Figure 3.7). There was no strain effect (P=0.20), with FP activity being around 0.1% for both stains. The density and week effects on the probability ducks would be involved in aggressive grooming are given in Figure 3.8. Density had no effect (P=0.16), but week had a highly significant effect (P<0.0001).

Figure 3.7. The pattern of probability (plus and minus the SEM: dotted lines) that ducks would be involved in FP during the 24 h monitoring period
3.4.9. General activities

3.4.9.1. Resting

The probability that birds would be resting was high throughout the 24 hour monitoring period (see Figure 3.9). The probability of the ducks resting was lowest at midday. Strain had an effect (P=0.032), with the probability of strain GF ducks (0.656±0.008) being more likely to be resting than strain CV birds (0.626±0.008). The density and week effects on the probability that ducks would be resting are given in Figure 3.10. Density had no effect (P=0.15), but week had a highly significant effect (P<0.0001).
Figure 3.10. The effect of stocking density (low=4.4 birds/m², medium=5.2 birds/m²) and week (W3=Week 3; W4=Week 4; W5=Week 5; W6=Week 6) on the probability that ducks would be resting

3.4.9.2. Sitting

The probability that birds would be sitting during any part of the 24 hour monitoring was reasonably consistent, at around 12%. Strain had no effect (P=0.39). The density and week effects on the probability ducks would be resting are given in Figure 3.11. Density had no effect (P=0.71), but week had a highly significant effect (P<0.0001).

Figure 3.11. The effect of stocking density (low=4.4 birds/m², medium=5.2 birds/m²) and week (W3=Week 3; W4=Week 4; W5=Week 5; W6=Week 6) on the probability that ducks would be sitting
3.4.9.3. General activity

The pattern of probability that birds would be engaged in general activity during any part of the 24 hour monitoring is given in Figure 3.12. The level of activity peaked midmorning. Strain had no effect on the level of general activity (P=0.20), with the probability of birds being engaged in general activity being 0.24±0.01 for the CV strain and 0.22±0.01 for the P2 strain. The density and week effects on the probability ducks would be engaged in general activity are given in Figure 3.13. Density had no effect (P=0.54), while week had a highly significant effect (P<0.0001).

**Figure 3.12.** The pattern of probability (±SEM: dotted lines) that ducks would be engaged in general activity during the 24 h monitoring period

![Graph showing the pattern of probability for general activity over 24 hours.](image)

**Figure 3.13.** The effect of stocking density (low=4.4 birds/m², medium=5.2 birds/m²) and week (W3=Week 3; W4=Week 4; W5=Week 5; W6=Week 6) on the probability that ducks would be engaged in general activity

![Bar chart showing the effect of density and week on the probability of general activity.](image)

3.4.9.4. All behaviours

The percentage of time spent on the various activities over the 24 hour monitoring period is shown in Figure 3.14. The effects of density and week on the cumulative probability that ducks would be engaged in various activities are given in Figure 3.15.
3.4.10. Feather damage

Light intensity had no effect (P=0.77) on the probability of birds registering feather damage scores (see Figure 3.16). For both light intensities the probably of there being no feather damage was greater than 92%.

Strain had an effect on the extent of feather damage (see Figure 3.17), but this depended on the period when the damage was evaluated, as the strain x period interaction was significant (P=0.003). In Period 1, the scores recorded by the strains were similar (P=0.39). In Period 2, the GF strain had a higher probability of having no feather damage than the CV strain (P=0.01).
Stocking density had an effect on the extent of feather damage (see Figure 3.18), but this depended on the period when the damage was evaluated, as the strain x period interaction was significant (P=0.005). The extent of feather damage was higher for ducks stocked at the medium density compared to those at low density in Period 2 only (P=0.03). In Period 2, the difference between ducks stocked at the high density and those at the medium density was marginally non-significant (P=0.06).
There was a significant interaction between the body region (wing or thigh) damaged and the period (P=0.001). In Period 1, the damage on the wing was greater than the damage on the thigh (P<0.001), but this was not the case in Period 2 (see Figure 3.19).

Figure 3.19. The feather damage scores for the wing and thigh regions in P1 and P2

3.5. Discussion

3.5.1. Performance

As birds aged and became heavier, the stocking density had an effect on LWG. In Weeks 5–6, it was lower when birds were kept at the high stocking density compared to the lower densities. At this time, the LWG was not different when the density was 5.2 birds/m² or 4.4 birds/m². The differences in LWG resulted in differences in final liveweight at processing age, with liveweight being higher for birds housed at the lowest density compared to the highest density. While the analysis indicated that
the final liveweight was not different between birds at the medium and high densities, this result would have to be close to significant, as the difference between the liveweight for the medium and low density treatments was only 3 g. Density effects on liveweight are often complicated by using group size to achieve density differences. In the current study, the group size remained the same for all treatments. However, like many density studies undertaken in experimental facilities the group size used was small and so there remains the question as to how relevant this is to large commercial flocks. Using trial and error over a long period the industry has settled on 5.2 birds/m² as being the density most suited to their housing conditions. The results from the current study identified 5.2 birds/m² as the likely maximum density to achieve best LWG. This would suggest that the small group sizes used do provide data relevant to commercial operations. Overall it feasible to conclude that the density being used in commercial sheds (5.5 birds/m²) is close to optimal for best performance.

In Weeks 3–4, LWG was superior for birds kept under low light intensity but this was not seen in Weeks 5–6. One explanation given for improved LWG of broilers in low light intensity is that there is less activity (Boshouwers and Nicaise 1987; Hester et al. 1987). Barber et al. (2004) found that at two weeks of age, birds spent less time moving and in environment-directed pecking in the dim light (>1 lux). At six weeks of age they spent less time preening, feeding and moving in this low light intensity. In the behavioural study, under high luminance ducks rest more at 3–4 weeks than at 5–6 weeks of age, and engage in less general activity. The effect of low light could add to the level of inactivity in Week 3–4, and this could help account for the LWG effects seen at this time.

Feed intake was not affected by stocking density or light intensity. Water intake was higher in Weeks 5–6 for the birds in the high light intensity groups. The feed to gain was better for birds at the low light intensity in Weeks 1–2 and 3–4 but not Weeks 5–6, although the overall feed to gain for the entire production cycle was not any better. The stocking density had no effect on feed to gain. Treatment had no effects on the water to feed ratio. When the efficiency of production was determined as the ratio of feed to breast yield there were no stocking density or light intensity effects.

The GF strain grows faster and achieves greater processing weight than the CV strain as a consequence of genetic selection. Males had a higher LWG and final weight than females. Light intensity and stocking density had no effect on the LWG or final liveweight of the two strains or the different sexes. Strain GF had a higher feed intake than the CV strain after two weeks of age, and had higher water intake in Weeks 5–6. The higher liveweight of the GF strain would account for these differences. Strain GF was more efficient than strain CV, with better feed to gain in all weeks. Females had a better breast weight to liveweight percentage than males. This has been reported previously (Downing 2010). Females mature earlier than males, reaching their maximum lean tissue growth rate earlier. This is supported by the lack of difference in absolute breast weight between the sexes. The GF strain had greater breast weight and was more efficient with the feed weight to breast weight being better. At low and medium stocking density the breast percentage was higher for the GF strain, but this was not the case at the higher density. Birds at the higher density had lower liveweight and this might indicate that the reduced weight is partially lost breast weight. At the end of Week 6, the density based on live weight for the GF birds was 19.6 kg/m² and for the CV birds 18.1 kg/m². While the bird density was the same, based on the weight density, the space available for the GF birds would be less and might result in more social stress for this strain.

### 3.5.2. Feather damage

Feather damage was evaluated at the end of Week 3 (Period 1) and Week 4 (Period 2). There is a distinctive period of FP damage directed at the wing around the time of feather emergence, which is commonly around the end of Week 3. Only about 8% of the birds had FP damage. The incidence of FP was relatively small and the probability of severe damage was much lower. Commercial producers have indicated that they see FP damage as more severe in the CV strain than the GF strain, and the data here support this. While the difference was only seen at the second evaluation period, the GF birds did have a lower incidence of FP damage. Laying hen strains differ in the degree they engage in FP (reviewed in Sedlackova et al. 2004), and selection for propensity to FP has resulted in lines of
hens of high and low FP activity (Kjaer et al. 2001). Genetic selection for low propensity to FP is not going to be a major priority in the Pekin stains used locally. Observations from laying hens indicate that only 8.3% of the flock were involved in SFP (Blick and Keeling 2000). Wechsler et al. (1998), again in laying hens, categorised 12% of the flock as ‘high peckers’. The same detail on the activity of individual birds has not been forthcoming in Pekin ducks. However, the role of individual birds in starting FP activity in commercial duck flocks should be considered.

Stocking density had an effect of the degree of FP damage, but this was only seen when the evaluation was made in Period 2. The damage seen for birds housed at the medium density was greater than for birds at the low density. The difference between the damage in birds at the medium density and at the high density was marginally non-significant, but the trend was for it to be worse in the medium density treatment. The general consensus is that damage from FP increases with group size and as the density increases (see Section 1.5.2.4). The pattern seen here in ducks does not seem to support this concept. If individual birds have different propensities to be involved in FP, the densities used in the current study may have little influence because the group and pen sizes are small.

In Period 1, the damage directed at the wing region was more severe than that directed at the thigh. This was not the case in Period 2. This tends to support the view that the first pecking activity is directed to the wing. It follows that there is likely to be some attraction that directs the ducks to the wing area. It has been proposed that this attraction is the red blood that can be seen in the feather shaft at the time of feather emergence. While this might be the initial attraction, blood from damaged feathers is smeared on the thigh and this could further attract the ducks to this area later. In this study, we did not observe FP damage directed at the back area. This probably accounts for the much easier removal of feathers at the processing plant as relayed to the author by staff at PEPE’s Ducks Pty Ltd. This can be identified by the need (or not) to wax duck carcasses to remove the pin feathers during processing. This casual observation was important because it suggested that the better environmental control experienced in the experimental facility might have a role in controlling FP activity directed to the back region.

3.5.3 Behavioural study

There are limited behavioural studies in ducks, and to the authors’ knowledge no comprehensive study has been made of the Pekin strains used in Australia. Ducks spend a moderate amount of time self-preening, about 6–7%, and this tends to increase as the birds age, with preening and grooming activities being more prominent in the morning. They spent very little time preening other birds or involved in mutual preening. The stocking density and strain had no effect on preening activity. The probability that ducks would be involved in aggressive grooming that resulted in some form of negative response from another bird was low. This activity might be part of the activities resulting in FP damage. Strain and stocking density had no effect on this form of grooming.

FP activity where feathers were actually pulled at was seen at a frequency of around 0.06% of the time. The strain and density effects were not significant. This activity is more prominent in the morning. The incidence does increase in Weeks 5 and 6. At the time when damage is directed at the wing, Weeks 3 and 4, this type of FP activity is low, with the probability of it occurring only 0.02–0.05%. It should be remembered that these probabilities are determined from the number of birds engaged in the activity of the total number of birds in the pen, and that the observations in this study cannot determine if the same bird is involved in the FP activity at different observation times. A low probability might mean that few birds are involved in the activity, or that one bird might be involved with regular frequency.

Ducks spend 65–75% of their time resting, with higher general activity seen around midday. The resting time is higher in Weeks 3 and 4 of age compared to Weeks 5 and 6. They spend a further 12% of their time alert but sitting and between 15–20% involved in general activity. The level of general activity is much higher in Weeks 5 and 6 (25–35%). This pattern might be significant in commercial duck sheds because if environmental conditions predispose ducks to higher FP activity, the increase in general activity might help perpetuate the problem by increasing the potential for social transmission.
Chapter 4: The effect of electrolyte supplementation and dietary electrolyte balance on the performance of commercial ducks exposed to cyclic heat stress

4.1. Introduction

Given the positive effect of electrolyte supplementation on broiler performance during cyclic high temperature reported on in Chapter 2, the following questions needed to be answered:

1. What concentration of electrolytes should be used as a water supplement to get best performance?
2. Can the electrolytes be added in the feed to improve performance rather than the water?

Ducks have a higher water to feed ratio than do broilers and so duck excreta is of higher water content. For this reason, and also the fact that ducks have webbed feet, the maintenance of litter quality is a significant management issue. Because of the effects that sodium and other ions can have on water intake (see Section 1.2.4), duck diets are formulated to have low DEB (DEB 150, see below), as a strategy to help with on-farm litter management. While this DEB level may be sufficient under thermoneutral conditions, it may be limiting during periods of high temperature. A higher DEB might be needed to support the increases in electrolyte requirements during HS.

4.2. Objective

The objective of the study was to assess the effects of increased DEB, and different concentrations of electrolyte supplementation in water, on the growth performance of ducks exposed to cyclic high ambient temperature during the last week of the production cycle. The working hypothesis was that increased electrolyte intake would benefit performance during the period of HS and that this could be meet by increasing the DEB or electrolyte supplementation of the water.

4.3. Material and methods

4.3.1. Experimental design

The experiment was conducted using a completely randomised design with blocking. There were 48 pens allocated to the study, with the shed being divided into four blocks of 12 pens. Each treatment was randomly allocated a pen in each block. Initially there were 25 ducks in each pen, but this number was reduced to 20 at Week 5 of age.

4.3.2. Birds and husbandry

CV ducks were used, and were reared as mixed sex groups. Ducks were breed by PEPE’s Pty Ltd (Windsor, NSW) 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. On arrival, ducklings were placed in their allocated pens. Equal numbers of males and females were placed in pens, with each alternative pen having an extra male or female. Birds had access to feed and water ad libitum.
4.3.3. Treatments

Two grower diets were fed: one with a low DEB and one with a high DEB. Four different electrolyte concentrations were added to the water: 0%, 50%, 100% and 150% of the electrolyte concentration used in the study detailed in Chapter 2. These electrolyte treatments were provided over Days 36–41 of age. A further electrolyte treatment, the 100% concentration, was supplied during the 36 hours (Days 40–41) prior to pick-up for processing. Betaine was added with all electrolyte supplements. It is regular practice to add betaine to duck grower feeds, and so this was included as a further treatment. The 12 treatments were:

1. Low DEB + water only
2. Low DEB + electrolytes at 50% + betaine in Week 6 (E50)
3. Low DEB + electrolytes at 100% + betaine in Week 6 (E100)
4. Low DEB + electrolytes at 150% + betaine in Week 6 (E150)
5. Low DEB + betaine in grower feed
6. Low DEB + electrolytes at 100% + betaine 36 hours before transport (E100-36h)
7. High DEB + water only
8. High DEB + electrolytes at 50% + betaine in Week 6 (E50)
9. High DEB + electrolytes at 100% + betaine in Week 6 (E100)
10. High DEB + electrolytes at 150% + betaine in Week 6 (E150)
11. High DEB + betaine in grower feed
12. High DEB + electrolytes at 100% + betaine 36 h before transport (E100-36h)

From Days 1–35 birds in all allocated groups were exposed to the same conditions. During Days 36–41 all birds were exposed to an ambient temperature of 30–32°C from 08:30- 17:30 h and then 22–24°C from 17:30 to 08:30 h each day.

4.3.4. Diets

The diets were formulated and supplied by Inghams Pty Ltd, Berrima, NSW. The starter diet was fed from Days 1–14 in crumble form and formulated to provide 12.52 MJ ME/kg, 22.0% protein, 0.17% sodium, 0.70% potassium and 0.19% chloride. This equates to a DEB of 198. Two grower diets were formulated, with the same energy content at 12.62 MJ ME/kg, 18.3% protein, 4.2% fat and calcium at 0.8%. The diet with low DEB was formulated to contain 0.15% sodium, 0.62% potassium and 0.18% chloride, giving a DEB of 173. The diet with high DEB was formulated to contain 0.35% sodium, 0.65% potassium and 0.30% chloride, giving a DEB of 233.

The 100% electrolyte supplement (E100) consisted of sodium chloride (157 g), sodium bicarbonate (171 g) and potassium chloride (88.4 g) dissolved in 100 L of tap water. The 50% (E50) electrolyte solution was formulated by adding only half the quality of salts to 100 L while the 150% solution was formulated by adding 1.5 times the quantity of salts used in the E100 to 100 L. Betaine was added to all electrolyte supplements at 40 g/100 L. The preparation of the betaine is given in Chapter 2.

Betaine was added to the grower pelleted diet by dissolving 284 g of betaine in 1.9 L of warm water, and then spraying it onto 259.0 kg of the control pelleted grower feed being gently turned in a paddle mixer. This gave a betaine concentration of 1,088 mg/kg. The water content of the grower diet was increased by 0.73%.

To determine the actual DEB, the grower diets were analysed for mineral concentrations by the University of New South Wales Analytical Centre, Kensington, Australia. Ground feed samples were extracted with water and analysed by ion chromatography for chloride. Samples were digested with nitric acid and hydrogen peroxide and analysed for sodium and potassium by inductively coupled plasma optical emission spectrometry ICPOES.
4.3.5. Performance and carcass measurements

At placement, a collective pen weight was recorded. On Days 14 (Week 2), 28 (Week 4), 35 (Week 5) and 41 (Week 6) all ducks were individually weighed. Feed intakes were determined over the same time periods and water intakes were recorded daily. On day 41, one male and one female duck from each pen was euthanised and the weight of breast muscle determined. The remaining birds were processed by PEPE’S Pty Ltd and carcass yields determined.

4.3.6. Statistical analysis

Data were stored in Microsoft Excel® and unless stated otherwise, statistical analysis was conducted using the REML linear mixed model function of Genstat® 11th edition. Data were first tested for equality of variance using residual plots. When the equality of variance could be improved using a loge transformation, the data were transformed.

The fixed model included the effects of treatment, DEB, strain, sex and week, and the random model included the effects of block, pen and tag. Initially all two-way interactions between fixed effects were included in the model. Significance testing of fixed effects was conducted using Wald tests with a significance threshold of P<0.05. Any non-significant interactions were removed from the model. The predicted means for all significant fixed effects were copied to Microsoft Excel®, as were the standard errors, which were used to calculate the SEM. The LSD was used to make pairwise comparisons of the means. Microsoft Excel® was used to create graphical summaries of the back-transformed means. All carcass measurements were analysed as a proportion of liveweight. The effects of treatment and DEB on the processing weights was analysed by ANOVA (Statview) and when effects were significant individual comparisons were performed using the Tukey-Kramer test.

There were a number of levels at which the performance of the ducks were analysed. In the first two weeks, all ducks were under the same management and the analysis was undertaken to check that there were no differences between the allocated groups. Over Weeks 3–5, the birds were either on the grower diet with the low DEB or the diet with the high DEB, while groups allocated to betaine in feed received this during the full grower period. In Week 6 (Days 36–41), the treatments were supplied while the cyclic temperature was applied.

4.4. Results

4.4.1. Determined DEB

The mineral concentrations for the starter and low and high DEB grower diets are shown in Table 4.1. The formulated and determined DEBs were slightly different. The formulated values were slightly higher for the starter and low DEB grower, but lower for the high DEB grower diet.

<table>
<thead>
<tr>
<th>Mineral (mg/kg) (%)</th>
<th>Starter</th>
<th>Grower Low DEB</th>
<th>Grower High DEB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium (mg/kg)</td>
<td>6,691 (0.67)</td>
<td>5,751 (0.57)</td>
<td>5,954 (0.59)</td>
</tr>
<tr>
<td>Sodium (mg/kg)</td>
<td>1,542 (0.15)</td>
<td>1,401 (0.14)</td>
<td>3,347 (0.33)</td>
</tr>
<tr>
<td>Chloride (mg/kg)</td>
<td>1,837.5 (0.18)</td>
<td>1,689.2 (0.17)</td>
<td>3,165.7 (0.32)</td>
</tr>
<tr>
<td>DEB</td>
<td>186</td>
<td>160</td>
<td>261</td>
</tr>
</tbody>
</table>
4.4.2. Liveweight

4.4.2.1. Week 2

At the end of Week 2, there were no differences (P=0.48) in liveweight between birds allocated to particular treatment groups (See Table 4.2). Sex had an effect (P<0.001), with females (692±7 g) being lighter than males (711±7 g) (P<0.05). There was no treatment group allocation x sex interaction, so while there was a sex effect it was the same for all allocated treatment groups.

Table 4.2. The two-week-of-age mean (±SEM) liveweight (g) of ducks allocated to the different treatment groups as day olds

<table>
<thead>
<tr>
<th>Allocated treatment group</th>
<th>Liveweight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>711±9</td>
</tr>
<tr>
<td>E50</td>
<td>701±8</td>
</tr>
<tr>
<td>E100</td>
<td>694±8</td>
</tr>
<tr>
<td>E150</td>
<td>702±8</td>
</tr>
<tr>
<td>E100-36h</td>
<td>698±8</td>
</tr>
<tr>
<td>Feed betaine</td>
<td>705±8</td>
</tr>
</tbody>
</table>

4.4.2.2. Weeks 3–5

At the end of Week 5 the DEB had no effect on the liveweight (P=0.75). The mean (±SEM) liveweight for birds on the diet with low DEB was 2,402±31 g and those on the diet with high DEB was 2,407±31 g. Adding betaine to the feed had no effect on liveweight at the end of Week 5 (P=0.84). The mean (±SEM) liveweight for birds receiving betaine in the feed was 2,402±34 g and those on the diet with no betaine was 2,407±29 g (controls). Sex had a significant effect on Week 5 liveweight (P<0.001), with this being higher in males (2,460±29 g) than females (2,349±28 g) (P<0.05). The sex effects were independent of the DEB and whether betaine was added to the feed.

4.4.2.3. Week 6

The effect of DEB on liveweight at the end of Week 6 was not significant (P=0.13). The liveweight of birds on the high DEB diet was 2,760±39 g and those on the low DEB diet was 2,738±39 g. The sex x treatment interaction (see Table 4.3) was significant (P<0.03). For all treatments, males were heavier than females (P<0.05). Females birds supplied with E150 had higher liveweight than female birds given other treatments, except those given E100 (P<0.05). For males, those supplied with E100 for 36 hours had greater liveweight than males in other treatment groups except those supplied with E150 (P<0.05). Also, those birds supplied with E150 had a higher liveweight than the control males (P<0.05).
Table 4.3. The six-week-of-age mean (±SEM) liveweight (g) of ducks allocated to the different treatment groups

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>2,638±42\textsuperscript{b}</td>
<td>2,813±45\textsuperscript{c}</td>
</tr>
<tr>
<td>E50</td>
<td>2,641±43\textsuperscript{b}</td>
<td>2,852±46\textsuperscript{bc}</td>
</tr>
<tr>
<td>E100</td>
<td>2,649±42\textsuperscript{ab}</td>
<td>2,847±45\textsuperscript{bc}</td>
</tr>
<tr>
<td>E150</td>
<td>2,694±43\textsuperscript{a}</td>
<td>2,878±46\textsuperscript{ab}</td>
</tr>
<tr>
<td>E100-36h</td>
<td>2,617±41\textsuperscript{b}</td>
<td>2,910±47\textsuperscript{n}</td>
</tr>
<tr>
<td>Feed betaine</td>
<td>2,625±42\textsuperscript{b}</td>
<td>2,849±45\textsuperscript{bc}</td>
</tr>
</tbody>
</table>

Note: Within each column values without common superscripts are significantly different (P<0.05)

4.4.3. Liveweight gain

4.4.3.1. Weeks 3–5

The DEB had no effect on the LWG over Weeks 3–5 (P=0.45). For birds fed the low DEB diet the mean (±SEM) gain was 1,674±24 g, and for those on the high DEB diet it was 1,706±24 g. Sex had a significant effect on the LWG over Weeks 3–5 (P<0.001). The mean (±SEM) gain for males (1,747±23 g) was greater than that of the females (1,654±21 g) (P<0.05).

4.4.3.2. Week 6

Sex had an effect on Week 6 LWG (P<0.001). Males (380±8 g) had greater gain than females (289±8 g) (P<0.05). The sex effects were independent of any interaction with other treatments. While the diet (P=0.29) and treatment effects (P=0.11) were not significant, there was a marginally non-significant (P=0.07) interaction between treatment and DEB (see Table 4.4). On the diet with low DEB, the tendency was for the gain to be greater for birds supplied with E150 and E100 for 36 hours compared to the control birds supplied with water alone. This trend was not obvious when the diet with the high DEB was fed. While the effects were not significant for the low DEB, the differences were reasonably large, being around 90–100 g total gain.

Table 4.4. The effects of treatment and DEB on the mean (±SEM) liveweight gain (g) of ducks exposed to high ambient temperature on Days 36–41 of age

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Gain (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low DEB</td>
</tr>
<tr>
<td>Control</td>
<td>264±20</td>
</tr>
<tr>
<td>E50</td>
<td>293±22</td>
</tr>
<tr>
<td>E100</td>
<td>355±26</td>
</tr>
<tr>
<td>E150</td>
<td>375±28</td>
</tr>
<tr>
<td>E100-36h</td>
<td>362±27</td>
</tr>
<tr>
<td>Feed betaine</td>
<td>310±23</td>
</tr>
</tbody>
</table>
4.4.4. Feed intake

4.4.4.1. Weeks 3–5

The DEB had no effect on the mean (±SEM) feed intake over Weeks 3–5 (P=0.15), with it being 3,516±46 g for the birds fed the low DEB diet and 3,526±49 g for those fed the high DEB diet. The addition of betaine to the feed had no effect on mean (±SEM) feed intake over the same period (P=0.22), with it being 3,543±53 g for the birds fed betaine supplemented feed and 3,501±42 g for those without betaine.

4.4.4.2. Week 6

The DEB had no effect on the mean (±SEM) feed intake in Week 6 (P=0.14), with it being 1,114±20 g for the birds feed the low DEB diet and 1,136±20 g for those fed the high DEB diet. The total feed intake on the low DEB diet (5,433±68 g) was similar (P=0.25) to that on the high DEB (5,477±68 g). Treatment (see Table 4.5) had no effect on the mean (±SEM) feed intake in Week 6 (P=0.94) or the total feed intake (P=0.76).

Table 4.5. The mean (±SEM) feed intake (g) of ducks exposed to high ambient temperature on Days 36–41 of age

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Feed intake (g) Week 6</th>
<th>Feed intake (g) Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1,112±24</td>
<td>5,445±78</td>
</tr>
<tr>
<td>E50</td>
<td>1,119±24</td>
<td>5,462±78</td>
</tr>
<tr>
<td>E100</td>
<td>1,131±24</td>
<td>5,412±78</td>
</tr>
<tr>
<td>E150</td>
<td>1,124±24</td>
<td>5,440±78</td>
</tr>
<tr>
<td>E100-36h</td>
<td>1,122±24</td>
<td>5,462±78</td>
</tr>
<tr>
<td>Feed betaine</td>
<td>1,139±25</td>
<td>5,508±79</td>
</tr>
</tbody>
</table>

4.4.5. Water intake

4.4.5.1. Weeks 3–5

The DEB had an effect on the mean (±SEM) water intake over Weeks 3–5 (P<0.001), with it being 11.57±0.13 L for the birds fed the low DEB diet and 12.32±0.16 L for those fed the high DEB diet. The addition of betaine to the feed had no effect on mean (±SEM) water intake over the same period (P=0.84), with it being 11.94±0.18 L for the birds fed supplemented betaine feed and 11.93±0.08 L for those having no betaine.

4.4.5.2. Week 6

The DEB had a marginally non-significant effect on the mean (±SEM) water intake in Week 6 (P=0.057), with it being 5.74±0.07 L for the birds feed the low DEB diet and 5.93±0.07 L for those fed the high DEB diet. Treatment (see Table 4.6) had a significant effect on the mean (±SEM) water intake in Week 6 (P<0.001). Birds supplied with E150 had a greater water intake compared to all other treatments (P<0.05). Those supplied with E100 had higher water intake compared to the remaining treatments (P<0.05). Also, birds given E50 had a higher water intake than those given E100h for 36 hours (P<0.05). The birds on the high DEB diet (21.35±0.17 L) drank more total water than those on
the low DEB diet (20.19±0.14 L) diet (P<0.001). The effect of treatment on the total water intake was marginally non-significant (P=0.06). The trend was for birds on the E150 and E100 electrolyte concentrations to consume more water.

Table 4.6. The mean (±SEM) water intake (L) of ducks exposed to high ambient temperature on Days 36–41 of age and the total water intake over Days 1–41 of age

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Water intake (L) Week 6</th>
<th>Water intake (L) Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>5.55±0.11&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>20.52±0.27</td>
</tr>
<tr>
<td>E50</td>
<td>5.79±0.11&lt;sup&gt;c&lt;/sup&gt;</td>
<td>20.85±0.27</td>
</tr>
<tr>
<td>E100</td>
<td>6.13±0.12&lt;sup&gt;b&lt;/sup&gt;</td>
<td>21.05±0.27</td>
</tr>
<tr>
<td>E150</td>
<td>6.56±0.13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21.35±0.28</td>
</tr>
<tr>
<td>E100-36h</td>
<td>5.40±0.11&lt;sup&gt;d&lt;/sup&gt;</td>
<td>20.19±0.26</td>
</tr>
<tr>
<td>Feed betaine</td>
<td>5.66±0.11&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>20.62±0.27</td>
</tr>
</tbody>
</table>

Note: Within each column values without common superscripts are significantly different (P<0.05)

4.4.6. Feed to gain

4.4.6.1. Weeks 3–5

The DEB had a marginally non-significant effect on the feed to gain (P=0.08). The feed to gain ratio tended to be better on the low DEB diet, with it being 2.06±0.01 and for those fed the high DEB diet, it was 2.09±0.1. The addition of betaine to the feed had an effect on the mean (±SEM) feed to gain over the same period (P=0.006), with it being worse (2.10±0.01) for the birds fed supplemented betaine than those without betaine (2.05±0.01).

4.4.6.2. Week 6

There was a significant interaction between treatment and DEB on the Week 6 feed to gain (P=0.047). On the diet with high DEB, the treatments had no effect on the feed to gain. When the diet with low DEB was fed there were treatment effects (see Table 4.7). The control birds had an inferior feed to gain compared to those supplied with E150 and E100 either continuously, or for the 36 hours prior to pick-up. The DEB had no effect (P=0.47) on the total feed to gain, with it being 2.02±0.01 for both diets. Treatment had an effect on the total feed to gain (P=0.03). The birds fed betaine in the feed had poorer feed to gain compared to birds that had received E150 or E100 continuously or for the 36 hours prior to pick-up (P<0.05). Supplementation with E150 gave better total feed to gain than providing water alone or the E50 (P<0.05).
Table 4.7. The mean (±SEM) feed to gain of ducks exposed to high ambient temperature on Days 36–41 of age and the total feed to gain over Days 1–41 of age

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Feed to gain Low DEB</th>
<th>Feed to gain High DEB</th>
<th>Feed to gain Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>4.09±0.22&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.35±0.22</td>
<td>2.03±0.01&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>E50</td>
<td>3.70±0.22&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>3.09±0.22</td>
<td>2.03±0.01&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>E100</td>
<td>3.08±0.22&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>3.57±0.22</td>
<td>2.01±0.01&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>E150</td>
<td>3.08±0.22&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>3.26±0.22</td>
<td>1.99±0.01&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>E100-36h</td>
<td>3.06±0.22&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>3.26±0.22</td>
<td>2.01±0.01&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>Feed betaine</td>
<td>3.57±0.20&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>3.15±0.26</td>
<td>2.05±0.01&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Note: Within column values without common superscripts are significantly different (P<0.05)

4.4.7. Water to feed

4.4.7.1. Weeks 3–5

The DEB had an effect on the water to feed ratio (P<0.001). The water to feed ratio for birds on the low DEB feed (3.29±0.05) was lower than for the birds on the high DEB feed (3.49±0.07). The addition of betaine to the feed had no effect on the mean (±SEM) water to feed ratio over the same period (P=0.34), with it being 3.37±0.07 for the birds fed supplemented betaine feed and 3.41±0.05 for those without betaine.

4.4.7.2. Week 6

The DEB had no effect on the mean (±SEM) water to feed ratio in Week 6 (P=0.44), with it being 5.16±0.08 for the birds fed the low DEB diet and 5.23±0.09 for those fed the high DEB diet. Treatment (see Table 4.8) had a significant effect on the mean (±SEM) water to feed ratio in Week 6 (P<0.001). Birds supplied with E150 had higher water to feed ratio compared to all other treatments (P<0.05). Those supplied with E100 had a higher water to feed compared to the control, E100-36h and betaine in feed treated birds (P<0.05). The E50 treated birds had a higher water to feed ratio compared to the E100-36 treated birds. The birds on the high DEB feed (3.90±0.05) had a higher total water to feed ratio than those on the low DEB diet (3.71±0.05) (P<0.001). The effect of treatment on the total water to feed was significant (P=0.03). Those birds on the E150 treatment had a higher water to feed ratio than the control, E100-36 and betaine in feed treated birds (P<0.05). The E100 treated birds had a higher water to feed ratio than the E100-36 and betaine in feed treated birds (P<0.05).
Table 4.8. The mean (±SEM) water to feed ratio of ducks exposed to high ambient temperature on Days 36–41 of age and the total water to feed ratio over Days 1–41 of age

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Water to feed ratio</th>
<th>Water to feed ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 6</td>
<td>Total</td>
</tr>
<tr>
<td>Control</td>
<td>4.99±0.12</td>
<td>3.77±0.06</td>
</tr>
<tr>
<td>E50</td>
<td>5.17±0.13</td>
<td>3.81±0.06</td>
</tr>
<tr>
<td>E100</td>
<td>5.42±0.13</td>
<td>3.89±0.07</td>
</tr>
<tr>
<td>E150</td>
<td>5.84±0.15</td>
<td>3.93±0.07</td>
</tr>
<tr>
<td>E100-36h</td>
<td>4.83±0.12</td>
<td>3.70±0.06</td>
</tr>
<tr>
<td>Feed betaine</td>
<td>4.98±0.12</td>
<td>3.75±0.06</td>
</tr>
</tbody>
</table>

Note: Within column values without common superscripts are significantly different (P<0.05)

4.4.8. Breast yield

The effects of DEB and treatment on the liveweight, breast weight, the ratio of breast weight to carcass weight expressed as a percentage and the feed weight to breast weight ratio are given in Table 4.9. There were no effects on any of these measures.

Table 4.9. The mean (±SEM) liveweight, breast weight, the ratio of breast weight to carcass weight and the feed weight to breast weight ratio of ducks exposed to high ambient temperature on Days 36–41 of age

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Liveweight (g)</th>
<th>Breast weight (g)</th>
<th>#Breast %</th>
<th>Feed to breast weight ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>2,754±77</td>
<td>225±11</td>
<td>8.17±0.27</td>
<td>24.7±1.1</td>
</tr>
<tr>
<td>E50</td>
<td>2,882±80</td>
<td>221±11</td>
<td>7.65±0.27</td>
<td>25.3±1.1</td>
</tr>
<tr>
<td>E100</td>
<td>2,769±79</td>
<td>229±11</td>
<td>8.24±0.26</td>
<td>24.4±1.1</td>
</tr>
<tr>
<td>E150</td>
<td>2,816±77</td>
<td>231±11</td>
<td>8.19±0.26</td>
<td>24.8±1.1</td>
</tr>
<tr>
<td>E100-36h</td>
<td>2,817±82</td>
<td>231±12</td>
<td>8.25±0.28</td>
<td>24.1±1.2</td>
</tr>
<tr>
<td>Feed betaine</td>
<td>2,749±77</td>
<td>227±11</td>
<td>8.23±0.26</td>
<td>24.8±1.1</td>
</tr>
<tr>
<td><strong>Diet effects</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low DEB</td>
<td>2,709±64</td>
<td>228±9</td>
<td>8.12±0.19</td>
<td>24.2±0.09</td>
</tr>
<tr>
<td>High DEB</td>
<td>2,805±64</td>
<td>226±9</td>
<td>8.06±0.19</td>
<td>24.9±0.09</td>
</tr>
</tbody>
</table>

P values

<table>
<thead>
<tr>
<th>P values</th>
<th>T=0.57</th>
<th>T=0.89</th>
<th>T=0.41</th>
<th>T=0.90</th>
</tr>
</thead>
<tbody>
<tr>
<td>*T</td>
<td>DEB=0.71</td>
<td>DEB=0.77</td>
<td>DEB=0.48</td>
<td>DEB=0.37</td>
</tr>
</tbody>
</table>

*P=Treatment, **DEB=Dietary electrolyte balance

*Breast weight to liveweight ratio expressed as a percentage
4.4.9. Processing weights

The weight of birds on arrival at the factory, and after the birds had been eviscerated but before entering the chiller (dry carcass weight), is given in Table 4.10. The factory arrival weight was similar for all treatments and the DEB. For the processed carcass dry weight the interaction between treatment and DEB was marginally non-significant ($P=0.06$). On the low DEB diet the birds supplemented with E100 for 36 hours prior to processing tended have a higher dry carcass processed weight, while on the high DEB diet the E150 treatment tended to support a heavier dry carcass weight.

Table 4.10. The effect of treatment and DEB on the mean (±SEM) liveweight weight of birds on arrival at the processing plant and the processed carcass dry weight after evisceration

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Factory arrival liveweight (g)</th>
<th>Processed carcass dry weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low DEB</td>
<td>High DEB</td>
</tr>
<tr>
<td>Control</td>
<td>2,587</td>
<td>1,964</td>
</tr>
<tr>
<td>E50</td>
<td>2,640</td>
<td>1,968</td>
</tr>
<tr>
<td>E100</td>
<td>2,609</td>
<td>1,943</td>
</tr>
<tr>
<td>E150</td>
<td>2,594</td>
<td>1,934</td>
</tr>
<tr>
<td>E100-36h</td>
<td>2,659</td>
<td>2,014</td>
</tr>
<tr>
<td>Feed betaine</td>
<td>2,592</td>
<td>1,953</td>
</tr>
<tr>
<td>SEM</td>
<td>23</td>
<td>18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DEB effects</th>
<th>Low DEB</th>
<th>High DEB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2,623</td>
<td>1,966</td>
</tr>
<tr>
<td></td>
<td>2,603</td>
<td>1,962</td>
</tr>
<tr>
<td>SEM</td>
<td>13</td>
<td>10</td>
</tr>
</tbody>
</table>

| P values           | *$T=0.16$ | T=0.77   |
|--------------------| **DEB=0.30** | DEB=0.81 |
|                    | T x DEB=0.11 | T x DEB=0.06 |

*$T$=Treatment

**DEB=Dietary electrolyte balance

4.5. Discussion

Betaine is regularly added to duck grower diets during summer. Being an organic osmolyte, it is reported to help birds maintain water balance under conditions of high osmotic pressure (Klasing et al. 2002). In the current study, betaine addition to the feed had no effect on LWG or final liveweight during Weeks 3–5 when the temperature was kept in thermoneutral range, or in Week 6 when the birds were exposed to cyclic high temperature. Work by Wang and colleagues (1999) using betaine at a concentration similar to that used in the current study found positive effects for betaine on LWG and feed efficiency in CV ducks. Later work found that at the same concentration, the effect of betaine supplementation was marginally non-significant for LWG but feed efficiency was better (Wang et al.
There are conflicting reports as to the value of betaine supplementation during periods of high temperature (see Section 1.6.3.3). The benefits attributed to betaine are likely to be seen when the birds are exposed to very high temperatures. Under very hot (30–41°C) and humid (45–93% RH) conditions betaine at 1,200 mg/kg, improved performance and decreased mortality from 33% to 3.3% in broilers (Khattak et al. 2012).

Over Weeks 3–5, betaine supplementation in feed had no effect on feed intake but the feed to gain was worse. This was not seen during the period of cyclic high temperature where the birds fed betaine in the feed had a feed to gain similar to the control birds on both DEB diets.

The DEB had no effect on LWG in Weeks 3–5 when the temperature was kept in the thermoneutral range. Grower duck diets are formulated to have a low DEB. This is a nutritional strategy to help in the management of the litter moisture content. Ducks have a higher water to feed ratio than broilers and this creates problems with wet litter. A high DEB encourages water consumption and increased excreta moisture, adding to the litter management problems. The low DEB diet supported the same LWG as the high DEB diet. Therefore, the low DEB being used in commercial grower diets is adequate when the temperature is in the thermoneutral range.

In Week 6, there was a marginally non-significant interaction between treatment and DEB (P=0.07). Of interest was the trend for the control birds on the high DEB to have a higher LWG than the control birds on the low DEB. While this needs further evaluation it suggests that the increased need for electrolytes at the higher temperature could be supplied in the feed. On the low DEB diet birds supplemented with electrolytes tended to have higher LWG than the control birds, with the trend being stronger when the E150 and E100-36h treatments were used. This trend was not evident when birds were fed the high DEB diet. These trends could account for the differences in final liveweight. Females supplemented with E150 and males supplemented with E100-36h had higher final liveweight compared to the control females and control males, respectively.

Betaine and electrolyte treatments had no effect on feed intake. Over Weeks 3–5 the birds on the high DEB diet had a higher water intake. This effect was marginally non-significant in Week 6. Supplementation with E150 or E100 resulted in higher water intake compared to the other treatments.

Over Weeks 3–5, the DEB had no effect on feed intake but there was a marginally non-significant effect on feed to gain. There was an interaction between the DEB and treatment on the feed to gain in Week 6. On the high DEB diet there was no benefit from any treatment. On the low DEB diet, supplementation with E150, E100 or E100-36h supported better feed to gain than that recorded for the control birds. The improvement seen in Week 6 was sufficient for the E150-treated birds to have a better total feed to gain compared to the control birds.

At processing, there was a marginally non-significant interaction between DEB and treatment for the effect on eviscerated dry carcass weight. On the low DEB diet, providing E100 for 36 hours before farm pick-up tended to increased dry carcass weight, while on the high DEB diet supplementation with E150 tended to increase dry carcass weight. This trend does provide some support that the trend seen for LWG gain on the low DEB diet carries through to the processing. Supplementation of birds with electrolytes for short periods during high temperature warranted further investigation.

While acceptance of the hypothesis is not fully supported, there is some evidence that there are some benefits to be gained from providing electrolytes and betaine supplementation during HS. The main support for this are the trends in LWG and carcass weight seen for birds on the low DEB diet and the improved feed to gain. It is probable that these improvements would be greater under conditions of more severe HS. Increased water consumption is supported by electrolyte supplementation and this will be a benefit to the birds’ welfare under HS conditions. Increased water intake helps the birds dissipate heat more efficiently and reduce the physiological stress on the birds.
Chapter 5: The effect of transport and electrolyte provision during lairage on the carcass weight loss during processing

5.1. Introduction
Because feed is removed three hours before farm pick-up for processing, and ducks have no access to water during transport and lairage, they lose weight prior to processing. While some of this initial loss is excreta expelled as the birds empty the GIT, the later loss is due to dehydration. This is particularly relevant during summer when birds can be exposed to high ambient temperatures. The extent of dehydration will have an affect on the degree of physiological stress the bird experiences. The extent of dehydration can be assessed by the weight loss during transport and lairage. To determine how relevant dehydration is to this potential weight loss, the effects of transport and providing electrolytes and betaine supplementation during the lairage period on processing carcass weight losses were investigated.

5.2. Objective
The objective of the study was to determine the effects of transport and time in lairage on bird dehydration measured as carcass weight changes during transport, lairage and processing, and whether providing electrolytes during lairage would reduce the weight lost at processing. The working hypothesis was that electrolyte supplementation during lairage would reduce the loss in carcass weight during processing, resulting in increased crass yield.

5.3. Material and methods

5.3.1. Experimental design
Pekin ducks of the CV strain were grown out on a commercial farm operated by PEPE’s Ducks Pty Ltd. The birds were housed and reared according to commercial practices. Birds used in the study were randomly collected from the main flock at the time of pick-up for processing at 42–43 days of age. More than the number of ducks required was penned off from the main flock. Each duck was individually wing-tagged and weighed before being placed in a transport crate (6 birds/crate). Each crate was randomly allocated to one of three treatments. The crates were then placed at designated locations on the transport vehicle so that the treatments groups were equally placed at different parts of the vehicle. Monitors to record the temperature and humidity were strategically place at the front, right and left sides and the middle of the vehicle.

5.3.2. Treatments
There were three treatment groups:

1. Ducks that were transported and then processed as soon as possible after arriving at the processing plant.
2. Ducks that were transported and then held in lairage and processed at the same time as Group 3 ducks.
3. Ducks that were transported and then held in lairage and processed at the same time as the Group 2 birds, but during lairage were provided with water supplemented with electrolytes and betaine.
The electrolyte supplementation contained sodium chloride at 1.57 g/L, sodium bicarbonate at 1.71 g/L and potassium chloride at 0.884 g/L, and betaine at 400 mg/L.

5.3.3. Liveweight and carcass measurements

All birds were individually weighed at the time of farm pick-up, and also when they arrived at the processing plant. Birds were then weighed just prior to being processed. After slaughter, feather removal and evisceration, the carcasses were weighed before they entered the processing line chiller (dry eviscerated weight) and then again after they had gone through the chiller (wet eviscerated weight).

5.3.4. Statistical analysis

Data were stored in Microsoft Excel® and, unless stated otherwise, statistical analysis was conducted using the REML linear mixed model function of Genstat® 11th edition. Data were first tested for equality of variance using residual plots. When the equality of variance could be improved using a loge transformation, the data were transformed.

The fixed model included treatment and the random model included the effects of crate and tag. Significance testing of fixed effects was conducted using Wald tests with a significance threshold of P<0.05. The predicted means for fixed effects were copied to Microsoft Excel®, as well as standard errors, which were used to calculate the SEM. The LSD, which is equal to two times the SED, was used to make pairwise comparisons of means. Microsoft Excel® was used to create graphical summaries of the back-transformed means.

5.4. Results

5.4.1. The timeline of events

The time from the start of transport to processing for Group 1 birds was 6 h 30 min and for Group 2 and Group 3 birds was 9 h 30 min.
Table 5.1. The time line of events from farm pick-up until processing

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:05</td>
<td>Ducks penned</td>
</tr>
<tr>
<td>10:15–11:00</td>
<td>Ducks wing-tagged and weighed</td>
</tr>
<tr>
<td>11:15</td>
<td>Loading of crates onto transport vehicle completed</td>
</tr>
<tr>
<td>11:40</td>
<td>Monitors placed on vehicle</td>
</tr>
<tr>
<td>11:45</td>
<td>Transported started</td>
</tr>
<tr>
<td>01:05</td>
<td>Arrival at the processing plant</td>
</tr>
<tr>
<td>01:40–2:20</td>
<td>Weighed all ducks—Group 1 first and then Groups 2 and 3</td>
</tr>
<tr>
<td>02:30</td>
<td>Birds in Group 3 moved to fabricated group pen and provided with water and electrolytes via nipple drinkers</td>
</tr>
<tr>
<td>05:20</td>
<td>Weighed Group 1 before processing</td>
</tr>
<tr>
<td>06:15</td>
<td>Group 1 processed</td>
</tr>
<tr>
<td>08:15</td>
<td>Weighed Groups 2 and 3</td>
</tr>
<tr>
<td>09:15</td>
<td>Groups 2 and 3 processed</td>
</tr>
</tbody>
</table>

5.4.2. Temperature and relative humidity

The temperatures recorded during transport and lairage are given in Figure 5.1. There was some variation between the different sites on the vehicle during transport, but these were not extreme. During lairage the temperature was relatively stable. The RHs recorded during transport and lairage are given in Figure 5.2. During transport the RH was lower at the front of the truck, while in lairage it ranged between 80–90%.
5.4.3. Liveweight

The liveweight is shown in Table 5.2. The liveweight at departure from the farm was similar all groups (P=0.35) and the weight lost during transport was similar for all groups (P=0.21).

The weight loss during lairage (from arrival to processing) was different (P<0.001). It was significantly greater for Group 2 (delayed processing) birds than Group 1 (early processing) and Group 3 (electrolytes and delayed processing) birds (P<0.05). The weight loss from the point of processing to the pre-chiller point (loss during evisceration) was also different (P=0.05). It was lower for the Group 2 birds than the Group 1 birds (P<0.05). The weight loss from the start of processing until the carcasses left the chiller was marginally non-significant (P=0.06). There was a tendency for it to be lower for Group 2 birds. The weight losses from the farm to post-processing points pre- (P=0.62) and post-chiller (P=0.83) were not different. There was no difference in final carcass weight after processing (P=0.19).
Table 5.2. The effects of treatment on the mean (±SEM) liveweight losses of ducks transported from farm and held in lairage prior to processing

<table>
<thead>
<tr>
<th>Measure</th>
<th>Treatment</th>
<th>Group 1 Immediate processing</th>
<th>Group 2 Delayed processing</th>
<th>Group 3 Electrolytes and delayed processing</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight at farm pick-up (g)</td>
<td></td>
<td>2,784±25</td>
<td>2,754±25</td>
<td>2,804±25</td>
<td>0.35</td>
</tr>
<tr>
<td>Loss weight from farm to arrival at processing plant (g)</td>
<td></td>
<td>51±9</td>
<td>35±7</td>
<td>56±9</td>
<td>0.21</td>
</tr>
<tr>
<td>Weight loss arrival to initial processing (g) (lairage)</td>
<td></td>
<td>41±5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>96±11&lt;sup&gt;b&lt;/sup&gt;</td>
<td>32±5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Weight loss processing to pre-chiller (g)</td>
<td></td>
<td>772±13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>677±12&lt;sup&gt;b&lt;/sup&gt;</td>
<td>708±13&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.05</td>
</tr>
<tr>
<td>Weight loss processing to post-chiller (g)</td>
<td></td>
<td>630±14</td>
<td>598±14</td>
<td>649±15</td>
<td>0.06</td>
</tr>
<tr>
<td>Weight accumulated from the chiller (g)</td>
<td></td>
<td>90±6</td>
<td>75±5</td>
<td>88±6</td>
<td>0.14</td>
</tr>
<tr>
<td>Farm to processing</td>
<td></td>
<td>785±11</td>
<td>788±10</td>
<td>774±11</td>
<td>0.62</td>
</tr>
<tr>
<td>Weight loss farm to pre-chiller (g)</td>
<td></td>
<td>692±18</td>
<td>708±18</td>
<td>701±18</td>
<td>0.83</td>
</tr>
<tr>
<td>Final processed wet weight</td>
<td></td>
<td>2,090±27</td>
<td>2,042±26</td>
<td>2,110±27</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Note: Within a row, values without common superscripts are significantly different (P<0.05)

5.5. Discussion

In the planning of this experiment, the goal was to investigate the role of electrolytes and betaine supplementation in lairage on carcass weight loss during a period of high temperature. Disappointingly, the experiment coincided with a day when the ambient temperature was moderate, although the RH was high. All treatments groups lost similar amounts of weight during transport, with this being less than 2% of the farm weight. In lairage, delayed processing resulted in 3.5% loss of farm liveweight, while supplying electrolytes limited this to 1.1% and was similar to the birds processed early (1.5%). After the birds were processed, the weight loss during evisceration was lower for the birds processed later without electrolytes. This suggests that the extra weight recorded for the early processed and electrolyte-supplemented birds was due the greater viscera weight, and this is probably increased gut water. The end result is a similar final processed weight.

While providing the electrolytes may have helped the birds cope by limiting the rate of dehydration, it had no effect on processing weight. The proposed benefit of electrolyte/betaine supplementation would be to help birds with their electrolyte balance and water retention. To obtain any advantage two factors are relevant: the first is the ambient temperature birds need to deal with, and the second is the length of time ducks have access to the supplements. A three hour supplementation period with electrolytes prior to processing had no effect on the weight losses during processing. The benefits to the ducks could be achieved with water alone at moderate ambient temperature. In practical terms, it is not feasible to provide water or supplements in lairage. If electrolytes are going to be of benefit, they will need to be provided on-farm before pick-up. This could be a way of increasing bird hydration and help
them better cope with the physiological stress associated with transport especially during periods of high temperature. This needed to be evaluated.

The results do not support the hypothesis. There was no advantage of electrolyte supplementation in lairage on carcass yield at processing and the benefits to bird welfare would be achieved with water alone.
Chapter 6: Identifying factors that predispose commercial Pekin ducks to feather pecking damage

6.1. Introduction

The detrimental effects of FP behaviour are a welfare concern for ducks and the producer and also an economic concern for the industry, as they result in both production losses and lower processing efficiency. One form of FP seen in ducks is directed at the wing and coincides with the emergence of the first feathers. This is clearly confirmed by field observations, and casual conversations with commercial farmers under Australian conditions.

While it is considered a ‘multi-factorial’ problem in laying hens (Hughes and Duncan 1972), the fact that the wing damage occurs at a reasonably precise time in ducks suggests that there might be a more specific reason for its occurrence. Our observations suggest that FP behaviour occurs at the time of early feather emergence when the red blood is easily recognised in the feather shaft. One approach to determine if this is the case is to disguise the feather shaft and measure the effect on FP behaviour. A further strategy is to distract the birds by providing them with foraging material so their pecking is directed away from other birds. The third strategy is to create an experimental environment that might predispose birds to FP. It is proposed the conditions which cause stress to the birds could predispose them to FP.

In these experiments, the strategies used to disguise the feather were to colour the wing with blue spray mark and to rear the birds under blue light. To distract the birds, straw bundles were provided in the pens. Poor litter quality has been suggested by producers to be an environmental stressor that can cause birds to engage in FP. Stress results in the release of corticosterone in birds. Elevating plasma corticosterone has been used as an experimental model to simulate stress in laying hens and broilers (Jiang et al. 2008; Shini and Kaiser 2009; Shini et al. 2009). Corticosterone can be administered in the feed or water to elevate plasma corticosterone concentrations. If stress-provoking stimuli do predispose ducks to FP then elevating plasma corticosterone would be a strategy to mimic this.

In commercial practice, ducks are reared as mixed sexes. Currently there is no clear indication whether males or females have a higher propensity to engage in FP. The effect of single sex rearing on FP was a further objective of the current experiment.

6.2. Objective

The objective of the study was to determine what conditions could potentially predispose Pekin ducks to FP. The investigation concentrated on factors related to FP damage directed at the wing tips. The wing damage occurs at a fairly predictable time and so it makes it easy to decide when to apply the proposed treatments. The effects of the different strategies on bird performance were also evaluated. The working hypothesis was that the essential factors causing FP wing damage in ducks are stress and attraction to the red blood seen in the shaft of the emerging feathers.

6.3. Material and methods

6.3.1. Experimental design

The experiment was conducted using a completely randomised design with blocking. There were 48 pens allocated to the study, with eight treatments and six replicate pens per treatment.
6.3.2. Birds and husbandry

CV Pekin ducks were reared as either mixed sexes or as single sexes. The birds were produced at a commercial breeding farm owned by PEPE’s Ducks Pty Ltd (Windsor, NSW) 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. On arrival, ducklings were placed in their allocated pens. On Day 7, all birds were individually wing-tagged.

Birds had access to feed and water ad libitum. The starter and grower feeds were provided by Ingham’s Pty Ltd. The starter diet was formulated to provide 12.56 MJ/kg ME and 21.5% protein, while the grower diet was formulated to provide 12.76 MJ/kg ME and 18.0% protein. The starter diet was in crumble form and was provided from Day 1 to Day 14. The finisher diet was in pellet form and was provided from Days 15 to 42.

6.3.3. Treatments

The eight treatments applied were:

1. Control, reared as mixed sexes
2. Females reared as single sex (FS)
3. Males reared as single sex (MS)
4. Poor litter quality, reared as mixed sexes (PL)
5. Wings coloured with blue spray mark, reared as mixed sexes (CW)
6. Straw bunched included in the pen, reared as mixed sexes (SB)
7. Birds reared under filtered blue light, reared as mixed sexes (BL)
8. Corticosterone-treated water, reared as mixed sexes (Cort).

Treatments 1–4 were applied over the 42 days of the experiment, while Treatments 5–7 were applied from Days 21 to 42 of the production period. Treatment 8 was applied from Days 21 to 35 of the production period.

6.3.3.1. Treatment details

Control birds, and the females and males reared as single sexes, were managed with standard commercial procedures as described in the general methodology section.

Poor litter (PL): During commercial production, all efforts are made to maintain litter quality in as good a condition as possible and this was the case in this study except for one treatment, where litter quality was allowed to deteriorate throughout the six week production period.

Coloured wings (CW): In an effort to disguise the red blood in the feather sheath during feather emergence, the wing of birds were covered with blue spray marks (Dy-MARK, Wacol, Queensland) on two occasions six days apart (see Figure 6.1).

Blue light (BL): As a further effort to disguise the red blood in the sheath during feather emergence, birds were reared under blue light. Four incandescent BL bulbs with electrical connections were fixed to wooden beams that ran the length of the pens at 75 cm above the floor. Each of the pens had black plastic screens placed from the floor to the roof on the sides of the pens to exclude the fluorescent lighting from other pens as much as possible and prevent BL filtering into the adjacent pens.
Straw bundles (SB): In an effort to distract birds from pecking at feathers, straw bundles were added to the pens (Figure 6.2). Two bundles were placed in each pen, one on the side and one at the front. Fresh straw was added daily.

Corticosterone (Cort): Corticosterone was supplemented in the drinking water. Corticosterone (Sigma-Aldrich) was dissolved in 400 mL ethanol and then made up to 100 L with tap water. The corticosterone concentration of water provided to ducks was 10 mg/L corticosterone and 4 mL/L ethanol.

6.3.4. Blood sampling

A blood sample was taken from one male and one female from each control and corticosterone-treated group on Days 23 and 41 of age, and then on Day 28 from one male and female from each pen, for all treatments. One bird was sampled from each pen within two minutes of being manually restrained. After finishing all pens, birds were left for 40 min and then the second bird of the opposite sex was
sampled from each pen. The plasma collected was stored at –20°C until it was analysed for corticosterone concentrations using a validated radioimmunoassay (Downing and Bryden 2008).

### 6.3.5. 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. Feed intakes were determined over the same time periods and water intakes were recorded daily. Liveweight was also determined at Day 35 for the control and corticosterone-treated birds only.

### 6.3.6. Commercial cut-up

On Day 42, the ducks were transported to PEPE’s Ducks Pty Ltd for processing. After processing 20–24 (equal numbers of males and females) carcasses for each treatment group were removed and refrigerated overnight and on the following day subjected to a commercial cut-up. After full dissection the carcass parts were weighed.

### 6.3.7. Feather damage

On Day 30 (Period 1) and Day 35 (Period 2), all birds were individually examined and the extent of FP damage was determined. The criteria used are described in the Methodology section of this report.

### 6.3.8. Statistical analysis

#### 6.3.8.1. Production performance

Data were stored in Microsoft Excel® and, unless stated otherwise, statistical analysis was conducted using the REML linear mixed model function of Genstat® 11th edition. Data were first tested for equality of variance using residual plots. When the equality of variance could be improved using a loge transformation, data were transformed. The fixed model included the effects of treatment, week and sex, and the random model included the effects of block, pen and tag. Initially all two-way interactions between fixed effects were included in the model. Significance testing of fixed effects was conducted using Wald tests with a significance threshold of P<0.05. Any non-significant interactions were removed from the model. The predicted means for all significant fixed effects were copied to Microsoft Excel®, as well as standard errors, which were used to calculate the SEM. The LSD was used to make pairwise comparisons of means. Microsoft Excel® was used to create graphical summaries of the back-transformed means.

#### 6.3.8.2. Feather pecking damage

Since the FP score data are recorded on an ordinal scale (0–3), not a measurement scale, the usual linear model methods such as REML cannot be used to analyse these data. Consequently, an ordinal logistic regression model was used, with a proportional odds method (Agresti, 2002). The form of the method specified in the analyses is:

\[
\log_e \left( \frac{P(Y \leq k)}{P(Y > k)} \right) = \theta_k + \text{Treatment + Period + Sex + Region + }
\]

\[
\]

Where:

\[P(Y \leq k) = \text{probability of obtaining a score of } k \text{ or lower, } k=0, 1, 2.\]

\[\theta_k = \text{intercept for a score of } k;\]
The fixed effects of the model are:

- **Treatment** = effect of treatment (BL, Females, PL, Control, Straw, Corticosterone, CW, Males) (fixed)
- **Period** = effect of ‘replicate’ (1: Day 30, 2: Day 35) (fixed)
- **Sex** = effect of male v female (fixed)
- **Region** = effect of body region (LW or RW), (LT or RT) and the tail, with Treatment.Period, Treatment.Region and Period.Region being interactions between these factors. Other interactions were tested, but were excluded because of non-significance. The random effects of the model were:

  - Block, assumed $N(0, \sigma_B^2)$
  - Block Pen (pen effect nested within block), assumed $N(0, \sigma_P^2)$
  - Block Pen.Tag (bird effect nested within pen), assumed $N(0, \sigma_T^2)$
  - Block Pen.Tag.Period (set of bird’s measurements at a particular period, assumed $N(0, \sigma_M^2)$).

This is a model for the cumulative log odds (logit) of obtaining a score of $k$ or lower. Note that the log odds assumption implies that difference in score probabilities is entirely accounted for by the separate intercepts of each score ($\theta_k$), i.e., the fixed (and random) effects of interest apply across all scores.

The significance of the fixed effects was assessed using Wald Chi-square tests, and individual treatment or other between-group comparisons were conducted using approximate $z$-tests:

$$z = \frac{\text{logit}_1 - \text{logit}_2}{\text{SED}}$$

Where:

- $\text{logit}_1 - \text{logit}_2 =$ difference in model-based logits of the two treatments
- $\text{SED} =$ standard error of the difference of the model-based logits.

A $z$-statistic greater than two (in absolute value) was identified as significant ($P<0.05$, approximately). For the current analysis, $\text{logit}[P(Y = 0)] = \log_p[P(Y = 0)/P(Y > 0)]$ was used to compare logits of different treatments, but any score cut-off could be used with identical results.

While the model fitting returns cumulative probabilities, $P(Y \leq k)$, individual event probabilities can then be calculated by difference, to allow visualisation, i.e.:

$$P(Y = k) = \begin{cases} P(Y \leq 0) & k = 0 \\ P(Y \leq k) - P(Y \leq k - 1) & k = 1, 2 \\ 1 - P(Y \leq 2) & k = 3 \end{cases}$$

The models were fitted using the stand-alone version of ASReml 3 (Gilmour et al. 2009). Note that in this package, it was required to recode scores from 0–3 to 1–4, but the results are unchanged.
6.4. Results

6.4.1. Plasma corticosterone concentrations

During the period of corticosterone supplementation the mean (±SEM) corticosterone intake was 7.02±0.13 mg/bird/day. The effect of treatment on the mean (±SEM) plasma corticosterone concentrations are given in Table 6.1. On Day 23 of age (after two days of treatment), the concentration of corticosterone was similar for the control and corticosterone-treated birds (P=0.09). On Day 28 of age, the treatment effect was significant (P=0.03), but not the sex effect (P=0.36). The mean corticosterone concentration for females was 1.79±0.23 ng/mL and 2.10±0.23 ng/mL for males. When the males were reared as single sex pens, the corticosterone concentration was similar to that of females reared in single sex pens and the birds with CW, but different to other treatments (P<0.05). On Day 41, the corticosterone concentrations were not different between the control and corticosterone-supplemented treatments (P=0.71). Furthermore, at this time the differences between males (0.54±0.13 ng/mL) and females (0.60±0.15 ng/mL) was not different (P=0.69).

Table 6.1. The effect of treatment on the mean (±SEM) plasma corticosterone concentrations

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Corticosterone concentration (ng/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 23</td>
</tr>
<tr>
<td>Control</td>
<td>2.79±0.71</td>
</tr>
<tr>
<td>BL</td>
<td>1.67±0.41b</td>
</tr>
<tr>
<td>CW</td>
<td>2.62±0.41ab</td>
</tr>
<tr>
<td>PL</td>
<td>1.74±0.41bc</td>
</tr>
<tr>
<td>SB</td>
<td>1.24±0.41c</td>
</tr>
<tr>
<td>Cort</td>
<td>1.71±0.28</td>
</tr>
<tr>
<td>FS</td>
<td>2.38±0.46abc</td>
</tr>
<tr>
<td>MS</td>
<td>2.96±0.44a</td>
</tr>
</tbody>
</table>

Note: Within column values without common superscripts are significantly different (P<0.05)

6.4.2. Production performance

The performance analysis was completed for all treatments where birds were reared as mixed sexes. The single sex reared groups were included in the analysis of FP but were analysed separately from other treatments for the effects on performance.

6.4.2.1. Liveweight

The effect of treatment on liveweight was significant (see Table 6.2), but this changed with time as the interaction with week was significant (P<0.001). In Weeks 3–4, the liveweight of birds treated with corticosterone was lower than other treatments (P<0.05), as was the liveweight of birds reared under BL (P<0.05). Birds on PL had lower liveweight than the control birds. In Weeks 5–6, birds supplemented with corticosterone had a liveweight lower than all other treatments (P<0.05). The birds reared under BL and having access to SB had lower liveweight than other treatments (P<0.05). The control birds and those with CW or on PL had similar liveweight.
Table 6.2. The effect of treatment on the mean (±SEM) liveweight (g) of ducks during different phases of the six week production cycle

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Liveweight (g)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weeks 1+2</td>
<td>Weeks 3+4</td>
<td>Weeks 5+6</td>
</tr>
<tr>
<td>Control</td>
<td>694±5</td>
<td>1,931±14 a</td>
<td>2,942±20 a</td>
</tr>
<tr>
<td>BL</td>
<td>697±5</td>
<td>1,880±13 c</td>
<td>2,878±20 b</td>
</tr>
<tr>
<td>CW</td>
<td>682±5</td>
<td>1,924±13 ab</td>
<td>2,945±2 a</td>
</tr>
<tr>
<td>PL</td>
<td>692±5</td>
<td>1,903±13 b</td>
<td>2,969±21 a</td>
</tr>
<tr>
<td>SB</td>
<td>694±5</td>
<td>1,908±13 ab</td>
<td>2,907±20 b</td>
</tr>
<tr>
<td>Cort</td>
<td>686±5</td>
<td>1,676±12 a</td>
<td>2,530±20 b</td>
</tr>
</tbody>
</table>

Note: Within column values without common superscripts are significantly different (P<0.05)

Sex had a significant effect on liveweight (see Table 6.3), but this changed with time as the sex x week interaction was significant (P<0.001). In all weeks, the males were heavier than the females, but the difference was greater as the age increased (P<0.05). The sex x treatment interaction was marginally non-significant (P<0.09). The differences between males and females tended to be less for the birds supplemented with corticosterone than other treatments.

Table 6.3. The effect of sex on the mean (±SEM) liveweight (g) of ducks during different phases of the six week production cycle. Ducks were reared in mixed sex groups

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Liveweight (g)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weeks 1+2</td>
<td>Weeks 3+4</td>
<td>Weeks 5+6</td>
</tr>
<tr>
<td>Females</td>
<td>684±4 b</td>
<td>1,834±11 b</td>
<td>2,766±17 b</td>
</tr>
<tr>
<td>Males</td>
<td>698±4 a</td>
<td>1,905±11 a</td>
<td>2,951±18 a</td>
</tr>
<tr>
<td>Difference</td>
<td>14</td>
<td>71</td>
<td>185</td>
</tr>
</tbody>
</table>

Note: Within column values without common superscripts are significantly different (P<0.05)

The effect of single sex rearing on mean liveweight (the error bars are too small to register readily on the graph) is given in Figure 6.3. The treatment x week interaction was significant (P<0.001). Males were heavier than females at Week 4 and Week 6 but not at Week 2 (P<0.05).
6.4.2.2. Liveweight gain

The effect of treatment on LWG was significant (Table 6.4), but this changed with time as the interaction with week was significant (P<0.001). In Weeks 3–4 the LWG of birds supplemented with corticosterone was lower than other treatments (P<0.05), as was the LWG of birds reared under BL, except when compared to those on PL (P<0.05). The difference in LWG between birds with the CW and those with PL was significant (P<0.05).

In Weeks 5–6, the birds supplemented with corticosterone had lower LWG than all other treatments (P<0.05). Birds on PL had higher weight gain than those given other treatments (P<0.05). Birds reared under BL and with SB had similar LWG, but this was lower than those with CW (P<0.05).

### Table 6.4. The effect of treatment on the mean (±SEM) LWG (g) of ducks during different phases of the six week production cycle

<table>
<thead>
<tr>
<th>Treatment</th>
<th>LWG (g)</th>
<th>Weeks 1+2</th>
<th>Weeks 3+4</th>
<th>Weeks 5+6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>641±6</td>
<td>1,235±11a</td>
<td>1,003±9c</td>
<td></td>
</tr>
<tr>
<td>BL</td>
<td>644±6</td>
<td>1,181±11c</td>
<td></td>
<td>996±9c</td>
</tr>
<tr>
<td>CW</td>
<td>626±6</td>
<td>1,239±11a</td>
<td></td>
<td>1,028±9b</td>
</tr>
<tr>
<td>PL</td>
<td>638±6</td>
<td>1,208±10c</td>
<td></td>
<td>1,068±11a</td>
</tr>
<tr>
<td>SB</td>
<td>640±6</td>
<td>1,212±11a</td>
<td></td>
<td>991±9c</td>
</tr>
<tr>
<td>Cort</td>
<td>630±6</td>
<td>984±9d</td>
<td></td>
<td>881±9a</td>
</tr>
</tbody>
</table>

Note: Within column values without common superscripts are significantly different (P<0.05)

Sex had a significant effect on LWG (Table 6.5), but this changed with time as the sex x week interaction was significant (P<0.001). In all weeks, the males were heavier than females (P<0.05), but the difference was greater as age increased. The sex x treatment interaction was significant (P=0.01).
While males were heavier than females for all treatments, the difference between the sexes was less for those supplemented with corticosterone compared to other treatments (see Table 6.6).

Table 6.5. The effect of sex on the mean (±SEM) LWG (g) of ducks during different phases of the six week production cycle

<table>
<thead>
<tr>
<th>Treatment</th>
<th>LWG (g)</th>
<th>Weeks 1+2</th>
<th>Weeks 3+4</th>
<th>Weeks 5+6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females</td>
<td>630±6\textsuperscript{b}</td>
<td>1,145±10\textsuperscript{b}</td>
<td>937±8\textsuperscript{b}</td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>644±6\textsuperscript{a}</td>
<td>1,201±11\textsuperscript{a}</td>
<td>1,053±9\textsuperscript{a}</td>
<td></td>
</tr>
</tbody>
</table>

Note: Within column values without common superscripts are significantly different (P<0.05)

Table 6.6. The effects of treatment and sex on the mean (±SEM) LWG (g) of ducks during different phases of the six week production cycle

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Liveweight (g)</th>
<th>Females</th>
<th>Males</th>
<th>Difference between means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>895±8</td>
<td>958±9</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>BL</td>
<td>882±8</td>
<td>942±8</td>
<td>59</td>
<td></td>
</tr>
<tr>
<td>CW</td>
<td>891±8</td>
<td>966±9</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>PL</td>
<td>903±8</td>
<td>974±9</td>
<td>71</td>
<td></td>
</tr>
<tr>
<td>SB</td>
<td>888±8</td>
<td>945±9</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>Cort</td>
<td>810±7</td>
<td>826±7</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>

Because it was decided to terminate the corticosterone treatment at the end of Week 5, the control and corticosterone-treated birds were weighed on Day 35 of age. The liveweight for these two treatments over Weeks 5 and 6 was analysed on a g/d basis. There were significant treatment x week (P=0.004) and sex x week (P=0.02) interactions. In both weeks the control birds had higher daily LWG (P<0.05). For the controls, the daily LWG was higher (P<0.05) in Week 5 (82±3 g) than in Week 6 (70±3 g). For the corticosterone-treated birds, the daily LWG was similar in both weeks (57±2 v 58±2 g). For the control birds, both males and females had higher daily LWG (P<0.05) than the corticosterone-treated males and females, respectively. For the control birds, the males had higher daily LWG (P<0.05) than females (71±3 v 80.7±3 g), but for the corticosterone-treated birds this was not the case (59±2 v 56±2 g).

The LWG for the controls and the corticosterone-treated birds in Week 5 and the total LWG for the control birds (577±14 g) was greater (P<0.001) than the birds supplemented with corticosterone (417±14 g). The difference between males (501±12 g) and females (480±11 g) was not significant (P=0.15).

The LWG of the birds reared in single sex pens is shown in Figure 6.4. The effect of sex on the LWG was significant, but it changed over time as the sex x week interaction was significant (P<0.001). For all weeks, the rate of LWG for both females and males were significantly different (P<0.05). Males had higher LWG than females at Week 4 and Week 6, but not at Week 2 (P<0.05).
6.4.2.3. Feed intake

The effect of treatment on mean (±SEM) feed intake is given in Table 6.7. Week had a significant effect on feed intake, but this depended on the treatment as the treatment x week interaction was significant (P<0.001). There were no differences in feed intake in Weeks 1–2. In Weeks 3–4, the main difference in feed intake was that it was higher for the ducks supplemented with corticosterone compared to other treatments (P<0.05). The birds reared under BL had lower intake than the control birds and those with CW (P<0.05). In Weeks 5–6 birds supplemented with corticosterone in Week 5 had a lower feed intake than other treatments (P<0.05). Birds maintained on PL had greater feed intake than those reared under BL or with SB (P<0.05). Treatment had no effect on the total amount of feed consumed during the full production period (P=0.19).

Males and females reared in single sex pens had similar total feed intakes during different weeks (P=0.86) of the production cycle and a similar total feed intake (P=0.56).
Table 6.7. The effects of treatment on mean (±SEM) feed intake (g) of ducks during different phases of the production cycle

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Feed intake (g)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weeks 1+2</td>
<td>Weeks 3+4</td>
<td>Weeks 5+6</td>
<td>Total all weeks</td>
</tr>
<tr>
<td>Control</td>
<td>845±15</td>
<td>2,242±40°b</td>
<td>2,771±50°ab</td>
<td>5,855±94</td>
</tr>
<tr>
<td>BL</td>
<td>830±15</td>
<td>2,150±39°c</td>
<td>2,689±48°b</td>
<td>5,670±91</td>
</tr>
<tr>
<td>CW</td>
<td>817±15</td>
<td>2,267±41°b</td>
<td>2,802±50°ab</td>
<td>5,884±94</td>
</tr>
<tr>
<td>PL</td>
<td>825±15</td>
<td>2,224±40°bc</td>
<td>2,861±52°a</td>
<td>5,914±95</td>
</tr>
<tr>
<td>SB</td>
<td>831±15</td>
<td>2,217±40°bc</td>
<td>2,735±49°b</td>
<td>5,791±93</td>
</tr>
<tr>
<td>Cort</td>
<td>830±15</td>
<td>2,453±44°a</td>
<td>2,482±45°c</td>
<td>5,768±93</td>
</tr>
<tr>
<td>Females</td>
<td>850±34</td>
<td>2,212±34</td>
<td>2,741±34</td>
<td>5,804±78</td>
</tr>
<tr>
<td>Males</td>
<td>831±34</td>
<td>2,228±34</td>
<td>2,810±34</td>
<td>5,870±78</td>
</tr>
</tbody>
</table>

Note: Within column values without common superscripts are significantly different (P<0.05)

6.4.2.4. Water intake

The treatments had a significant effect on water intake (see Table 6.8), but this changed with time as the treatment x week interaction was significant (P<0.001). In Weeks 3–4, the birds supplemented with corticosterone had greater water intake and those on PL had a lower water intake compared to all other treatments (P<0.05). In Weeks 5–6, birds supplemented with corticosterone in Week 5 had higher water intake than other treatments except the control birds (P<0.05). Treatment had an effect on the total water consumption (P<0.001), with it being higher for the corticosterone-supplemented birds compared to other treatments (P<0.05). Males and females reared in single sex pens had similar water intakes (P=0.86). The total intake was not different (P=0.73).
Table 6.8. The effects of treatment on mean (±SEM) water intake (L) of ducks during different phases of the production cycle

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Water intake (L)</th>
<th>Weeks 1+2</th>
<th>Weeks 3+4</th>
<th>Weeks 5+6</th>
<th>Total all weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td></td>
<td>1.49±0.03</td>
<td>6.35±0.14b</td>
<td>10.17±0.22ab</td>
<td>18.02±0.34b</td>
</tr>
<tr>
<td>BL</td>
<td></td>
<td>1.54±0.03</td>
<td>6.42±0.14b</td>
<td>9.88±0.22b</td>
<td>17.84±0.34b</td>
</tr>
<tr>
<td>CW</td>
<td></td>
<td>1.49±0.03</td>
<td>6.31±0.14b</td>
<td>9.88±0.22b</td>
<td>17.69±0.34b</td>
</tr>
<tr>
<td>PL</td>
<td></td>
<td>1.48±0.03</td>
<td>5.97±0.13c</td>
<td>9.77±0.21b</td>
<td>17.22±0.33b</td>
</tr>
<tr>
<td>SB</td>
<td></td>
<td>1.49±0.03</td>
<td>6.25±0.14b</td>
<td>10.06±0.22b</td>
<td>17.80±0.34b</td>
</tr>
<tr>
<td>Cort</td>
<td></td>
<td>1.47±0.03</td>
<td>7.82±0.17a</td>
<td>10.56±0.23a</td>
<td>19.85±0.38a</td>
</tr>
</tbody>
</table>

Single sex rearing

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Water intake (L)</th>
<th>Weeks 1+2</th>
<th>Weeks 3+4</th>
<th>Weeks 5+6</th>
<th>Total all weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Females</td>
<td></td>
<td>1.52±0.17</td>
<td>6.09±0.17</td>
<td>9.95±0.17</td>
<td>17.57±0.38</td>
</tr>
<tr>
<td>Males</td>
<td></td>
<td>1.49±0.17</td>
<td>6.24±0.17</td>
<td>9.68±0.17</td>
<td>17.39±0.38</td>
</tr>
</tbody>
</table>

Note: Within column values without common superscripts are significantly different (P<0.05)

6.4.2.5. Feed to gain

Treatment had a significant effect on the feed to gain ratio (see Table 6.9), but this changed with time as the treatment x week interaction was significant (P=0.001). In both Weeks 3–4 and Weeks 5–6, the feed to gain was worse for the corticosterone-supplemented birds compared to other treatments (P<0.05). Over the full production period, the birds treated with corticosterone had the poorest feed to gain (P<0.05).

The feed to gain ratio for males and females reared in single sex pens was different (P=0.008). The females had a poorer feed to gain than the males in all weeks (P<0.05). The total feed to gain was different (P=0.02), with it being better for males.
Table 6.9. The effects of treatment on mean (±SEM) feed to gain ratio of ducks during different phases of the production cycle

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Feed to gain ratio</th>
<th></th>
<th></th>
<th>Total All weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weeks 1+2</td>
<td>Weeks 3+4</td>
<td>Weeks 5+6</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>1.31±0.02</td>
<td>1.80±0.03b</td>
<td>2.76±0.04b</td>
<td>2.03±0.02b</td>
</tr>
<tr>
<td>BL</td>
<td>1.30±0.02</td>
<td>1.81±0.03b</td>
<td>2.70±0.04b</td>
<td>2.01±0.02b</td>
</tr>
<tr>
<td>CW</td>
<td>1.29±0.02</td>
<td>1.82±0.03b</td>
<td>2.76±0.04b</td>
<td>2.03±0.02b</td>
</tr>
<tr>
<td>PL</td>
<td>1.29±0.02</td>
<td>1.84±0.03b</td>
<td>2.69±0.04b</td>
<td>2.03±0.03b</td>
</tr>
<tr>
<td>SB</td>
<td>1.30±0.02</td>
<td>1.82±0.03b</td>
<td>2.75±0.04b</td>
<td>2.03±0.02b</td>
</tr>
<tr>
<td>Cort</td>
<td>1.31±0.02</td>
<td>2.47±0.04a</td>
<td>3.09±0.05a</td>
<td>2.37±0.03a</td>
</tr>
</tbody>
</table>

| Single sex rearing |  |  |  |  |
|                    |  |  |  |  |
| Females            | 1.32±0.02a         | 1.86±0.02a | 2.28±0.04a | 2.07±0.02a        |
| Males              | 1.28±0.02b         | 1.81±0.02b | 2.65±0.04b | 2.00±0.02b        |

Note: Within column values without common superscripts are significantly different (P<0.05)

6.4.2.6. Water to feed

Treatment (see Table 6.10) had a significant effect on the water to feed ratio, but this changed with time as the treatment x week interaction was significant (P<0.001). In Weeks 3–4 and Weeks 5–6, the water to feed ratio was higher for the ducks supplemented with corticosterone compared to all other treatments (P<0.05). In Weeks 5–6, the water to feed ratio was lower for the birds maintained in PL compared to other treatments, except those birds with CW (P<0.05). Over the full production period the birds treated with corticosterone had the highest water to feed ratio (P<0.05), while the birds maintained on the PL had a lower water to feed ratio compared to those maintained under BL (P<0.05). The water to feed ratio for males and females reared in single sex pens was not different (P=0.31), although it was different at all weeks (P<0.001).
Table 6.10. The effects of treatment on mean (±SEM) water to feed ratio of ducks during different phases of the production cycle

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Water to feed ratio</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weeks 1+2</td>
<td>Weeks 3+4</td>
<td>Weeks 5+6</td>
<td>Total all weeks</td>
</tr>
<tr>
<td>Control</td>
<td>1.76±0.05</td>
<td>2.83±0.09&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.67±0.11&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.07±0.09&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>BL</td>
<td>1.86±0.06</td>
<td>2.99±0.09&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.67±0.11&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.15±0.09&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>CW</td>
<td>1.83±0.06</td>
<td>2.78±0.08&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.53±0.11&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>3.01±0.09&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>PL</td>
<td>1.80±0.05</td>
<td>2.69±0.08&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.42±0.10&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.91±0.09&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>SB</td>
<td>1.80±0.05</td>
<td>2.82±0.08&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.68±0.11&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.07±0.09&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>Cort</td>
<td>1.78±0.05</td>
<td>3.19±0.10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.26±0.13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.45±0.09&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single sex rearing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Females</td>
<td>1.79±0.04</td>
<td>2.76±0.06</td>
<td>3.63±0.08</td>
<td>3.03±0.07</td>
</tr>
<tr>
<td>Males</td>
<td>1.78±0.04</td>
<td>2.79±0.06</td>
<td>3.42±0.08</td>
<td>2.95±0.07</td>
</tr>
</tbody>
</table>

Note: Within column values without common superscripts are significantly different (P<0.05)

6.4.3. Commercial cut-up

The effect of treatment on the yield of muscle and fat following the commercial processing and cut-up is given in Table 6.11. While absolute weights are relevant to the processor, the treatment effects are best analysed as a percentage of total carcass weight as this accounts for differences in individual carcass weights. When expressed as a percentages of carcass weight the treatment effects on breast weight percentage (P<0.0001), thigh weight percentage (P<0.0001), drumstick weight percentage (P=0.0004), cod weight percentage (P=0.0010 and subcutaneous fat percentage (P=0.001) were all significant.

The breast percentage was lower for the corticosterone-treated birds than for the control birds, those with CW and those on PL (P<0.05). Birds provided with SB had greater thigh weight than the control birds (P<0.05). The drumstick percentage was greater for the control birds than other treatments except those on PL (P<0.05). The cod fat (abdominal) percentage was higher for the corticosterone-treated birds than for the other treatments, except the control birds and those on PL (P<0.05). The subcutaneous fat percentage was higher for the corticosterone-treated birds compared to all other treatments (P<0.05).

The total meat yield of the processed carcass was lower for the corticosterone-treated birds than other treatments, except those reared under BL or those with CW (P<0.05). The carcass fat yield was higher for the corticosterone-treated birds compared to all other treatments (P<0.05).
Table 6.11. The effects of treatment on mean (±SEM) carcass muscle and fat weights as a percentage of the carcass weight following the commercial processing and cut-up

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Control</th>
<th>BL</th>
<th>CW</th>
<th>PL</th>
<th>SB</th>
<th>Cort¹</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carcass weight (g)</td>
<td>2.153 ±38</td>
<td>2.186 ±36</td>
<td>2.125 ±30</td>
<td>2.156 ±30</td>
<td>2.089 ±20</td>
<td>2.119 ±29</td>
<td>0.35</td>
</tr>
<tr>
<td>Breast weight as % of CW³</td>
<td>11.36 ±0.30ab</td>
<td>10.74 ±0.17b ³bc</td>
<td>11.31 ±0.26ab³</td>
<td>11.83 ±0.21a</td>
<td>10.74 ±11bc</td>
<td>9.87 ±0.26c</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Thigh weight as % of CW</td>
<td>6.08 ±0.17b ³</td>
<td>6.30 ±0.24a²</td>
<td>6.32 ±0.29ab³</td>
<td>6.44 ±0.19a²</td>
<td>7.54 ±0.11a</td>
<td>6.45 ±0.25a²</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Drumstick weight as % of CW</td>
<td>6.05 ±0.13a³</td>
<td>5.41 ±0.11b ³</td>
<td>5.53 ±0.1b ³</td>
<td>5.74 ±0.09ab³</td>
<td>5.43 ±0.09b³</td>
<td>5.55 ±0.11b³</td>
<td>0.0004</td>
</tr>
<tr>
<td>Cod fat weight as % of CW</td>
<td>1.74 ±0.08ab³</td>
<td>1.63 ±0.08b³</td>
<td>1.64 ±0.06b³</td>
<td>1.85 ±0.07ab³</td>
<td>1.56 ±0.07b³</td>
<td>2.10 ±0.12a³</td>
<td>0.001</td>
</tr>
<tr>
<td>Sub-fat weight² as % of CW</td>
<td>30.1 ±0.5b³</td>
<td>31.6 ±0.4b³</td>
<td>30.8 ±0.4b³</td>
<td>31.9 ±0.7b³</td>
<td>31.3 ±0.4b³</td>
<td>34.2 ±0.7a³</td>
<td>0.001</td>
</tr>
<tr>
<td>% meat in the carcass</td>
<td>23.5 ±0.4ab³</td>
<td>22.4 ±0.4b³</td>
<td>23.2 ±0.4ab³</td>
<td>24.0 ±0.3³</td>
<td>23.7 ±0.2ab³</td>
<td>21.9 ±0.4³</td>
<td>0.002</td>
</tr>
<tr>
<td>% fat in the carcass</td>
<td>32.2 ±0.5b³</td>
<td>33.2 ±0.4b³</td>
<td>32.5 ±0.4b³</td>
<td>33.7 ±0.8b³</td>
<td>32.8 ±0.4b³</td>
<td>36.3 ±0.8³</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Note: Within column values without common superscripts are significantly different (P<0.05)
¹Cort=Corticosterone treatment
²Sub-fat=subcutaneous fat weight
³CW=Processed carcass weight

6.4.4. Feather pecking damage

The extent of FP damage was minimal, with 93.2% of the scores being recorded as zero (no damage), 2.4% recorded as Score 1, 4.1% recorded as Score 2 and 0.3% recorded as Score 3.

There are highly significant interactions between treatment and period, treatment and region, and period and region (all P<0.001). The other main effects could not be tested because they are already included due to the significant interactions. Despite these overall significant results, relatively few specific comparisons showed up as significant based on the z-tests. However, only specific comparisons were actually tested; namely, other treatment effects were compared with the control. The overall objective was to compare how the allocated treatments compared to the control birds. The figures show the cumulative probability and normally would be shown on a scale of 0–1; however, because the overwhelming majority of scores were zero (no damage), the probability of a score of zero is consistently very high (~0.99). To reveal the patterns of FP the graphs have been plotted from 0.99 to 1.

The effect of sex on the FP score (see Figure 6.5) was not significant (P=0.12).
The effect of sex on the probability of recording a specific feather damage score is shown in Figure 6.5. In Period 1 (Day 30 of age), the birds with CW had a significantly lower damage score than the control birds ($P=0.013$). Birds reared under BL had marginally lower damage scores than control birds ($P=0.096$). In Period 2, when treatments are compared to control birds, no differences were detected (all $P<0.1$).

The effect of treatment on the probability of FP damage being recorded in the two sampling periods is given in Figure 6.6. In Period 1 (Day 30 of age), the birds with CW had a significantly lower damage score than the control birds ($P=0.013$). Birds reared under BL had marginally lower damage scores than control birds ($P=0.096$). In Period 2, when treatments are compared to control birds, no differences were detected (all $P<0.1$).
The effect of treatment on the probability of FP damage being recorded at different body regions is given in Figure 6.7. For this analysis, comparisons were performed within a body region, by comparing the various treatments to the control birds. There were indications that the LW and the RW had higher scores across most treatment groups, although this effect was subtle. One comparison was marginally non-significant; that being for the differences in the tail scores for the SB and control birds (P=0.07). Nevertheless, it should be noted the higher scores for the LW and RW were recorded for birds on PL and males reared on single sex pens (MS) but these differences failed to reach significance.

**Figure 6.7.** The effect of treatment on the probability of a feather damage score being recorded at different areas on the body

Note: In the figure, not all labels on the x-axis are shown but for each treatment group the order (left to right) is for the LW, RW, LT, RT and tail regions

The effects of treatment on the probability of feather damage scores being recorded at different body regions at Period 1 (Day 30) and Period 2 (Day 35) are given in Figure 6.8. Within each body region, scores changed significantly between Period 1 and Period 2 (all P<0.005). For the LW, RW, LT and RT the scores increased from Period 1 to Period 2, although there was a slight but significant reduction in tail scores from Period 1 to Period 2. Also, in both periods, the wings sustained the highest scores (both RW and LW), with the lowest scores on the thighs and tail.
6.5 Discussion

A notable observation was the failure to detect any increase in plasma corticosterone concentration when ducks were given corticosterone-supplemented water. Two blood samples were taken during the supplemented period and one after the supplementation ceased, and in none of these was the concentration of corticosterone different from the control birds. Using broilers Lin et al. (2004) showed that corticosterone administered in the feed (30 mg/kg) will substantially elevate plasma corticosterone (>80 ng/mL). While this seems an excessively high concentration, a similar inclusion rate resulted in only a 30% increase in plasma corticosterone (Hu et al. 2010).

Simulating stress by adding corticosterone at a concentration of 20 mg/L in water has been used in laying hens (Shini et al. 2008) and in broilers (Post et al. 2003; Jiang et al. 2008; Hu et al. 2010). Starting with 21 day old broilers, Post et al. (2003) provided water supplemented with corticosterone at 5, 10 or 20 mg/L. The treatment lasted 10 days and blood samples were taken before and then on Days 1, 3 and 8 after the start of the supplementation. For all doses the corticosterone concentration quickly increased to a peak (Day 1 for 20 mg/L and Day 3 for the 5 and 10 mg/L doses) and then gradually decreased. The plasma corticosterone concentrations for the 5 mg/L dose were only different from the control values on Day 8.

Of further interest in this study was the dose response inhibition of corticosterone release following an ACTH challenge five days after treatments started. There was no response from the birds supplemented with 20 mg/L corticosterone, and compared to the control birds, a much reduced response in broilers on the 5 and 10 mg/L supplemented water. Feedback regulation of the HPA axis is a mechanism involved in the control of adrenal function. The unresponsiveness of the adrenal gland to an ACTH challenge in the corticosterone-supplemented birds could be part of the adaptation to prolonged high plasma corticosterone concentrations. Based on water consumption and weight the birds received 1, 2 or 4 mg/kg liveweight per day (Post et al. 2003). Based on the water intake and the liveweight in the current study, ducks received 3.5 mg/kg at Day 21 of age and 3.8 mg/kg at Day 35. It is difficult to understand why there was no increase in plasma corticosterone concentrations in the
ducks, considering a similar supplementation rate elevated concentrations in broilers for more than 8 days.

While the corticosterone was dissolved in ethanol, no treatment with ethanol alone in water was included in the current study. This exclusion was based on the work of Post et al. (2003). They included an ethanol treatment in their work and found no differences between the ethanol treatment and the control for a range of physiological measures. For reasons of animal ethics, including an ethanol treatment in the current duck study was not warranted.

While there was no increase in plasma corticosterone concentration, there were definite measurable physiological effects on the ducks. A notable observation was the depressed LWG in the birds supplemented with corticosterone. Although the corticosterone was supplemented in Weeks 3–5, the effect on LWG was severe enough to significantly depress liveweight at market age. The final liveweight was around 400 g lower than the control birds. Males were heavier than females in all treatments but this difference was less for the birds treated with corticosterone. In fact, in Week 5 the difference was not significant. It could be that the effects on LWG are more severe in the males because they normally grow at a faster rate than females during Weeks 5–6 (Downing 2010). The pattern of feed intake in these birds was also unique. They had the highest feed intake in Weeks 3–4 and the lowest in Weeks 5–6, with the overall total feed intake being similar to all other treatment groups. Compared to other treatments the water intake in Weeks 3–4 was highest for the corticosterone birds and the effect was similar in Weeks 5–6 except when compared to the controls. These differences in feed and water intake resulted in the corticosterone-treated birds having the worst feed to gain and highest water to feed ratio.

Suppressed LWG is a regular effect seen when broilers are supplemented with corticosterone in the feed or water (Post et al. 2003; Lin et al. 2004; 2006; Yuan et al. 2007; Dong et al. 2007; Virden et al. 2007; Jiang et al. 2008). The feed intake of corticosterone-treated ducks was higher in Weeks 3–4. The effects of corticosterone treatment on feed intake in broilers is equivocal, with some researchers reporting that it increases (Bartov et al. 1980; Nasir et al. 1999; Yuan et al. 2007; Jiang et al. 2008) and others that it decreases feed intake (Buyse et al. 1987; Malheiros et al. 2003, Lin et al. 2004, 2006). However, in some instances when feed intake is expressed as feed consumed per kilogram metabolic body weight (body weight/kg$^{0.75}$), what appeared to be a decrease in feed intake was actually an increase in relative ME intake (Lin et al. 2004).

While feed intake increased, the feed to gain was worse for the corticosterone-treated birds. Poorer feed to gain was commonly seen in corticosterone treated broilers (Lin et al. 2006; Dong et al. 2007; Jiang et al. 2008). This lower efficiency could be related to energy wastage. In a pair feeding experiment, where broilers had the same feed consumption, corticosterone treatment depressed growth rates compared to the untreated bird in each pair. This indicated that one effect of corticosterone was to increase energy waste (Dong et al. 2007). Recent work has shown that one effect of dietary supplemented corticosterone is to significantly decrease small intestine wet weight by 31% and length by 12%, although when the relative weight and length (as % of liveweight) are determined they are not different to control birds (Hu et al. 2010). The difference in liveweight for the corticosterone-treated birds at the end of Week 6 was not realised after evisceration. After evisceration, the carcass weight was similar for all treatments. This would suggest that the corticosterone-treated birds had greater feather weight and or lower viscera weight. Increased energy wastage could be related to the retarded development of the digestive tract.

The changes in carcass composition for the corticosterone-treated ducks provide further support that the dose of corticosterone administered was sufficient to cause physiological perturbations. The corticosterone-treated ducks had a lower total carcass muscle percentage and a higher total carcass fat percentage. The effect of corticosterone on carcass fat is well documented in broilers (Bartov et al. 1980; Buyse et al. 1987; Malheiros et al. 2003; Lin et al. 2006; Dong et al. 2007; Yuan et al. 2007; Jiang et al. 2008). The reduced breast percentage is also similar to what occurs in broilers (Dong et al. 2007). The higher thigh percentage seen in the corticosterone treated ducks is not consistent with what occurs in broilers (Lin et al. 2006; Dong et al. 2007). These differences could be related to the later
development of breast muscle in ducks compared to broilers (Downing et al. 2010). Corticosterone treatment stimulates increased plasma glucose and uric acid concentrations in broilers (Lin et al. 2004; Lin et al. 2006; Dong et al. 2007). This indicates that the processes of glycogenolysis, gluconeogenesis and protein catabolism are influenced by corticosterone (Lin et al. 2004; Lin et al. 2006; Dong et al. 2007). A significant decrease in protein synthesis of breast muscle in corticosterone-treated broilers has been reported by Dong et al. (2007). Savary et al. (1998) reported that glucocorticoids induced a significant decrease in protein synthesis in mammalian muscles. The current results indicate that there is redistribution of nutrients in stressed ducks, as is the case in broilers.

Rearing birds under BL resulted in lower LWG over Weeks 3–4 compared to controls and similar LWG in Weeks 5–6, but the earlier effect was sufficient to depress final liveweight compared to the controls. The pattern of feed intake followed the pattern seen in LWG; however, the total amount of feed consumed was similar to the controls, as was the feed to gain at all times. Water intakes and water to feed ratio were similar for these two groups. It could be that the ducks took some time to adjust to the BL and this might account for the lower LWG in Weeks 3–4. Compared to the controls providing SB or colouring the birds’ wings had no effect on any performance measure. While there were some differences between control and birds on PL during the treatment period these were not consistent and overall there were no differences in final performance measures.

While the absolute carcass yield is important for commercial processing, when comparing treatment effects, the weight to liveweight ratio expressed as a percentage is the best measure as it takes account of the absolute liveweight differences. This becomes more important because only a random sub-sample of treated birds were actually taken through the cut-up analysis. In this discussion, treatment effects will be compared with the control birds. When treatments were compared, there were some differences in carcass components as a percentage carcass weight. Treatments had no effect on the total carcass muscle and fat percentage compared to the control birds except as has already been discussed for the corticosterone-treated birds.

Overall, the extent of FP in the experiment was low, and this is an obstacle when experimentally, investigating this problem in ducks. There is no way of predicting how extensive FP will be under the experimental conditions being employed. Because the treatments were designed to limit FP or test if FP could be increased under some conditions, the comparisons of treatment effects were made to the control birds rather than comparisons between the applied treatments. Sex had no effect on feather damage. Compared to the control birds those with CW had lower damage scores than the control birds on Day 30 but not on Day 35. There was a trend for the birds reared under BL to have lower scores than the controls, with the difference being marginally non-significant on Day 30. There were no treatment effects on Day 35. On both assessment days, the wings sustained the highest scores, with lowest scores on the thighs and tail. It should be noted that higher scores for the wings were recorded for birds on PL and males reared in single sex pens but these differences failed to reach significance.

It has been proposed by some producers that conditions that cause stress in ducks seem to increase the propensity for FP and the associated damage. The use of supplementary corticosterone certainly affected performance, but had no effect on FP damage. The corticosterone supplementation was continuous and used to simulate chronic stress. Stress acts through different pathways and it could be that the HPA pathway is not the central pathway for any link between stress and FP activity.

Environmental conditions that are not suitable could cause anxiety and stress in ducks. Producers have suggested that PL quality associated with low temperatures in winter seem to predispose ducks to FP activity. In the current study, litter quality was kept in poor condition and in fact was considered to be as poor as it would ever be in commercial sheds. Producers work very hard to maintain good litter quality and so the experimental conditions could be considered extreme. Birds on the PL performed well, and based on plasma corticosterone levels, were not stressed. The PL treatment had no effect on FP damage.

While there was some suggestion that males reared as a single sex tended to have higher FP damage to the wings, this was not significant. Males reared as single sexes had similar higher plasma
corticosterone concentrations as females reared as a single sex. In other treatments, there was no sex effect detected for FP damage.

It has been reported previously that FP damage directed at the wings in ducks occurs at the time of feather emergence. Observations from previous studies undertaken at the current facility suggested that birds could be attracted to the red colour of the blood which is readily visible in the feather shaft during the initial phases of feather emergence. When this was disguised with a blue spray mark the FP damage was significantly lower than seen in control hens. Further support for this is given by the trend for FP damage to be lower in birds reared under BL.

The data support a role for the blood in the feather shaft as an attraction for ducks to pick at the wings and cause damage. Simulation of stress or PL quality had no effect on the extent of FP damage.
Chapter 7: The electrolyte supplementation of commercial Pekin ducks during short periods of high ambient temperature

7.1. Introduction

Of the strategies tested to help commercial ducks during periods of high temperature, the use of electrolytes and betaine-supplemented water has provided the best opportunity to achieve improvements in performance. Improved growth performance indicates less physiological stress and this will benefit bird welfare. As identified previously, under Australian summer conditions, ducks can be exposed to periods of HS for short periods lasting 1–3 days, although there are some instances where heatwaves can last longer.

Previously, as reported here the electrolyte supplements have been supplied continuously during periods of cyclic high temperature. Continuous supplementation of ducks in commercial sheds would be associated with some management imposition. Producers would need to provide the electrolytes through existing water lines linked to a header tank. On most commercial farms, this would require refilling these tanks more than once daily. If the supplementation could be applied during only part of the day, it might be possible that filling header tanks is only required once daily. The current experiment compared the effect of supplying electrolytes for short periods (2–3 days) in Weeks 5 and 6 of the production cycle, either continuously or during only part of each day.

7.2. Objective

The objective of the study was to assess the effects of continuous or intermittent electrolyte supplementation on the performance of Pekin ducks exposed to short periods of high ambient temperature, during Week 5 and Week 6 of the production cycle. Improved performance is associated with less physiological stress and in turn better welfare. The working hypothesis was that intermittent electrolyte supplementation is sufficient to improve duck performance during periods of cyclic HS.

7.3. Material and methods

7.3.1. Experimental design

There were 48 pens allocated to the study. The pens were number sequentially and divided into six blocks. Each treatment was randomly allocated a pen in each block.

7.3.2. Birds and husbandry

The treatments were applied to two strains of Pekin ducks reared as mixed sex groups consisting of equal numbers of males and females. The strains used were the CV and an industry strain (P2), selected from the parent CV strain for higher growth rate. The strains were produced by the appropriate matings at a commercial breeding farm owned by PEPE’s Ducks Pty Ltd (Windsor, NSW), 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. On arrival, 26 ducklings were placed in each pen. Surrounds were used for the first five days, restricting the ducklings to half the pen area. This helped to keep them within close proximity of the brooding lamps. By Week 6, there were 24 birds in each pen, with a floor space of 1,875cm²/bird. Birds were identified individually with wing tags applied at seven days of age.

Birds had access to feed and water ad libitum. The starter and grower feeds were provided by Ingham’s Pty Ltd. The composition of the starter and grower diets is given in Table 7.1.
Table 7.1. The composition of the starter and grower diets

<table>
<thead>
<tr>
<th>Formulated composition</th>
<th>Starter diet</th>
<th>Grower diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude protein (g/kg)</td>
<td>220</td>
<td>186</td>
</tr>
<tr>
<td>Metabolisable energy (MJ/kg)</td>
<td>12.77</td>
<td>12.90</td>
</tr>
<tr>
<td>Fat (g/kg)</td>
<td>5.5</td>
<td>4.9</td>
</tr>
<tr>
<td>Potassium (g/kg)</td>
<td>6.69</td>
<td>5.95</td>
</tr>
<tr>
<td>Sodium (g/kg)</td>
<td>1.54</td>
<td>3.35</td>
</tr>
<tr>
<td>Chloride (g/kg)</td>
<td>1.84</td>
<td>3.17</td>
</tr>
</tbody>
</table>

7.3.3. Treatments

The eight treatments were:

1. CV strain with water alone
2. CV strain with electrolyte supplementation in water
3. CV strain with electrolyte plus betaine supplementation in water
4. CV strain with electrolyte plus betaine supplementation provided 08:00–1700 h during Heat Period 1 (Days 30–32) and 17:00–08:00 h during Heat Period 2 (Days 40–42)
5. P2 strain with water alone
6. P2 strain with electrolyte supplementation in water
7. P2 strain with electrolyte plus betaine supplementation in water
8. P2 strain with electrolyte plus betaine supplementation provided 08:00 to 1700 h during Heat Period 1 (Days 30–32) and 17:00 to 08:00 during Heat Period 2 (Days 40–42).

The treatments are identified as:

- control=water alone
- E=continuous electrolyte supplementation in water
- E+B=continuous electrolyte plus betaine supplementation in water
- EL+BL=electrolyte plus betaine supplementation in water for a limited time

The electrolyte solution consisted of 126 g sodium chloride, 214 g sodium bicarbonate and 111 g potassium chloride dissolved in 100 L of tap water. The electrolyte and betaine solution consisted of the same electrolytes with 40 g betaine dissolved in 100 L tap water. The betaine preparation is described in Chapter 2.

The treatments were supplied to the birds on Days 30–32 and Days 40–42. During these periods the temperature was raised to 32°C from 08:00–17:00 h and then reduced to 24°C from 17:00–08:00 h. Over Days 33–39, temperature was maintained at 20°C.

7.3.4. Performance and carcass measurements

At placement, a collective pen weight was recorded. Individual liveweights were recorded on Days 15, 29, 32, 39, and 42. At these same times, feed intake was determined as the difference between weights of feed added less the weights of feed refusals removed. Water consumption was recorded daily. On each day during the second heat period (Days 40–42), the intake during the period of high temperature (08:00–17:00 h) and moderate temperature (17:00–08:00 h) was also measured and recorded as mL/h.
7.3.5. Commercial cut-up

On Day 43, the ducks were transported to PEPE’s Ducks Pty Ltd for processing. After processing, 20–24 (equal number of males and females) carcasses for each group were removed and refrigerated overnight, and then on the following day subjected to a commercial cut-up. Different carcass parts following the cut-up were weighed.

7.3.6. Water holding capacity

Water holding capacity for the breast muscle was determined according to the method described by Han et al. (2009). On Day 42, one male duck was removed from each of the control and E+B treatment pens. The birds were weighed and euthanised using a sodium phenobarbital injection. A slice of muscle tissue from the left and right breast were removed and weighed, before being placed between multiple layers of filter paper (Whatman, UK) and these then placed between two glass plates. The samples were then subjected to a 15 kg weight for 10 minutes. The muscle slices were then re-weighed and the water holding capacity calculated as a percentage:

Water holding capacity (%) = (Wet weight – pressed weight)/wet weight) x 100

Following this calculation the muscle slices were then dried in an oven at 55°C over two days and the dry weight calculated as:

Muscle wet weight (%) = (Wet weight* – dry weight)/wet weight x 100

(*The wet weight was the weight of the remaining samples after the water holding determination).

The mean value for the left and right breast samples were calculated for each male and used in the statistical analysis.

7.3.7. Calculation of electrolyte intakes

The individual average daily electrolyte (Na⁺, K⁺, and Cl⁻) intake and total electrolyte intake was calculated from the daily feed and water intakes and concentration of these electrolytes in the feed and water. Any electrolyte concentrations in the tap water were ignored in the calculation.

7.3.8. Statistical analysis

Data were stored in Microsoft Excel® and, unless stated otherwise, statistical analysis was conducted using the REML linear mixed model function of Genstat® 11th edition. Data were first tested for equality of variance using residual plots. When the equality of variance could be improved using a loge transformation, data were transformed.

The fixed model included the effects of treatment, strain, sex and day, and the random model included the effects of block, pen and tag. Initially, all two-way interactions between fixed effects were included in the model. Significance testing of fixed effects was conducted using Wald tests with a significance threshold of P < 0.05. Any non-significant interactions were removed from the model. The predicted means for all significant fixed effects were copied to Microsoft Excel®, as well as standard errors, which were used to calculate the SEM. The LSD, which is equal to two times the SED, was used to make pairwise comparisons of means. Microsoft Excel® was used to create graphical summaries of the back-transformed means.

Differences in water holding capacity and the carcass components from the commercial cut-up were analysed by ANOVA (Statview). Where main effects were significant, pairwise comparisons of means were made using the Tukey/Kramer test with significance set at P<0.05.
7.4 Results

7.4.1. Liveweight

The effects on treatment, strain and sex on the final Day 42 liveweight were significant (all \(P<0.001\)). The control birds (2,774±22 g) had lower liveweight (\(P<0.05\)) than the other treatments, which were all similar (E=2,884±23 g, E+B=2,875±23 g and EL+BL=2,844±23 g). Males at 2,960±20 g were heavier than females at 2,730±19 g (\(P<0.05\)). At 2,919±21 g, birds of the P2 strain were heavier than CV birds, at 2,771±19 g (\(P<0.05\)).

7.4.2. Daily liveweight gain

The effect of treatment of average LWG is given in Table 7.2. Treatment had a significant effect on daily LWG, but this changed with time as the treatment x day interaction was significant (\(P<0.001\)). For all treatments, the gain per day was significantly different in all periods (\(P<0.05\)). There were no differences between the allocated treatment groups over Days 1–29. During the first heat period (Days 30–32) the birds given E and those given E+B had superior daily LWG compared to control birds or those given EL+BL (\(P<0.05\)). Over Days 33–39, the EL+BL birds had higher daily LWG compared to those given E or E+B (\(P<0.05\)), while control birds had better daily LWG than the E+B birds (\(P<0.05\)) during the previous heat period. During the second heat period (Days 40–42) the daily LWG was different for all treatments (\(P<0.05\)). The control birds had the poorest daily LWG, and those with E the highest, while supplementation with E+B was superior to EL+BL.

Table 7.2. The effect of treatment on the mean (±SEM) LWG (g/d) of ducks exposed to periods of high ambient temperature in Weeks 5 and 6

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>45±1</td>
<td>87±2</td>
<td>57±2(^a)</td>
<td>71±2(^b)</td>
<td>33±1(^d)</td>
</tr>
<tr>
<td>E</td>
<td>45±1</td>
<td>88±2</td>
<td>76±2(^a)</td>
<td>67±2(^bc)</td>
<td>60±2(^a)</td>
</tr>
<tr>
<td>E+B</td>
<td>45±1</td>
<td>90±2</td>
<td>75±2(^a)</td>
<td>65±2(^c)</td>
<td>54±2(^b)</td>
</tr>
<tr>
<td>EL+BL</td>
<td>45±1</td>
<td>89±2</td>
<td>55±2(^b)</td>
<td>72±2(^a)</td>
<td>49±2(^c)</td>
</tr>
</tbody>
</table>

Note: Values within a column without common superscripts are significantly different (\(P<0.05\))

While strain had a significant effect on daily LWG (see Table 7.3) this changed, as the strain x day interaction was significant (\(P<0.001\)). In all periods, except over Days 16–29, the P2 strain had significantly greater LWG than the CV strain (\(P<0.05\)). Strain CV had different rates of LWG in all periods except for Days 1–15 and Days 40–42 (\(P<0.05\)), while strain P2 had different rates of LWG in all periods except for Days 30–32 and Days 33–39 (\(P<0.05\)).
The effect of strain on the mean (±SEM) LWG (g/d) of ducks exposed to periods of high ambient temperature in Weeks 5 and 6

<table>
<thead>
<tr>
<th>Days</th>
<th>LWG (g/d)</th>
<th>Strain CV</th>
<th>Strain P2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–15</td>
<td>44±1d</td>
<td>46±1d</td>
<td></td>
</tr>
<tr>
<td>16–29</td>
<td>89±2a</td>
<td>88±2a</td>
<td></td>
</tr>
<tr>
<td>30–32</td>
<td>58±1c</td>
<td>73±2b</td>
<td></td>
</tr>
<tr>
<td>33–39</td>
<td>64±1b</td>
<td>74±2b</td>
<td></td>
</tr>
<tr>
<td>40–42</td>
<td>44±1d</td>
<td>51±1c</td>
<td></td>
</tr>
</tbody>
</table>

Note: Values within a column without common superscripts are significantly different (P<0.05)

The effect of sex on average daily gain is shown in Table 7.4. Sex had a significant effect on daily LWG, but this was influenced by interactions with day and strain, with these being significant (P<0.001). For females, the daily LWG for Days 30–32 and 33–39 were similar but all other comparisons were different (P<0.05). For males, the daily LWG was different for all periods (P<0.05). During all periods males had a better daily LWG than females (P<0.05). The difference between males and females was greater (P<0.05) for Strain P2 (69±1 v 60±1 g/d) than it was for strain CV (60±1 v 55±1 g/d).

<table>
<thead>
<tr>
<th>Days</th>
<th>Daily LWG (g/d)</th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–15</td>
<td>44±1d</td>
<td>46±1e</td>
<td></td>
</tr>
<tr>
<td>16–29</td>
<td>87±2a</td>
<td>91±2a</td>
<td></td>
</tr>
<tr>
<td>30–32</td>
<td>64±1c</td>
<td>67±1c</td>
<td></td>
</tr>
<tr>
<td>33–39</td>
<td>63±1b</td>
<td>75±2b</td>
<td></td>
</tr>
<tr>
<td>40–42</td>
<td>42±1d</td>
<td>54±1d</td>
<td></td>
</tr>
<tr>
<td>40–42</td>
<td>44±1d</td>
<td>51±1c</td>
<td></td>
</tr>
</tbody>
</table>

Note: Values within a column without common superscripts are significantly different (P<0.05)

### 7.4.3. Average daily feed intake

The effect of treatment on average daily feed intake in the different phases of the production cycle is given in Table 7.5. Treatment had an effect on feed intake, but this changed with time as the treatment x day interaction was significant (P<0.001). For the control and E+B treatments, the feed intake was different on all days (P<0.05), except for the comparison between the Days 16–29 and Days 30–32 (P<0.05). For the E treatment, the feed intake was different on all days (P<0.05), except for the comparison between Days 33–39 and Days 40–42. For the EL+BL treatments, the feed intake was different on all days (P<0.05), except for the comparison between Days 30–32, Days 16–29 and 40–42.
There were significant treatment differences in feed intake during the two periods of high temperature. Over Days 30–32, birds supplemented with E all day had a higher feed intake than other treatments (P<0.05) and the birds with EL+BL supplementation had a higher intake than the control birds (P<0.05). During Days 40–42, the birds supplemented with E and E+B had a higher feed intake than the other two treatments (P<0.05). During days 33–39, the control birds had lower intake than the birds given EL+BL in the previous heat period (P<0.05).

Table 7.5. The effect of treatment on the mean (±SEM) daily feed intake (g/d) of ducks exposed to periods of high ambient temperature in Weeks 5 and 6

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>54±1</td>
<td>166±3</td>
<td>166±3c</td>
<td>196±4b</td>
<td>177±3b</td>
</tr>
<tr>
<td>E</td>
<td>54±1</td>
<td>167±3</td>
<td>183±4a</td>
<td>199±4ab</td>
<td>197±4a</td>
</tr>
<tr>
<td>E+B</td>
<td>55±1</td>
<td>165±3</td>
<td>168±3bc</td>
<td>202±4ab</td>
<td>192±4a</td>
</tr>
<tr>
<td>EL+BL</td>
<td>55±1</td>
<td>168±3</td>
<td>175±3b</td>
<td>205±4a</td>
<td>181±3b</td>
</tr>
</tbody>
</table>

Note: Values within a column without common superscripts are significantly different (P<0.05)

Strain had a significant effect on feed intake (see Table 7.6), but this changed with time as the strain x week was significant (P<0.001). For both strains, daily feed intakes were different for all periods (P<0.05). Strain P21 had a higher feed intake than Strain CV in all periods after Day 29 (P<0.05).

Table 7.6. The effect of strain on the mean (±SEM) daily feed intake (g/d) of ducks exposed to periods of high ambient temperature in Weeks 5 and 6

<table>
<thead>
<tr>
<th>Days</th>
<th>CV</th>
<th>P2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–15</td>
<td>54±1</td>
<td>55±1</td>
</tr>
<tr>
<td>16–29</td>
<td>167±2</td>
<td>166±2</td>
</tr>
<tr>
<td>30–32</td>
<td>162±1b</td>
<td>184±1a</td>
</tr>
<tr>
<td>33–39</td>
<td>191±1b</td>
<td>210±2a</td>
</tr>
<tr>
<td>40–42</td>
<td>177±1b</td>
<td>197±1a</td>
</tr>
<tr>
<td>40–42</td>
<td>44±1d</td>
<td>51±1c</td>
</tr>
</tbody>
</table>

Note: Values within a column without common superscripts are significantly different (P<0.05)

7.4.4. Average daily water intake

The effect of treatment on water intake is given in Table 7.7. This effect changed over time, as the treatment x day interaction was significant (P<0.001). For the control, E and EL+BL birds the daily water intake was different for all periods (P<0.05). This was the same for the birds supplemented with E+B (P<0.05), except for the comparison between Days 30–32 and Days 33–39.

While there were significant differences in intake over Days 1–15, these have not been considered because in the first week, birds have access to bell drinkers as well nipple drinkers and accurate
measures of water intake were not possible. Over Days 30–32, the birds supplemented with E or E+B had higher daily water intakes (P<0.05) than those on the other two treatments, which were similar. During Days 33–39, the control birds drank less than birds allocated to the other treatments (P<0.05). During Days 40–42 the water intakes were different for all treatments (P<0.05). Strain had no effect on daily water intake (P=0.84).

Table 7.7. The effect of treatment on the mean (±SEM) daily water intake (g/d) of ducks exposed to periods of high ambient temperature in Weeks 5 and 6

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Daily water intake (mL/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>173±5</td>
</tr>
<tr>
<td>E</td>
<td>199±6</td>
</tr>
<tr>
<td>E+B</td>
<td>186±5</td>
</tr>
<tr>
<td>EL+BL</td>
<td>106±6</td>
</tr>
</tbody>
</table>

Note: Values within a column without common superscripts are significantly different (P<0.05)

Over Days 40–42, the average hourly water intake during the period of high temperature (08:00–17:00 h) and moderate temperature (17:00–08:00 h) is given in Table 7.8. There was a significant treatment x temperature period interaction (P<0.001). In the high temperature period the birds on E had a higher hourly water intake than the control birds (P<0.05). In the low temperature period, birds on EL+BL had lower hourly water intake than other treatments (P<0.05). The EL+BL birds drank much less water in the lower temperature period, in contrast to the other treatments (P<0.05).

Table 7.8. The effect of treatment on the mean (±SEM) hourly water intake (g/d) over Days 40–42 when the ducks were exposed to a daily period (08:00–1700 h) of high ambient temperature

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fluid intake (mL/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High temperature (08:00–17:00 h)</td>
</tr>
<tr>
<td>Control</td>
<td>96±4b</td>
</tr>
<tr>
<td>E</td>
<td>111±3a</td>
</tr>
<tr>
<td>E+B</td>
<td>104±4ab</td>
</tr>
<tr>
<td>EL+BL</td>
<td>102±4ab</td>
</tr>
</tbody>
</table>

Note: Values within a column without common superscripts are significantly different (P<0.05)

7.4.5. Feed to gain

The effect of treatment on the feed to gain is given in Table 7.9. The treatment differences were influenced by day, as the treatment x day interaction was significant (P<0.001). For those birds supplemented with E, the feed to gain was different for all periods (P<0.05). This was the same for the control birds and those supplemented with EL+BL, except when the comparison is between Days 30–32 and Days 33–39. For the birds supplemented with E+B the differences were significant for all comparisons, except between Days 33–39 and Days 40–42 (P<0.05).
During the first heat period (Days 30–32), the feed to gain was superior for the birds supplemented with E or E+B compared to the other treatments (P<0.05). During the second heat period, control birds had poorer feed to gain compared to other treatments (P<0.05). The birds given E+B had better feed to gain than those given EL+BL (P<0.05), but similar to those given E.

Strain had a significant effect (P=0.004) on the feed to gain ratio. At all times, the P21 ducks had better feed to gain (2.19±0.03) than birds of the CV strain (2.32±0.02) (P<0.05).

Table 7.9. The effect of treatment on the mean (±SEM) feed to gain ratio of ducks exposed to periods of high ambient temperature in Weeks 5 and 6

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Feed to water ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.20±0.05</td>
</tr>
<tr>
<td>E</td>
<td>1.21±0.05</td>
</tr>
<tr>
<td>E+B</td>
<td>1.22±0.05</td>
</tr>
<tr>
<td>EL+BL</td>
<td>1.21±0.05</td>
</tr>
</tbody>
</table>

Note: Values within a column without common superscripts are significantly different (P<0.05)

7.4.6. Water to feed

The effect of treatment on the water to feed ratio is given in Table 7.10. The differences were influenced by time, as the treatment x day interaction was significant (P<0.001). For the control and E birds, the water to feed ratio was different for all periods (P<0.05), except on Days 30–32 and 33–39. For the birds supplemented with E+B, the water to feed ratio was different for all periods (P<0.05), except when Days 30–32 and Days 40–42 are compared. When supplementing with EL+BL for a limited time, the water to feed ratio during Days 30–32 compared to days 33–39 and 16–29 compared to Days 40–42 were similar, but other comparisons were different (P<0.05).

While there are differences in Days 1–15, these are not considered because of the difficulty in accurately measuring water intake when birds have access to bell drinkers in the first week. During the first heat period birds supplemented with E+B had higher water to feed ratio than other treatments (P<0.05). Supplementation with E resulted in higher water to feed than when birds were supplemented with EL+BL (P<0.05). During the second heat period the feed to water ratio was lower for birds supplemented with EL+BL (P<0.05).
Table 7.10. The effect of treatment on the mean (±SEM) water to feed ratio of ducks exposed to periods of high ambient temperature in Weeks 5 and 6

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Water to feed ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>3.20±0.11c</td>
</tr>
<tr>
<td>E</td>
<td>3.68±0.13a</td>
</tr>
<tr>
<td>E+B</td>
<td>3.40±0.12b</td>
</tr>
<tr>
<td>EL+BL</td>
<td>1.93±0.07d</td>
</tr>
</tbody>
</table>

Note: Values within a column without common superscripts are significantly different (P<0.05)

Strain had a significant effect on the water to feed ratio (Table 7.11) but this changed with time as the strain x day interaction was significant (P<0.001). For all periods after Day 29 the CV strain had a higher water to feed ratio than the P21 strain (P<0.05). For both strains, the water to feed ratio increased as the birds aged. For the P2 strain, the water to feed ratio was higher in the two heat periods than at other times (P<0.05). This was similar for the CV strain, except that the difference between Days 30–32 and Days 33–39 was similar.

Table 7.11. The effect of strain on the mean (±SEM) water to feed ratio of ducks exposed to periods of high ambient temperature in Weeks 5 and 6

<table>
<thead>
<tr>
<th>Days</th>
<th>Water to feed ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CV</td>
</tr>
<tr>
<td>1–15</td>
<td>2.96±0.07d</td>
</tr>
<tr>
<td>16–29</td>
<td>2.71±0.07c</td>
</tr>
<tr>
<td>30–32</td>
<td>4.46±012ab</td>
</tr>
<tr>
<td>33–39</td>
<td>4.21±012b</td>
</tr>
<tr>
<td>40–42</td>
<td>4.54±0.12a</td>
</tr>
</tbody>
</table>

Note: Values within a row without common superscripts are significantly different (P<0.05)

7.4.7. Electrolyte intakes

The effects of treatment and strain on the daily electrolyte and betaine intakes during the two heat periods are given in Table 7.12. The period of HS had a significant effect on average daily feed intake (P<0.001), with it higher during the second period (187±4 g) than in the first (170±4 g). During HS, strain had an effect (P=0.007) on the average daily feed intake, with it being higher for the P2 strain (186±4 g) than for the CV strain (172±4 g). Treatment also had an effect on average daily feed intake (P=0.004), with it being higher in the E-supplemented birds (195±6 g) compared to the controls (171±5 g), those supplemented with E+B (176±5 g) and EL+BL (175±5 g) (P<0.05).

The differences in the intake of individual electrolytes are depended on differences in feed and water intakes. During the first heat period, the total intake of electrolytes was similar between ducks supplemented with E and E+B, and these were different to the intake of control or EL+BL-supplemented birds, with these latter two treatments also different (P<0.05). During the second heat period, all treatment effects on total electrolyte intake were different (P<0.05).
For all electrolyte measures Strain P2 had a higher intake than the CV strain. For obvious reasons, the EL+BL ducks consumed less betaine than the E+B birds (P<0.05).

**Table 7.12. The effect of treatment and strain on the mean (±SEM) daily electrolyte and betaine intakes during Days 30–32 and 40–42 when birds were exposed to high temperature**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Electrolytes</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Betaine (mg/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Na⁺ (mEq/d)</td>
<td>K⁺ (mEq/d)</td>
<td>Cl⁻ (mEq/d)</td>
<td>Total (mEq/d)</td>
<td>Betaine (mg/d)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>P1</td>
<td>P2</td>
<td>P1</td>
<td>P2</td>
<td>P1</td>
<td>P2</td>
<td>P1</td>
</tr>
<tr>
<td>Control</td>
<td>24.1±0.6c</td>
<td>25.8±0.6d</td>
<td>25.1±0.7d</td>
<td>26.9±0.8d</td>
<td>14.8±0.3c</td>
<td>15.8±0.4d</td>
<td>64±2c</td>
</tr>
<tr>
<td>E all day</td>
<td>60.9±1.5a</td>
<td>77.9±1.9b</td>
<td>38.3±1.1b</td>
<td>47.7±1.4b</td>
<td>43.4±1.0b</td>
<td>56.9±1.3b</td>
<td>143±4a</td>
</tr>
<tr>
<td>E+B all day</td>
<td>61.1±1.5a</td>
<td>70.7±1.8b</td>
<td>37.3±1.1b</td>
<td>42.2±1.3b</td>
<td>43.9±1.1b</td>
<td>51.1±1.2b</td>
<td>142±4a</td>
</tr>
<tr>
<td>E+B limited</td>
<td>55.9±1.4b</td>
<td>55.9±1.3c</td>
<td>35.7±1.1b</td>
<td>35.4±1.1b</td>
<td>39.7±0.9b</td>
<td>35.5±0.8c</td>
<td>131±3b</td>
</tr>
<tr>
<td>Strain effects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>48.4±0.8b</td>
<td>34.3±0.6b</td>
<td>33.3±0.5b</td>
<td>116±2b</td>
<td>122±2a</td>
<td>288±6</td>
<td></td>
</tr>
<tr>
<td>P2</td>
<td>50.8±0.8a</td>
<td>36.5±0.7b</td>
<td>34.8±0.5a</td>
<td>116±2b</td>
<td>122±2a</td>
<td>288±6</td>
<td></td>
</tr>
<tr>
<td>P values</td>
<td>+St=0.098</td>
<td>++TxP&lt;0.001</td>
<td>St=0.009</td>
<td>TxP&lt;0.001</td>
<td>St=0.03</td>
<td>TxP&lt;0.001</td>
<td>St=0.18</td>
</tr>
</tbody>
</table>

Note: For main effects of treatment and strain, values within a column without common superscripts are significantly different (P<0.05)
+P1=Period 1 (Days 30–32)
++P2=Period 2 (Days 40–42)
St=Strain
++TxP=Treatment x Period interaction

**7.4.8. Commercial cut-up**

The ratios of the weight of carcass components compared to carcass weight, expressed as a percentage, are given in Table 7.13. For the commercial processor, the absolute weights are the important measure, but to determine treatment and strain effects the percentage is more relevant as it accounts for differences in the carcass weight of individual birds. Where there is an interaction between the main effects, the differences within the main effects are considered only.

Treatment (P=0.04) and strain (P=0.004) had an effect on carcass weight. The processed carcass weight was lower for the control birds (P<0.05). The differences between E, E+B and EL+BL birds just failed to be significant. The P2 strain gave a heavier carcass weight than the CV strain (P<0.05).

For breast percentage, there was a significant interaction between treatment and strain (P=0.008). The breast percentage was higher in the P2 strain than the CV strain, but the treatment had no effect in the P2 strain. For the CV strain, the breast percentage was higher for the birds on E and E+B supplementation than those on the EL+BL supplementation, but not the control birds (P<0.05). For thigh percentage treatment effect was significant, but it was influenced by the strain as the interaction was significant (P<0.001). Treatment had no effect on the birds of the P2 strain but for the CV strain, birds supplemented with E had higher thigh percentage than other treatments, as did the control birds (P<0.05), while it was similar between E+B and EL+BL treatments. Neither the treatment, nor the strain, had an effect on drumstick percentage, although the interaction was almost significant (P=0.051).
Both treatment (P<0.001) and strain (P<0.001) influenced the percentage of cod fat. The cod fat percentage was higher in the CV strain than the P2 strain (P<0.05), and was lower in the control birds compared to those on E+B and EL+BL (P<0.05), while the difference between E and E+B birds was also different (P<0.05). Treatment and strain had an effect on the subcutaneous fat percentage, but the interaction between them was significant (P=0.003). Treatment had no effect on subcutaneous fat percentage in the P2 strain but for the CV strain the subcutaneous fat percentage was higher in the EL+BL supplemented birds compared to other treatments (P<0.05).
Table 7.13. The effects of treatment and strain on the mean (±SEM) weight of carcass components expressed as a percentage of the total processed carcass weight

<table>
<thead>
<tr>
<th>Strain CV</th>
<th>Trt</th>
<th>Carcass weight (kg)</th>
<th>Breast %</th>
<th>Thigh %</th>
<th>Drumstick %</th>
<th>Cod fat %</th>
<th>Sub fat %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1,891±29</td>
<td>11.30±0.24^ab</td>
<td>6.19±0.16^b</td>
<td>5.61±0.10</td>
<td>1.08±0.08</td>
<td>28.6±0.5^b</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>1,931±29</td>
<td>11.98±0.25^a</td>
<td>6.75±0.17^b</td>
<td>5.42±0.10</td>
<td>1.38±0.10</td>
<td>29.7±0.5^b</td>
<td></td>
</tr>
<tr>
<td>E+B</td>
<td>1,980±30</td>
<td>11.89±0.29^a</td>
<td>5.61±0.17</td>
<td>5.69±0.12</td>
<td>1.45±0.12</td>
<td>29.8±0.6^b</td>
<td></td>
</tr>
<tr>
<td>EL+BL</td>
<td>1,945±32</td>
<td>10.81±0.24^a</td>
<td>5.41±0.14^c</td>
<td>5.83±0.11</td>
<td>1.57±0.12</td>
<td>32.1±0.5^a</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strain P2</th>
<th>Trt</th>
<th>Carcass weight (kg)</th>
<th>Breast %</th>
<th>Thigh %</th>
<th>Drumstick %</th>
<th>Cod fat %</th>
<th>Sub fat %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1,945±30</td>
<td>15.26±0.32</td>
<td>6.73±0.17</td>
<td>5.50±0.10</td>
<td>0.81±0.06</td>
<td>25.7±0.4</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>2,024±37</td>
<td>15.31±0.38</td>
<td>7.18±0.21</td>
<td>5.58±0.12</td>
<td>0.84±0.07</td>
<td>25.8±0.5</td>
<td></td>
</tr>
<tr>
<td>E+B</td>
<td>1,978±31</td>
<td>15.31±0.33</td>
<td>6.90±0.17</td>
<td>5.61±0.10</td>
<td>1.11±0.08</td>
<td>26.9±0.4</td>
<td></td>
</tr>
<tr>
<td>EL+BL</td>
<td>2,059±31</td>
<td>15.94±0.34</td>
<td>7.03±0.18</td>
<td>5.39±0.10</td>
<td>0.96±0.07</td>
<td>25.9±0.4</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment effect</th>
<th>Trt</th>
<th>Carcass weight (kg)</th>
<th>Breast %</th>
<th>Thigh %</th>
<th>Drumstick %</th>
<th>Cod fat %</th>
<th>Sub fat %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1,917±21^b</td>
<td>13.16±0.20</td>
<td>6.45±0.11</td>
<td>5.56±0.07</td>
<td>0.93±0.08^b</td>
<td>27.1±0.3</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>1,978±23^a</td>
<td>13.56±0.22</td>
<td>6.97±0.13</td>
<td>5.50±0.08</td>
<td>1.07±0.06^bc</td>
<td>27.7±0.3</td>
<td></td>
</tr>
<tr>
<td>E+B</td>
<td>1,978±23^a</td>
<td>13.46±0.22</td>
<td>6.23±0.12</td>
<td>5.62±0.08</td>
<td>1.27±0.07^a</td>
<td>28.3±0.3</td>
<td></td>
</tr>
<tr>
<td>EL+BL</td>
<td>2,002±22^c</td>
<td>13.16±0.21</td>
<td>6.18±0.11</td>
<td>5.60±0.08</td>
<td>1.23±0.07^bc</td>
<td>28.8±0.3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strain effect</th>
<th>Trt</th>
<th>Carcass weight (kg)</th>
<th>Breast %</th>
<th>Thigh %</th>
<th>Drumstick %</th>
<th>Cod fat %</th>
<th>Sub fat %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV</td>
<td>1,935±22^b</td>
<td>11.45±0.18</td>
<td>5.97±0.11</td>
<td>5.63±0.08</td>
<td>1.35±0.07^a</td>
<td>30.1±0.4</td>
<td></td>
</tr>
<tr>
<td>P2</td>
<td>2,000±23^a</td>
<td>15.46±0.25</td>
<td>6.95±0.13</td>
<td>5.51±0.07</td>
<td>0.92±0.05^b</td>
<td>26.0±0.3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P values</th>
<th>Trt</th>
<th>Strain</th>
<th>Trt x strain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.045</td>
<td>0.004</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>&lt;0.001</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>&lt;0.001</td>
<td>0.08</td>
<td>0.051</td>
</tr>
<tr>
<td></td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Note: Values within a column for Strain CV, Strain P2, treatment effect and strain effect without common superscripts are significantly different (P<0.05). Where an interaction is found the comparison of treatment effects are considered within strains only.

*Trt=Treatment

The effect of treatment and strain on the total carcass muscle and fat is given in Table 7.14. While treatment had a significant effect on the carcass muscle and fat percentages, this was modified by the strain, as the treatment x strain interaction was significant (muscle, P=0.002; fat, P=0.001). Strain P2 had a higher muscle percentage than Strain CV, but there was no treatment effect in the P2 strain. For
Strain CV, birds supplemented with E had a higher muscle percentage than birds from other treatments, while the muscle percentage was lower for the EL+BL birds compared to the controls and those supplemented with E+B (P<0.05). Strain P2 had a lower fat percentage than Strain CV. In Strain P2, the E+B-supplemented birds had a higher fat percentage than the other treatments (P< 0.05). In the CV strain, the E and E+B-supplemented birds had similar total carcass fat percentage but other comparisons were different (P<0.05).

Table 7.14. The effects of treatment and strain on the mean (±SEM) weight of total carcass muscle and fat expressed as a percentage of the processed carcass weight

<table>
<thead>
<tr>
<th>Trt</th>
<th>Strain CV</th>
<th>Strain P2</th>
<th>Strain CV</th>
<th>Strain P2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>23.2±0.3b</td>
<td>27.5±0.3</td>
<td>29.7±0.5c</td>
<td>26.6±0.4b</td>
</tr>
<tr>
<td>E all day</td>
<td>24.2±0.3a</td>
<td>28.1±0.4</td>
<td>31.2±0.5b</td>
<td>26.7±0.5b</td>
</tr>
<tr>
<td>E+B all day</td>
<td>23.1±0.3b</td>
<td>27.8±0.4</td>
<td>31.3±0.6b</td>
<td>28.0±0.5a</td>
</tr>
<tr>
<td>E+B limited</td>
<td>22.2±0.3c</td>
<td>28.5±0.4</td>
<td>33.7±0.6a</td>
<td>26.9±0.5b</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strain</th>
<th>Total carcass muscle</th>
<th>Total carcass fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV</td>
<td>23.3±0.2</td>
<td>31.4±0.4</td>
</tr>
<tr>
<td>P2</td>
<td>28.0±0.3</td>
<td>27.0±0.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trt</th>
<th>Treatment=0.02</th>
<th>Strain &lt;0.001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment x strain=0.002</td>
<td>Treatment x strain=0.003</td>
<td></td>
</tr>
</tbody>
</table>

Note: Values within a column for strain CV and P2 without common superscripts are significantly different (P<0.05). Where an interaction is found the comparison of treatment effects are considered within strains only

7.4.9. Water holding capacity of muscle

There was no difference in water holding capacity between males of the control (5.75±0.74%) or E+B-treated (7.59±1.03%) groups at the Day 42 sampling (P=0.16). The water holding capacity of the CV strain (7.47±1.01%) and the P2 strain (5.87±0.80%) was not different (P=0.23). The control (76.1±0.5%) and E+B-supplemented birds (76.6±0.4%) had similar muscle water percentages (P=0.55). The CV strain (77.2±0.2%) had greater muscle water percentage than did the P2 strain (75.4±0.6%) (P=0.01).
7.5. Discussion

During the cyclic HS periods, the treatments had an effect on daily LWG. During the first period (Days 30–32), continuous supplementation with electrolytes or electrolytes plus betaine improved LWG compared to the control birds. Supplying the electrolytes plus betaine only during the period of high temperature was not sufficient to have any effect. Supplying the electrolytes and betaine for the heat period only was probably not long enough to be of any benefit. It was for this reason that during the second heat period this treatment was applied during the thermoneutral period (17:00–08:00 h) rather than the high temperature period. In the second heat period (Days 40–42), there was a significant difference in LWG between all treatments. All supplemented groups had superior LWG compared to the controls. Of the treatments, for the birds on electrolytes alone the LWG was superior to the other electrolyte treatments, followed by those on the electrolytes and betaine continuously and then by birds on this treatment when it was given for the thermoneutral period only.

The differences in LWG gain were sufficient for there to be significant differences in final liveweight. All electrolyte-treated groups had greater liveweight than the controls, and this ranged from 70–180 g. This is a significant improvement and resulted in a higher carcass processing weight of 60–80 g, this being a 3–4% improvement in carcass yield over the controls.

There is an inherent sex affect for LWG, and this is seen in the present study. The difference between males and females was greater in the heavier P2 strain. In both heat periods the reduction in LWG gain was similar for males and females.

Feed intake differences tended to be related to the differences in LWG. In Heat Period 1, the E-supplemented birds had the highest feed intake. In the second heat period, feed intake was highest in the E and E+B-supplemented birds. The same treatments resulted in higher water intake in both heat periods. Supplying the EL+BL supplements during the thermoneutral period over days 40–42 significantly depressed water intakes when compared to other treatments. When the hourly water intakes during the high temperature and low temperature periods on Days 40–42 were compared, this indicated that the water intake pattern, was for consumption to be higher during the thermoneutral period in all treatments, except where EL+BL was supplied for the limited period during the thermoneutral temperature period. The reason for this is not clear, but a suggestion could be that the changes in salinity disrupt the birds and they can limit their intake of the supplement because it is provided in the cool part of the temperature cycle.

There were large treatment effects on feed to gain. Prior to Day 30, the feed to gain ratio was the same for all allocated groups. During the high temperature periods, the feed to gain of the control birds was poor, especially over Days 40–42. In Heat Period 1 (Days 30–32) the birds given E or E+B continuously had superior feed to gain compared to the control birds and those given EL+BL. In the second heat period (Days 40–42), all treatments gave better feed to gain compared to the controls. Birds supplemented with E+B all day had the best feed to gain, while it was similar for the groups given E all day and EL+BL.

The complexity of these changes in feed and water intakes gave a range of effects on the water to feed ratio. In Heat Period 1, the water to feed ratio was highest in the birds supplemented with E+B and the ratio was lower for the EL+BL birds compared to the control birds. In Heat Period 2, where the EL+BL was supplemented for only part for the day the birds had lower water to feed ratio compared to all other treatments. This would be expected, considering the very low water intake for these birds when the treatment is applied during the thermoneutral period of each day.

While there are calculations given for the individual electrolyte and betaine intakes for the treatments, the important things to note are the differences in total intakes. In Heat Period 1, the total electrolyte intake for the E-supplemented group and those supplemented with E+B all day were similar and slightly higher than for those given EL+BL, and all were much higher than the controls. In Heat Period 2, the electrolyte intake was higher for the E group, and then the E+B all day group followed by those given the EL+BL, but all were much higher than the intake of the control birds. The daily betaine
intake for the group supplemented with E+B all day was 317 mg in Period 1 and 370 mg in Period 2, respectively. The daily betaine intake for the group supplemented with EL+BL for a limited time was 270 mg in Period 1 and 218 mg in Period 2, respectively. For the control treatment the Na+/K+ intake ratio was 0.96, and for other treatments was between 1.55–1.65.

After processing, the control birds had lower carcass weight compared to the electrolyte treatment groups. This was probably not as a result of increased water retention in the muscle, as there were no differences in water holding capacity or dry matter of the muscles tissues collected from the males of the control compared to the males continuously supplemented with E+B. The breast yield as a percentage was not affected by treatment in the P2 strain, but there were effects in the CV strain. In this strain, the E supplementation and E+B given all day increased the breast percentage compared to the limited used of EL+BL. For the same strain, those treatments having betaine included had lower thigh muscle percentage than the other treatments. These effects seen in the CV strain resulted in higher carcass muscle percentage in the birds with E all day compared to other treatments, with it being similar for birds treated with E+B all day and the controls, but higher than the birds treated with EL+BL for a limited time.

Those birds supplied with betaine had higher abdominal fat (cod fat) percentage. Treatment effects on subcutaneous fat percentage were limited to the CV strain. In this strain, the supplementation with EL+BL for the limited time resulted in a higher subcutaneous fat percentage than the other treatments. The treatment effects on the total carcass fat depended on the strain. In both strains, the electrolyte and betaine treatments resulted in a higher carcass fat percentage. In the CV strain, continuous provision of the combined treatment gave the highest carcass fat percentage, and in the P2 strain it was when it was given for the limited period. Betaine has been reported to decrease abdominal fat in CV ducks (Wang 2000, 2004). This is thought to be due to increased β-oxidation of long chain fatty acids (Wang et al. 1999). Under thermoneutral conditions, betaine might have these lipotrophic effects, but under conditions of HS other physiological control pathways, such as the HPA axis, may be prominent. Also, in the current study, strain had an effect, with the betaine effects on carcass composition only seen in the CV strain and not the faster-growing P2 strain.

The use of electrolytes during short periods of HS will assist ducks to cope with the physiological stress associated with high temperatures. While the effects being measure are performance indicators the relevance for the duck, is that strategies which improve these indicators, must have a positive effect on the birds’ physiology. Any reduction in the physiological stress has to be help the bird cope with the environmental challenge and this is linked to better welfare.
Chapter 8: Further evaluation of factors potentially involved in feather pecking in commercial Pekin ducks

8.1. Introduction

The earlier studies detailed in Chapters 3 and 6 investigated some aspects considered to be potential contributors to FP in commercial ducks. Evidence for the role that the attraction to the blood in the feather shaft played in FP damage to the wing area was provided in Chapter 6. Further confirmation of this was undertaken in the experiment described here. Further evaluation of the inclusion of SB was also included in the current experiment.

Aggression has been associated with FP in laying hens, and it could have a role in ducks. L-tryptophan is the precursor for serotonin, and dietary supplementation results in increased brain turnover of serotonin (Van Hierden et al. 2004b). Increased rates of FP are associated with low serotonergic neurotransmission (Van Hierden et al. 2002, 2004b). Researchers have reported that feeding TRP improved plumage condition (Savory et al. 1999; Van Hierden et al. 2004a). Supplementing the diets of skip-a-day fed broiler breeder males is reported to decrease aggressive behaviour (Shea et al. 1990). A similar feeding strategy has been used in pigs to reduce aggression (Poletto et al. 2010). If aggression is a component of FP behaviour in ducks, then feeding increased dietary TRP could be a strategy to test this.

The extent of FP on commercial farms is higher in winter than in summer. Again, working from observations provided by PEPE’s Ducks Pty Ltd and commercial producers who felt that air movement in the shed during the cold winter increased the extent of FP, a treatment was included that simulated increased air movement over the ducks. Producers felt that the air movement ruffled the fine feathers, especially on the back, and this was seen as an attraction to FP by the ducks.

One further objective of the overall project was to develop a growth model for a new Star 43 GF strain imported to Australia in 2012. Because of the limited number of breeding stock, this had to be delayed, but has been included as part of the current experiment where the performance of the new strain was compared to the control birds used in the FP component of the experiment.

8.2. Objective

The objective of the study was to further investigate factors that could be involved in FP in commercial CV ducks. An understanding of the predisposing factors could help to identify strategies to limit FP and improve the welfare of commercial ducks. A further objective was to compare the growth performance of the CV strain of Peking ducks with a new imported strain of GF Pekin duck.

8.3. Material and methods

8.3.1. Experimental design

The experiment was conducted using a completely randomised design, with blocking. There were essentially two studies within the one experimental framework. The FP study involved the P2 strain of CV Pekin duck with five treatments, including a control. The sixth treatment was where a new imported GF strain was reared as a control treatment. The growth performance of the GF controls and P2 controls were compared as an independent adjunct to the main FP study.
8.3.2. Birds and husbandry

The ducks were reared as mixed sexes, with equal number of females and males. The birds were produced at a commercial breeding farm owned by PEPEs Ducks Pty Ltd (Windsor, NSW) 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. On arrival, ducklings were placed in their allocated pens. On Day 7 of age all ducks were individually wing-tagged. Birds had access to feed and water ad libitum. The starter and grower feeds were provided by Ingham’s Pty Ltd. The starter diet was formulated to provide 12.76 MJ ME/kg and 22% protein, while the grower diet was formulated to provide 12.89 MJ ME/kg and 18.5% protein. The starter diet was in crumble form and was fed from Day 1 to Day 14. The finisher diet was in pellet form and was provided from Days 15–42.

8.3.3. Treatments

The six treatments were:

1. Control=GF strain reared as mixed sexes
2. Control=P2 strain reared as mixed sexes
3. CW=wings coloured with blue, P2 strain reared as mixed sexes
4. SB=Straw bunches included in the pen, P2 strain reared as mixed sexes
5. TRP=Grower feed supplemented with TRP, P2 strain reared as mixed sexes
6. AF=Increased AF, P2 strain reared as mixed sexes.

8.3.3.1. Treatment details

Control birds were managed according standard procedures as described in the Methodology section. In an effort to disguise the red blood in the feather sheath during feather emergence, the wings of birds were covered with blue spray mark (Dy-MARK, Wacol, Queensland, see Figure 6.1). Wings were coloured on Day 19, and the again on Day 24. As described in Chapter 6, birds were supplied with SB in an effort to distract them from FP (Figure 6.2).

The TRP-supplemented grower diet was prepared by taking 200 kg of control grower pellet diet and hammer milling this before mixing it with 20 kg of TRP using a paddler mixer. The TRP-enriched grower diet was then re-pelleted. The re-pelleting was performed by cold pressing (no steam) in an effort to avoid any major effects on the nutritive value of the supplemented feed. The TRP concentrated pellet (132 kg) was then mixed with 468 kg of control unsupplemented grower diet. The concentration of TRP in the final mixed grower diet was 20mg/kg.

To increase the AF over the ducks, a fan was set up at the end of the relevant pens and operated so that the flow rate of air over the birds at the back of the pen was 0.7–0.8 m/sec at bird height (see Figure 8.1). For Days 18–22, the fan remained on from 08:30–16:30 h, and from Days 23–42, for 24 h/d.

Over Days 1–18, all ducks were managed similarly. Treatments 3–6 were applied from Day 18 to Day 42. The control treatments for both the P2 and GF strains were applied over Days 1– 44. Days 1–42 were used as the evaluation of the FP treatments and Days 1–44 for the growth evaluation between the control P2 strain and GF strain.
8.3.4. Plasma tryptophan analysis

A blood sample was taken from one male and one female in each of the control P2 and TRP treatment pens. After centrifugation the plasma was collected and 1 mL from each male and female of individual pens was bulked to provide a single sample for each P2 control and TRP-treated pens. The samples were stored at –80°C until assayed. The plasma samples were analysed by the Australian Proteome Analysis Facility at Macquarie University, Sydney. In brief, samples were brought to room temperature and mixed with equal volumes of an internal standard (Norvaline). The diluted plasma was deproteinated by ultrafiltration through a 10 kDa molecular weight cut-off filter. Amino acids contained in the filtrate were labelled using the Water AccQ.Tag chemistry was performed following the supplier’s recommendations and analysed using a Waters Acquity UPLC system. Duplicate analyses were conducted and results averaged.

8.3.5. Performance and carcass measurements

At placement, a collective pen weight was recorded. On Days 14 (Week 2), 28 (Week 4), and 42 (Week 6), all ducks were individually weighed. For the control P2 and control GF strains, a liveweight measurement was also made on Days 7, 21 and 45 just prior to processing on Day 46. Feed intakes were determined over the same time periods and water intakes were recorded daily.

8.3.6. Commercial cut-up

On Day 46, ducks were transported to PEPE’S processing plant and a sub-sample of birds were subjected to a commercial cut-up for determination of carcass muscle and fat content. The birds were transported in crates (6 birds/crate). An average bird weight was determined for each crate. The birds were processed in these groups of six and an average hot carcass weight (after evisceration) was determined for each group. The following day, after overnight refrigeration, 20 birds (equal numbers of males and females) from each treatment and strain were processed as a commercial cut-up. The various carcass components from individual birds were then weighed.

8.3.7. Feather damage

8.3.7.1. Period 1 (Day 32)

At this stage, the FP damage is isolated to the areas around the wing and on the thigh. The feather damage was evaluated on a scale of 0–3 as described in the Methodology section.
8.3.7.2. Period 2 (Day 42)

At this stage, any new FP damaged was isolated to the back of the bird from between the wing and the tail. Because of the range in extent of damage, a scale of 0–5 was used as described in the Methodology section.

8.3.8. Statistical analysis

8.3.8.1. Production performance

The data were analysed as two sets. The treatment effects were analysed for the P2 strain while the effects of strain was analysed for the P2 and GF control birds separately. Data were stored in Microsoft Excel® and, unless stated otherwise, statistical analysis was conducted using the REML linear mixed model function of Genstat® 11th edition. Data were first tested for equality of variance using residual plots. When the equality of variance could be improved using a loge transformation, data were transformed.

The fixed model included the effects of treatment, week and sex, and the random model included the effects of block, pen and tag. For the strain analysis, the fixed model included strain and sex. Initially, all two-way interactions between fixed effects were included in the model. Significance testing of fixed effects was conducted using Wald tests with a significance threshold of P<0.05. Any non-significant interactions were removed from the model. The predicted means for all significant fixed effects were copied to Microsoft Excel®, as well as standard errors, which were used to calculate the SEM. The LSD was used to make pairwise comparisons of means. Microsoft Excel® was used to create graphical summaries of the back-transformed means.

Differences in plasma TRP concentration for the P2 control and TRP-supplemented groups were analysed by unpaired t-test. The carcass cut-up data were analysed using ANOVA (Statview). When significant differences were detected the individual comparisons were made using the LSD (2 x SED) with significance set at P<0.05.

8.3.8.2. Feather damage

The analysis of the treatment effects in the FP study were evaluated separately to the strain effects, with the control P2 measures used in both. FP damage was evaluated separately for wing damage in Period 1 (Day 35) and for damage to the back region in Period 2 (Day 42). The analysis was conducted using an ordinal logistic regression model with a proportional odds method (Agresti, 2002). Because of the very low frequency of damage observed on the thighs (LT, RT) and tail, analysis using ordinal logistic GLMMs was not attempted on these data sets.

The form of the method specified in the analyses is:

Period 1: For wing region:

For treatment comparisons:

\[
\log_e \left( \frac{P(Y \leq k)}{P(Y < k)} \right) = \theta_k + \text{Treatment} + \text{Sex} + \text{Side (RW or LW)} + \text{Block} + \text{Block.Pen}
\]

For strain comparisons:

\[
\log_e \left( \frac{P(Y \leq k)}{P(Y < k)} \right) = \theta_k + \text{Strain} + \text{Sex} + \text{Side (RW or LW)} + \text{Block} + \text{Block.Pen}
\]

Period 2: For the back region the same models were used for the strain and sex comparisons,
Where:
\[ P(Y \leq k) = \text{probability of obtaining a score of } k \text{ or lower, } k = 0, 1, 2 \]
\[ \theta_k = \text{intercept for a score of } k. \]

The fixed effects of the model are:
- **Treatment** = effect of treatment (Control, SB, CW, AF and TRP (fixed))
- **Sex** = effect of male vs female (fixed)
- **Side** = wing affected (LW, RW) (fixed)
- **Strain** = P2 or GF (fixed).

All interactions were tested but were excluded because of non-significance:
- **Block**, assumed \( N(0, \sigma^2_B) \)
- **Block Pen** (pen effect nested within block), assumed \( N(0, \sigma^2_P) \).

That is, this is a model for the cumulative log odds (logit) of obtaining a score of \( k \) or lower. Note that the log odds assumption implies that difference in score probabilities is entirely accounted for by the separate intercepts for each score (\( \theta_k \)); i.e., the fixed (and random) effects of interest apply across all scores.

The significance of the fixed effects was assessed using Wald Chi-square tests, and individual treatment or other between-group comparisons were conducted using approximate \( z \)-tests:

\[
z = \frac{\text{logit}_1 - \text{logit}_2}{\text{SED}}
\]

Where:
- \( \text{logit}_1 - \text{logit}_2 \) = difference in model-based logits of the two treatments
- \( \text{SED} \) = standard error of the difference of the model-based logits.

A \( z \)-statistic greater than two (in absolute value) was identified at significant (\( P<0.05 \), approximately). For the current analysis, \( \text{logit}[P(Y = 0)] = \log_e[P(Y = 0)/P(Y > 0)] \) was used to compare logits of different treatments, but any score cut-off could be used with identical results.

While the model fitting returns cumulative probabilities, \( P(Y \leq k) \), individual event probabilities can then be calculated by difference to allow visualisation; i.e.,

\[
P(Y = k) = \begin{cases} 
P(Y \leq 0) & k = 0 \\
P(Y \leq k) - P(Y \leq k - 1) & k = 1, 2 \\
1 - P(Y \leq 2) & k = 3 \
\end{cases}
\]

The models were fitted using the stand-alone version of ASReml 3 (Gilmour et al. 2009). Note that in this package, it was required to recode scores from 0–5 to 1–6, but the results are unchanged.
8.4. Results

The performance analysis was completed for all treatments applied to the P2 strain birds (treatment effects) and then for the comparison between the P2 control and GF control birds (strain effects).

8.4.1. Strain effects

8.4.1.1. Liveweight

The effect of strain on liveweight is given in Figure 8.2. Strain had significant effects on liveweight, but these effects changed over time as the strain x day and was significant (P<0.001). On all days, Strain GF birds were heavier than those of the P2 strain (P<0.05), with the difference between the two strains increasing as the birds aged.

Figure 8.2. The effects strain on the mean (±SEM) liveweight

The sex effects on liveweight were significant but changed with time as the interaction was significant (P<0.001). For both males and females, the liveweight on all days (see Table 8.1) were different (P<0.05). Males were significantly heavier than females on all days (P<0.05), with this difference increasing as the birds aged.
Table 8.1. The effects of sex on the mean (±SEM) liveweight

<table>
<thead>
<tr>
<th>Day</th>
<th>Females (g)</th>
<th>Males (g)</th>
<th>Difference (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>280±3(g)</td>
<td>291±3(g)</td>
<td>11</td>
</tr>
<tr>
<td>14</td>
<td>779±8(f)</td>
<td>817±8(f)</td>
<td>38</td>
</tr>
<tr>
<td>21</td>
<td>1,425±14(e)</td>
<td>1,494±15(e)</td>
<td>69</td>
</tr>
<tr>
<td>28</td>
<td>2,061±21(d)</td>
<td>2,175±22(d)</td>
<td>104</td>
</tr>
<tr>
<td>35</td>
<td>2,749±27(c)</td>
<td>2,899±29(c)</td>
<td>150</td>
</tr>
<tr>
<td>42</td>
<td>3,245±32(b)</td>
<td>3,505±35(b)</td>
<td>260</td>
</tr>
<tr>
<td>45</td>
<td>3,344±33(a)</td>
<td>3,659±37(a)</td>
<td>315</td>
</tr>
</tbody>
</table>

Note: Within rows, values without common superscripts are significantly different (P<0.05)

8.4.1.2. Liveweight gain

The effect of strain on average daily LWG is given in Figure 8.3, and the effects of sex are given in Table 8.2. Strain and sex had significant effects on LWG, but these effects changed over time as the interactions with day were significant (both P<0.001). On all days except Day 45, the GF strain had a significantly higher daily LWG compared to the P2 strain (P<0.05). For strain GF, the daily gain was significantly different on all days (P<0.05), except for the differences on Days 21 and 28. For strain P2, the daily LWG on Day 14 was similar to Day 42, as were the values for Day 21 compared to Day 28. On all other days the differences for strain P2 were significant (P<0.05).

Figure 8.3. The effect of strain on the mean (±SEM) average daily LWG

On all days, males had higher LWG than females (P<0.05), as shown in Table 8.3. For females, the LWG for Days 28, 35 and 21 were similar but all other comparisons were different (P<0.05). For males the LWG on Days 21 and 28 were similar, but all other comparisons were different (P<0.05).
Table 8.2. The effect of sex on mean (±SEM) average daily LWG

<table>
<thead>
<tr>
<th>Day</th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>32±1(^f)</td>
<td>33±1(^f)</td>
</tr>
<tr>
<td>14</td>
<td>71±1(^c)</td>
<td>7±1(^d)</td>
</tr>
<tr>
<td>21</td>
<td>92±1(^b)</td>
<td>96±1(^b)</td>
</tr>
<tr>
<td>28</td>
<td>92±1(^ab)</td>
<td>97±1(^b)</td>
</tr>
<tr>
<td>35</td>
<td>96±1(^a)</td>
<td>104±2(^a)</td>
</tr>
<tr>
<td>42</td>
<td>69±1(^d)</td>
<td>84±1(^c)</td>
</tr>
<tr>
<td>45</td>
<td>34±1(^c)</td>
<td>48±1(^c)</td>
</tr>
</tbody>
</table>

Note: Within columns, values without common superscripts are significantly different (P<0.05)

8.4.1.3. Average daily feed intake

Strain had a significant effect on feed intake (P<0.001). The GF strain (143±2 g) had greater feed intake than Strain P2 (129±2 g) (P<0.05). Day had a significant effect (P<0.001) on feed intake (see Table 8.3). The average daily feed intake for all days was significantly different (P<0.05), except for the differences between Day 21 compared to Day 45.

Table 8.3. The effect of day on mean (±SEM) average daily feed intake

<table>
<thead>
<tr>
<th>Day</th>
<th>Feedg/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>36±1(^f)</td>
</tr>
<tr>
<td>14</td>
<td>101±2(^c)</td>
</tr>
<tr>
<td>21</td>
<td>157±3(^c)</td>
</tr>
<tr>
<td>28</td>
<td>149±3(^d)</td>
</tr>
<tr>
<td>35</td>
<td>236±4(^b)</td>
</tr>
<tr>
<td>42</td>
<td>260±5(^a)</td>
</tr>
<tr>
<td>45</td>
<td>164±3(^c)</td>
</tr>
</tbody>
</table>

Note: Within columns, values without common superscripts are significantly different (P<0.05)

8.4.1.4. Average daily water intake

Strain had a significant effect on daily water use (see Table 8.4), but this changed over time as the strain x day was significant (P=0.02). For both strains the water use was significantly different on all days (P<0.05). There was no difference in water use for the strains over Days 7–21 but after this the GF strain had greater water use than did the P2 strain (P<0.05).

Table 8.4. The effect of strain on mean (±SEM) average water intake

<table>
<thead>
<tr>
<th>Day</th>
<th>GF</th>
<th>P2</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>87±2</td>
<td>84±2</td>
</tr>
<tr>
<td>14</td>
<td>227±6</td>
<td>217±5</td>
</tr>
<tr>
<td>21</td>
<td>336±8</td>
<td>328±8</td>
</tr>
<tr>
<td>28</td>
<td>473±12(^a)</td>
<td>434±11(^b)</td>
</tr>
<tr>
<td>35</td>
<td>673±17(^b)</td>
<td>585±15(^b)</td>
</tr>
<tr>
<td>42</td>
<td>836±21(^a)</td>
<td>743±19(^b)</td>
</tr>
<tr>
<td>45</td>
<td>625±16(^a)</td>
<td>532±13(^b)</td>
</tr>
</tbody>
</table>

Note: Within columns, values without common superscripts are significantly different (P<0.05)

8.4.1.5. Feed to gain

The effect of day on the feed to gain is shown in Table 8.5. Day had a significant effect on the feed to gain (P<0.001) but the strain effect was not significant (P=0.39). The feed to gain for all days was significantly different (P<0.05), except for the differences between Days 14, 21 and 28. The feed to gain for the GF strain was 1.96±0.06, and for the P2 strain was 2.04±0.06.
Table 8.5. The effect of day on the feed to gain

<table>
<thead>
<tr>
<th>Day</th>
<th>Feed to gain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>1.12 ±0.06g</td>
</tr>
</tbody>
</table>

Note: Within columns, values without common superscripts are significantly different (P<0.05)

8.4.1.6. Water to feed ratio

The effect of day on the water to feed ratio (see Table 8.6) was significant, but it was influenced by strain as the strain x day interaction was significant (P=0.002). For strain GF, the water to feed ratio on Day 7 v 14, Day 14 v 21 and Day 28 v 42 were similar, while all other comparisons were significantly different (P<0.05). For strain P2, the water to feed ratio on Days 28, 42 and 45 were similar, as was the comparison between Days 14 and 21. For this strain, other comparisons were significantly different (P<0.05). It was only on Day 7 and 45 that the GF strain had higher water to feed ratio (P<0.05) than the P2 strain. As mentioned previously, in the first week it is not possible to accurately measure water intake, as birds have access to both nipple and bell drinkers.

Table 8.6. The effect of strain on the mean (±SEM) water to feed ratio

<table>
<thead>
<tr>
<th>Day</th>
<th>GF</th>
<th>P2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>2.25 ±0.07d</td>
<td>2.17 ±0.07de</td>
</tr>
<tr>
<td></td>
<td>±0.07de</td>
<td>±0.07c</td>
</tr>
<tr>
<td></td>
<td>2.55 ±0.08d</td>
<td>2.24 ±0.07c</td>
</tr>
<tr>
<td></td>
<td>±0.07c</td>
<td>±0.07c</td>
</tr>
</tbody>
</table>

Note: Within columns, values without common superscripts are significantly different (P<0.05)

8.4.2. Treatment effects

8.4.2.1. Liveweight

Treatment had a significant effect on liveweight (see Table 8.7), but this changed with time as the treatment x week effect was significant (P<0.001). At Week 4, the birds supplemented with the TRP had lower liveweight compared to birds of all other treatments (P<0.05) and birds with CW had higher liveweight than the birds exposed to increased AF (P<0.05). At Week 6, the birds supplemented with TRP remained at a lower liveweight compared to birds of all other treatments (P<0.05). The AF and CW birds were heavier than control birds (P<0.05).
Table 8.7. The effect of treatment on the mean (±SEM) liveweight (g)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Week 2</th>
<th>Week 4</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>770±6</td>
<td>2,004±16&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3,178±29&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>AF</td>
<td>760±7</td>
<td>1,992±18&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3,229±29&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>CW</td>
<td>774±7</td>
<td>2,030±18&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3,239±29&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>SB</td>
<td>756±7</td>
<td>2,004±18&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3,210±29&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>TRP</td>
<td>764±7</td>
<td>1,884±17&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3,072±28&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Note: Within columns, values without common superscripts are significantly different (P<0.05)

The effect of sex on liveweight is given in Table 8.8. Males were heavier than females in all weeks (P<0.05), with this difference increasing with age. For both males and females the liveweight was different in all weeks (P<0.05).

Table 8.8. The effect of sex on the mean (±SEM) liveweight (g)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Week 2</th>
<th>Week 4</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>748±4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1,939±12&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3,047±18&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Male</td>
<td>782±5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2,026±12&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3,328±20&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Difference</td>
<td>34</td>
<td>87</td>
<td>281</td>
</tr>
</tbody>
</table>

Note: Within columns, values without common superscripts are significantly different (P<0.05)

8.4.2.2. Liveweight gain

Treatment had a significant effect on LWG (see Table 8.9), but this changed with time as the treatment x week effect was significant (P<0.001). At Week 4, the TRP birds had lower LWG compared to birds in all other treatment groups (P<0.05). In Week 6, the LWG for the AF birds was higher than it was for the other treatments (P<0.05).

Table 8.9. The effect of treatment on the mean (±SEM) liveweight gain (g)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Week 2</th>
<th>Week 4</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>715±8</td>
<td>1,231±12&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1,168±13&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>AF</td>
<td>705±8</td>
<td>1,229±13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1,228±13&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>CW</td>
<td>721±8</td>
<td>1,253±14&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1,196±13&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>SB</td>
<td>706±7</td>
<td>1,246±14&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1,193±14&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>TRP</td>
<td>713±8</td>
<td>1,115±12&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1,176±13&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Note: Within columns, values without common superscripts are significantly different (P<0.05)

The effect of sex on the LWG is given in Table 8.10. The sex x week interaction was significant (P<0.001). Males were heavier than females in all weeks (P<0.05), with this difference increasing with age. For both males and females the LWG was different in all weeks (P<0.05).
Table 8.10. The effect of sex on the mean (±SEM) LWG (g)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Week 2</th>
<th>Week 4</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>696±4</td>
<td>1,188±7</td>
<td>1,100±8</td>
</tr>
<tr>
<td>Male</td>
<td>729±5</td>
<td>1,240±7</td>
<td>1,292±9</td>
</tr>
<tr>
<td>Difference</td>
<td>33</td>
<td>52</td>
<td>129</td>
</tr>
</tbody>
</table>

Note: Within columns, values without common superscripts are significantly different (P<0.05)

8.4.2.3. Feed intake

The effect of treatment on the feed intake is shown in Table 8.11. The week x treatment interaction was significant (P<0.001). For all treatments the differences between weeks were significant (P<0.05). At Week 4, the feed intake of the TRP birds was significantly higher (P<0.05) than other treatments, except for the CW birds. In Week 6, the feed intake of the TRP birds was significantly higher than all other treatments (P<0.05). Treatment had a significant effect on total intake (P=0.05), with it being higher in the TRP birds than the SB birds (P<0.05).

Table 8.11. The effect of treatment on the mean (±SEM) feed intake (g)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Week 2</th>
<th>Week 4</th>
<th>Week 6</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>92±19</td>
<td>2,347±49</td>
<td>3,412±72</td>
<td>6,681±217</td>
</tr>
<tr>
<td>AF</td>
<td>90±21</td>
<td>2,373±55</td>
<td>3,443±79</td>
<td>6,721±218</td>
</tr>
<tr>
<td>CW</td>
<td>908±21</td>
<td>2,421±56</td>
<td>3,354±77</td>
<td>6,680±217</td>
</tr>
<tr>
<td>SB</td>
<td>899±21</td>
<td>2,308±53</td>
<td>3,351±77</td>
<td>6,154±200</td>
</tr>
<tr>
<td>TRP</td>
<td>911±21</td>
<td>2,538±58</td>
<td>3,936±98</td>
<td>7,230±234</td>
</tr>
</tbody>
</table>

Note: Within columns, values without common superscripts are significantly different (P<0.05)

8.4.2.4. Water intake

The effect of treatment of water intake is given in Table 8.12. The week x treatment interaction was significant (P=0.004). For all treatments, the differences between all weeks were significant (P<0.05). At Week 4, the only difference was between the SB and TRP treatments (P<0.05). At Week 6, the control birds had significantly higher water intake compared to all other treatments (P<0.05). Treatment had no effect on total water intake (P=0.09).
Table 8.12. The effect of treatment on the mean (±SEM) water intake (L)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Week 2</th>
<th>Week 4</th>
<th>Week 6</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>2.68±0.46</td>
<td>6.75±0.11ab</td>
<td>9.72±0.17a</td>
<td>19.19±0.53</td>
</tr>
<tr>
<td>AF</td>
<td>2.80±0.50</td>
<td>6.62±0.12ab</td>
<td>9.10±0.16b</td>
<td>18.58±0.52</td>
</tr>
<tr>
<td>CW</td>
<td>2.81±0.51</td>
<td>6.50±0.12ab</td>
<td>9.13±0.16b</td>
<td>18.38±0.51</td>
</tr>
<tr>
<td>SB</td>
<td>2.77±0.50</td>
<td>6.47±0.12b</td>
<td>8.89±0.16b</td>
<td>17.17±0.48</td>
</tr>
<tr>
<td>TRP</td>
<td>2.72±0.54</td>
<td>6.79±0.12a</td>
<td>9.28±0.17b</td>
<td>18.94±0.53</td>
</tr>
</tbody>
</table>

Note: Within columns, values without common superscripts are significantly different (P<0.05)

8.4.2.5. Feed to gain

Treatment (see Table 8.13) had a significant effect on the feed to gain but again this changed with time as the treatment x week interaction was significant (P<0.001). For all treatments, the differences between weeks was significant (P<0.05). At Week 4, the TRP birds had a poorer feed to gain than other treatments (P<0.05). At Week 6, both the control and TRP birds had poorer feed to gain than other treatments (P<0.05) which were similar. Treatment had a significant effect on total feed to gain (P=0.004). Compared to all other treatments the TRP birds had poorer feed to gain (P<0.05), while the SB had better feed to gain than the controls (P<0.05).

Table 8.13. The effect of treatment on the mean (±SEM) the feed to gain ratio

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Week 2</th>
<th>Week 4</th>
<th>Week 6</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.28±0.03</td>
<td>1.89±0.04b</td>
<td>2.93±0.06b</td>
<td>2.14±0.06b</td>
</tr>
<tr>
<td>AF</td>
<td>1.29±0.03</td>
<td>1.91±0.04b</td>
<td>2.77±0.06c</td>
<td>2.11±0.07bc</td>
</tr>
<tr>
<td>CW</td>
<td>1.29±0.03</td>
<td>1.92±0.04bc</td>
<td>2.76±0.06c</td>
<td>2.09±0.07bc</td>
</tr>
<tr>
<td>SB</td>
<td>1.29±0.03</td>
<td>1.85±0.04bc</td>
<td>2.74±0.06c</td>
<td>1.94±0.06c</td>
</tr>
<tr>
<td>TRP</td>
<td>1.29±0.03</td>
<td>2.29±0.05s</td>
<td>3.15±0.07s</td>
<td>2.40±0.08s</td>
</tr>
</tbody>
</table>

Note: Within columns, values without common superscripts are significantly different (P<0.05)

8.4.2.6. Water to feed ratio

Treatment (see Figure 8.14) had no effect on water to feed ratio (P=0.78). Week had a significant effect (P<0.001), with the interaction between treatment and week being marginally non-significant (P=0.095). For all treatments except the control birds, the water to feed ratio was different in all weeks (P<0.05). Treatment had marginally non-significant effect on the total water to feed ratio (P=0.07). It tended to be lower for TRP birds.
Table 8.14. The effect of week on the mean (±SEM) water to feed ratio

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Week 2</th>
<th>Week 4</th>
<th>Week 6</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>2.91±0.08</td>
<td>2.88±0.08</td>
<td>1.98±0.06</td>
<td>2.87±0.06</td>
</tr>
<tr>
<td>AF</td>
<td>3.10±0.09</td>
<td>2.79±0.08</td>
<td>1.92±0.06</td>
<td>2.76±0.06</td>
</tr>
<tr>
<td>CW</td>
<td>3.10±0.09</td>
<td>2.69±0.08</td>
<td>1.94±0.06</td>
<td>2.76±0.06</td>
</tr>
<tr>
<td>SB</td>
<td>3.07±0.09</td>
<td>2.80±0.08</td>
<td>1.93±0.06</td>
<td>2.78±0.06</td>
</tr>
<tr>
<td>TRP</td>
<td>3.12±0.09</td>
<td>2.67±0.08</td>
<td>1.81±0.05</td>
<td>2.62±0.05</td>
</tr>
</tbody>
</table>

Note: Within columns, values without common superscripts are significantly different (P<0.05)

8.4.3. Plasma tryptophan concentrations

The birds supplemented with TRP in their feed had higher (P=0.002) plasma TRP concentrations (659±147 µg/100mL) than the control birds (184±12 µg /100mL).

8.4.4. Cut-up

The ratio of the weight of carcass components to total carcass weight, expressed as a percentage, is given in Table 8.15. The significantly lower liveweight of the TRP birds observed on Day 42 was also seen on arrival at the processing plant. This TRP effect was also seen in the lower hot carcass weight (P<0.05). The control birds had a lower hot carcass weight than the AF birds (P<0.05). Treatment had no effect on the breast, drumstick, cod fat or total meat expressed as percentage of carcass weight. The TRP birds had greater thigh percentage (P<0.05) than other treatments and the control birds had a higher percentage than the CW birds (P<0.05). The control birds had lower subcutaneous fat percentage (P<0.05) compared to other treatments, and the TRP birds had a lower percentage than the SB birds (P<0.05). These differences help account for the differences seen in the total fat percentage.

Strain GF had higher liveweight on arrival at the factory and this resulted in higher hot carcass weight (P<0.05). The only difference in carcass components was the higher breast percentage seen in the P2 strain (P<0.05).
Table 8.15. The effects of treatment and strain on the mean (±SEM) weight of carcass components expressed as a percentage of the processed hot carcass weight.

<table>
<thead>
<tr>
<th>*Trt</th>
<th>Arrival weight (kg)</th>
<th>Hot carcass weight (kg)</th>
<th>Breast</th>
<th>Thigh</th>
<th>Drum stick</th>
<th>Cod fat</th>
<th>Sub fat</th>
<th>Total fat</th>
<th>Total meat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>3.19 ±0.02a</td>
<td>2.40 ±0.02b</td>
<td>15.89 ±0.28</td>
<td>5.52 ±0.13ab</td>
<td>5.29 ±0.10</td>
<td>1.11 ±0.08</td>
<td>26.7 ±0.5c</td>
<td>27.8 ±0.6c</td>
<td>26.7 ±0.3</td>
</tr>
<tr>
<td>AF</td>
<td>3.23 ±0.03a</td>
<td>2.46 ±0.02a</td>
<td>16.17 ±0.30</td>
<td>5.22 ±0.14bc</td>
<td>5.06 ±0.11</td>
<td>1.51 ±0.08</td>
<td>29.2 ±0.5ab</td>
<td>30.3 ±0.6ab</td>
<td>26.5 ±0.3</td>
</tr>
<tr>
<td>CW</td>
<td>3.20 ±0.03a</td>
<td>2.42 ±0.02ab</td>
<td>15.49 ±0.30</td>
<td>4.91 ±0.13c</td>
<td>5.35 ±0.11</td>
<td>1.07 ±0.08</td>
<td>28.5 ±0.5ab</td>
<td>29.6 ±0.6ab</td>
<td>25.8 ±0.3</td>
</tr>
<tr>
<td>SB</td>
<td>3.18 ±0.03a</td>
<td>2.42 ±0.02ab</td>
<td>15.53 ±0.28</td>
<td>5.31 ±0.13bc</td>
<td>5.22 ±0.10</td>
<td>1.24 ±0.08</td>
<td>29.9 ±0.5ab</td>
<td>31.2 ±0.6a</td>
<td>26.1 ±0.3</td>
</tr>
<tr>
<td>TRP</td>
<td>3.06 ±0.03b</td>
<td>2.32 ±0.02a</td>
<td>15.51 ±0.29</td>
<td>5.80 ±0.15a</td>
<td>5.37 ±0.10</td>
<td>1.13 ±0.08</td>
<td>27.9 ±0.5bc</td>
<td>29.0 ±0.5bc</td>
<td>26.7 ±0.3</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.37</td>
<td>&lt;0.001</td>
<td>0.25</td>
<td>0.65</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Strain effects

<table>
<thead>
<tr>
<th>Strain</th>
<th>Arrival weight (kg)</th>
<th>Hot carcass weight (kg)</th>
<th>Breast</th>
<th>Thigh</th>
<th>Drum stick</th>
<th>Cod fat</th>
<th>Sub fat</th>
<th>Total fat</th>
<th>Total meat</th>
</tr>
</thead>
<tbody>
<tr>
<td>GF</td>
<td>3.58 ±0.03a</td>
<td>2.70 ±0.02a</td>
<td>14.77 ±0.28b</td>
<td>5.63 ±0.13</td>
<td>5.44 ±0.11</td>
<td>1.28 ±0.08</td>
<td>27.4 ±0.5</td>
<td>28.7 ±0.6</td>
<td>25.9 ±0.5</td>
</tr>
<tr>
<td>P2</td>
<td>3.19 ±0.03b</td>
<td>2.40 ±0.02b</td>
<td>15.83 ±0.30a</td>
<td>5.56 ±0.13</td>
<td>5.29 ±0.11</td>
<td>1.11 ±0.08</td>
<td>26.8 ±0.5</td>
<td>27.9 ±0.5</td>
<td>27.9 ±0.6</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.014</td>
<td>0.70</td>
<td>0.32</td>
<td>0.32</td>
<td>0.40</td>
<td>0.34</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Note: Values within a column for treatment and strain without common superscripts are significantly different (P<0.05)

*Trt=treatment

8.4.5. Feather pecking damage

8.4.5.1. Damage to the wing region

There was no difference in the extent of damage inflicted to the RW compared to the LW (P=0.52). The damage recorded for the males and females were similar (P=0.21). The effect of treatment on feather damage score to the wings is given in Figure 8.4. The treatment effect was not significant (P=0.25).
8.4.5.2. Damage to the back region

The effect of treatment on damage to the back region is shown in Figure 8.5. There was no significant effect of treatment on FP damage (P=0.23). However, it is interesting to note that in the plot of fitted score distributions, using the fitted model, scores tend to be higher in all four treatment groups relative to the control; that is, there were relatively few zero scores and relatively more higher damage scores.

Figure 8.5. The effect of treatment on the feather damage to the back region

The effect of sex on the extent of damage to the back region (see Figure 8.6) was significant (P=0.002). Males had greater feather damage scores than females.
In this analysis, the control GF and CV birds were compared. For the wing damage, strain (P=0.34) and sex (P=0.90) had no effects on the damage scores. The left and right wings had similar damage (P=0.14). For the damage to the back region, strain (P=0.58) had no effect on the scores, but sex was significant (P=0.001), with males having higher damage scores.

8.5. Discussion

8.5.1. Production performance

8.5.1.1. Strain effects

Both strains had similar patterns of LWG, with it reaching close to maximum by Day 21. However, LWG was higher in the GF strain until Day 45 when it was the same for both strains. While the maximum LWG was maintained until Day 35, it decreased rapidly after that and this decline was much faster in the GF strain. As has been shown previously, the females reach maturity earlier than males as the reduction in LWG from maximum begins earlier in females (Downing 2010). The study was undertaken in winter when growth performance is not readily influenced by temperature. The GF strain was heavier than the P2 strain at all times. At Day 45, the GF birds averaged 3,718±37 g. While this might be suitable for the cut market, it is not ideal for the whole bird market. Even at Day 42, GF birds were 3,587±36 g, which is still not suitable to meet current market specifications. In fact, if the birds were to be processed at the correct market weight they would need to be removed around Day 35 when the liveweight averaged 2,899±29 g.

While this might seem ideal costwise, it is not practical due to how breast muscle develops in ducks. As identified in a previous RIRDC project, breast development in ducks occurs comparatively late in the production cycle (Downing 2010). Processing the GF birds at 35 days is not feasible, as they would not have sufficient breast muscle to meet consumer requirements. The slower growth rate seen in summer might actually benefit the GF strain as it is more likely to meet the market requirements at 42 days, whereas the CV strain needs to be reared to 44–46 days to achieve this. The new strain would seem to create some management problems for the growers and processor in winter. In the current study, the GF females might better meet the market needs because they are lighter at 42 days, and mature earlier, so have better breast muscle development. Ideally, if the sexes were reared separately the females could be used for the whole bird market and males for the cut-up market. The current problem with this approach is that the industry needs the majority of its production to meet the demand for the whole bird market. Both strains had similar feed to gain and so the new GF has no efficiency
advantage over the P2 strain. A real economic concern is the rapid loss of feed efficiency in both strains after Day 35. At the Day 46 processing both strains had similar carcass meat and fat percentage, but the P2 strain had a better breast percentage. While it was not determined here, ideally what needs to be known is the pattern of breast muscle development in the new GF strain, because if this occurs late in development then it would not suit the market needs.

8.5.1.2. Treatment effects

The TRP treatment resulted in a higher plasma TRP concentration. On the control diet it was 184±12 µg/100mL of plasma and 659±147 µg/100mL of plasma for the treated birds.

The TRP-treated birds had lower LWG at Week 4 and while this difference was not seen in Week 6, the overall effect was for the TRP birds to have lower final liveweight at the end of the production cycle. The AF birds had higher LWG in Week 6 compared to other treatments, and this resulted in higher final liveweight compared to the controls. While there were no obvious LWG differences between the birds with CW and the controls, the final liveweight was lower in the control birds. Interestingly, the lower LWG in Weeks 3–4 and 5–6 of the TRP-treated birds was associated with higher feed intake. This resulted in a much poorer feed to gain in the same periods and an overall total poorer feed to gain for TRP treated birds. The better feed to gain for the birds with SB in Weeks 5–6 resulted in better total feed to gain for these birds compared to the controls. While those birds with CW or those exposed to increased AF had better feed to gain in Weeks 5–6, this did not result in better total feed to gain than the control. There were no effects of treatment on total water intake or the water to feed ratio.

8.5.2. Feather pecking damage

8.5.2.1. Strain effects

Strain had no effect on the FP damage recorded for wing-directed FP or that directed to the back. Sex had no effect on wing-directed damage but it did for the back-directed damage. Males had more damage than females.

8.5.2.2. Treatment effect

Treatment had no effect on the FP damage recorded for the wing-directed FP or that directed to the back. It was noted that for the damage to the back, scores tend to be higher in all four treatment groups relative to the control, in that is there were relatively few zero scores and relatively higher damage scores. This observation was more pronounced for the AF-treated birds. Sex had no effect on the wing-directed damage but it did for the back-directed FP damage, with males having more damage than females.

This was the first time that the back-directed form of feather pecking was observed in the current project. The area affected could be extensive but the extent varied greatly between pens. With there being no treatment effect, although increased air flow needs further evaluation, it does suggest that PF is likely initiated by individual birds in the pen and that once started individual birds could be responsible for most of the activity; or it is imitated by other birds in the pen. This could account for the fact that in some pens there was no PF activity and others extensive damage.
Chapter 9: The use of electrolyte and betaine supplementation to alleviate weight loss during transport and lairage of commercial ducks

9.1. Introduction

As per normal practice, ducks are removed off feed for three hours before farm pick-up. They remain on water until pick-up, but the time during transporting and lairage results in some level of dehydration. This is especially the case during summer, when the ambient temperature is outside the birds’ thermal comfort zone. The problem of high ambient temperature can be escalated by the microclimate within the transport vehicle. Electrolytes and betaine have been used to maintain water balance and retention in poultry. Providing ducks with electrolytes and betaine supplementation for 30–36 hours before pick-up could help to reduce dehydration and weight loss during transport and lairage and benefit the birds’ welfare, especially during high temperature periods. In this experiment, the effect of electrolyte and betaine supplementation for 32 hours prior to farm pick-up on weight loss during transport and lairage were investigated. The working hypothesis was that the supplementation of ducks with electrolytes and betaine will result in lower carcass weight loss, greater hydration during transport and lairage.

9.2. Methods

9.2.1. On-farm treatments

The study was completed on a commercial duck farm in southwestern Sydney. Birds were at the end of the grow-out period (42 days of age). On the day before pick-up for processing, an area of the shed was fenced off and used to house the electrolyte-supplemented birds. The birds were housed at 5 birds/m². Two nipple drinker lines (12 nipples per line) with 60 L reservoirs were set up in the area allocated to the electrolyte-supplemented birds (see Figure 9.1). Starting at 13:00 h on the day before bird pick-up, 160 birds were randomly selected from the population of birds in the shed. These were individually wing-tagged and weighed before being placed in the fenced-off area. A random sample of 80 birds from the remainder of the flock were weighed as representative of the control birds. From 16:00 h on the day before pick-up, the electrolyte supplemented birds had access to electrolytes plus betaine. The electrolyte solution contained 1.57 g NaCl, 1.71 g NaH CO₃, 0.88 g KCl and 0.4 g betaine/L.
9.2.2. Temperature and humidity

Digital temperature and humidity recorders were placed in the commercial shed at the time of the initial weighing. Similar recorders were attached to some crates and cages during transport and lairage.

9.2.3. Bird pick-up and transport

Starting at 00:00 h on the night of farm pick-up, the electrolyte-supplemented birds were all individually weighed. Eighty birds were transferred to transport crates with six birds per crate (Trial A). The remaining 80 supplemented birds (Trial B) were transferred to cages set up on a trailer with five birds per cage. Four cages were set up on the floor on both sides of the trailer and then four cages were placed on top of these on both sides of the trailer. On one side of the trailer, birds (n=40) had access to a drinker line (2 nipples per cage) running through the bottom and top set of four cages (see Figure 9.2). These drinker lines were attached to a 30 L reservoir containing the electrolytes plus betaine solution. The birds in the cages on the other side of the trailer had no access to the electrolytes plus betaine supplement. These birds were then transferred to the processing plant.

Starting at 01:30 h, 80 control birds were randomly selected from the shed flock, wing-tagged and individually weighed (Trial A), and then transferred to crates with six birds per crate. Birds allocated to Trial A (control and electrolyte-supplemented groups) were loaded onto the transport vehicle and transferred to the processing plant.
9.2.4. Liveweight during lairage and processing

Both transport vehicles arrived at the processing plant at 03:25 h. On arrival, birds allocated to Trial A were individually weighed. The birds were then weighed again at 05:30, 07:30 and 09:30 h. After arrival at the processing plant, birds allocated to Trial B were weighed at 09:30 h only.

At 11:40 h, the birds in both trials were processed. After feather removal and evisceration prior to entry into the chiller (dry weight) carcasses were weighed. They were also weighed after exiting the chiller (wet weight).

9.2.5. Statistics

9.2.5.1. Trial A

Differences between the initial weights and those at the time of pick-up were analysed by ANOVA. Similar analysis was preformed for differences in water addition in the chiller, and the weight losses from farm to processing and evisceration expressed as a percentage of the farm liveweight.

The pattern of liveweight loss during transport and lairage were analysed using the REML linear mixed model function of Genstat® 11th edition. Data were first tested for equality of variance using residual plots. When the equality of variance could be improved using a loge transformation, the data were transformed. Because of the differences in the start times for the electrolyte and control treatments at farm pick-up, these were analysed separately. Time was included as the fixed model and the random model included the effects of crate and tag. The significance testing of fixed effects was conducted using Wald tests with a significance threshold of $P<0.05$. The predicted means for all significant time effects were copied to Microsoft Excel®, as well as standard errors, which were used to calculate the SEM. The LSD, which is equal to two times the SED, was used to make pairwise comparisons of means. Microsoft Excel® was used to create graphical summaries of the back-transformed means. The changes in the weight losses and the percentage weight loss relative to the processing weight were also analysed by the same REML method, with the fixed effects being treatment and stage of processing and the random model being crate and tag.

For the control and electrolyte-supplemented treatments, the predicted means from the REML analysis were plotted again time and then the relationship analysed using the coefficient of correlation. The
equations fitted to the relationship for both treatments were used to determine the predicted weight loss during transport and lairage over a similar time period.

9.3.5.2. Trial B

The effects of treatments in Trial B were analysed by ANOVA.

9.3. Results

9.3.1. The pattern of temperature and relative humidity

The pattern of temperature and RH while treatments were applied on-farm and then during transport and lairage is shown in Figure 9.3. During the first night of supplementation, the RH was close to 100% and the temperature around 20°C. During the following day the temperature increased slightly to 25°C with the RH around 50%. During the evening of the farm pick-up, transport and lairage the temperature was again around 20°C, with the RH around 80%.

Figure 9.3. The pattern of temperature and relative humidity

9.3.2. Trial A

9.3.2.1. Initial liveweight at farm pick-up

At the time when the birds were allocated to the two treatment groups on the farm, and prior to the supplementation with electrolytes, the mean liveweights were similar (P=0.31). The liveweight of birds supplied with electrolytes (2,947±19 g) was heavier than those supplied with water (2,821±25 g) at the time of farm pick-up (P<0.001). Supplementation of birds with electrolytes on-farm significantly increased liveweight from the start of supplementation until farm pick-up (2,947±19 v 2,799±17 g; P<0.001). The control birds gained little weight during the same period (2,794±25 v 2,821±25 g; P=0.39).

9.3.2.2. The percentage weight loss from farm pick-up to processing

The effect of treatment on the loss in liveweight expressed as a percentage of the initial liveweight, over the time from farm pick-up until processing is given in Table 9.1. For both treatments time had a significant effect on the percentage loss in weight (P<0.001). For both treatments, the percentage loss was different at all times (P<0.05).
Table 9.1. The effect of treatment on the loss in weight (expressed as a percentage of the initial liveweight weight) over time

<table>
<thead>
<tr>
<th>Electrolyte treatment</th>
<th>Time (h)</th>
<th>3.42</th>
<th>5.5</th>
<th>7.5</th>
<th>9.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Liveweight loss/initial liveweight (%)</td>
<td>2.72±0.16&lt;sup&gt;d&lt;/sup&gt;</td>
<td>4.10±0.24&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.90±0.29&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.73±0.34&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Control Treatment</th>
<th>Time (h)</th>
<th>1.92</th>
<th>4</th>
<th>6</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liveweight loss/initial liveweight (%)</td>
<td>2.31±0.15&lt;sup&gt;d&lt;/sup&gt;</td>
<td>3.15±0.20&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.93±0.25&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.50±0.29&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

Note: Values within rows without common superscripts are significantly different (P<0.05)

The relationship between the percentage liveweight loss and the time after farm pick-up for the control and electrolyte treated birds are given in Figures 9.4 and 9.5, respectively. Both relationships are significant (control, P=0.008; electrolytes, P=0.003). The equations for these relationships were used to predict the potential percentage liveweight loss for the treatments over a similar time period.

Figure 9.4. The relationship between the percentage liveweight loss and the time from farm pick-up for the control birds

\[
y = 1.5713\ln(x) + 2.2254 \\
R^2 = 0.9836
\]
Figure 9.5. The relationship between the percentage liveweight loss and the time from farm pick-up for the electrolyte-supplemented birds

$y = 2.1173 \ln(x) + 2.6775$

$R^2 = 0.9938$

9.3.2.3. Predicted weight loss

The predicted weight loss over the period of 2–12 hours after farm pick-up based on the relationships identified in Figures 9.4 and 9.5, is shown in Figure 9.6. This extrapolation from the data is made in an effort to predict what is likely to happen over the first 12 hours from farm pick-up to processing. The extrapolation is made to 12 hours, as this is the likely maximum time the birds would be held before processing.

Figure 9.6. The predicted final liveweight loss expressed as percentage of farm pick-up weight for ducks supplied with water or electrolytes and betaine for 32 hours prior to pick-up for processing

**Control**  
**Electrolyte**
Figure 9.7. The predicted final liveweight changes based on the initial liveweight at the time of farm pick-up less the predicted weight loss during transport and lairage for ducks supplied with water or electrolytes and betaine for 32 hours prior to pick-up for processing

9.3.2.4. Processing losses

The effects of treatment on the processing liveweight changes and the percentage liveweight losses are shown in Table 9.2. The electrolyte-supplemented birds had higher liveweight at the last weighing before processing (P<0.001). Treatment had a significant effect on the evicerated weights, but this dependent on the stage of eviceration (dry or wet evicerated weight) as the interaction was significant (P=0.011). The electrolyte-treated birds had higher absolute evicerated carcass weights (P<0.05), with the difference between the dry and wet evicerated weights being different for the electrolyte-treated birds (P<0.05) but not for the control birds. The amount of water accumulated during transit through the chiller by the electrolyte-treated birds was higher than that of the control birds (P=0.047). Treatment (P<0.001) and the stage of eviceration (P<0.001) had an effect on the weight loss expressed as percentage of the initial processing weight, while the interaction between the two was marginally non-significant (P=0.06). The percentage weight loss was higher in the electrolyte-treated birds (P<0.05). The difference in percentage loss between dry and wet eviceration weight tended to be less for the control birds.

The percentage weight loss from the farm to processing and during processing is shown in Table 9.2. The effect of treatment on percentage weight loss from farm to processing (P<0.001), from farm to dry evisceration (P<0.001), from farm to wet evisceration (P=0.02) were all greater for the electrolyte-treated birds.
Table 9.2. The effect of treatment on the carcass weight and percentage weight loss during processing

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Control</th>
<th>Electrolytes</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute liveweight (g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Processing weight</td>
<td>2,694±23b</td>
<td>2,830±23a</td>
<td>T&lt;0.001</td>
</tr>
<tr>
<td>Dry weight of eviscerated carcass</td>
<td>2,065±18b</td>
<td>2,130±19a</td>
<td>T=0.004</td>
</tr>
<tr>
<td>Wet weight of eviscerated carcass</td>
<td>2,075±18b</td>
<td>2,162±19a</td>
<td>S=&lt;0.001 TxS=0.011</td>
</tr>
<tr>
<td>Weight gain in the chiller</td>
<td>13±10b</td>
<td>41±9a</td>
<td>T=0.047</td>
</tr>
</tbody>
</table>

Changes in liveweight from processing point expressed as a percentage

| From initial processing point to dry eviscerated weight | 23.2±0.2b | 24.6±0.2a | T<0.001 |
| From initial processing point to wet eviscerated weight | 22.8±0.2b | 23.45±0.2a | S=<0.001 TxS=0.067 |

Change in liveweight from the farm to processing expressed as a percentage

| From farm to initial processing               | 4.50±0.3b  | 5.73±0.3a  | T<0.001 |
| From farm to dry eviscerated weight          | 26.9±0.3b  | 29.1±0.3a  | T<0.001 |
| From farm to wet eviscerated weight          | 26.5±0.4b  | 27.7±0.4a  | T=0.02 |

Note: Values within rows not having the same superscripts are significantly different (P<0.05)
T=treatment
S=stage of evisceration

9.3.3. Trial B

Birds were weighed at the farm, and again nine hours later at the processing plant. They were then processed two hours later. The birds allocated the electrolyte and betaine supplemented water consumed on average 115 mL of the supplement while in transit and lairage (9 h). The effect of supplying electrolyte supplementation during transport and lairage is shown in Table 9.3. At farm pick-up, the liveweight of the two groups were similar (P=0.16). At the last weighing before processing, nine hours after farm pick-up, the birds with continued access to electrolytes were heavier (P=0.03). However, after evisceration there were no differences in dry (P=0.19) or wet (P=0.22) carcass weight. During transport and lairage, the unsupplemented birds lost a higher percentage of their liveweight (P<0.001). Contrary to this, the percentage weight loss from the farm to the dry and wet carcass weight were not different (P=0.26 and P=0.23, respectively). When the dry and wet eviscerated carcass weights are expressed as a percentage of the processing initial weight there were significant treatment effects. The birds given continuous electrolyte supplementation had higher percentage loss from both processing to dry eviscerated weight (P=0.005) and wet eviscerated weight (P=0.001). The water added after transit through the chiller was the same for both treatments (P=0.95).
Table 9.3. The effects of supplementing ducks with electrolytes and betaine during transport and lairage on the absolute weight loss and percentage weight loss during transport, lairage and processing

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Control</th>
<th>Continued electrolyte supplementation</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute liveweight (g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm weight</td>
<td>2,867±36</td>
<td>2,937±34</td>
<td>0.16</td>
</tr>
<tr>
<td>Processing weight</td>
<td>2,737±35&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2,842±33&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.03</td>
</tr>
<tr>
<td>Dry weight of eviscerated carcass</td>
<td>2,107±28</td>
<td>2,172±26</td>
<td>0.19</td>
</tr>
<tr>
<td>Wet weight of eviscerated carcass</td>
<td>2,123±29</td>
<td>2,172±27</td>
<td>0.22</td>
</tr>
<tr>
<td>Weight gain in the chiller (g)</td>
<td>25±9</td>
<td>24±8</td>
<td>0.95</td>
</tr>
<tr>
<td>Changes in liveweight expressed as a percentage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From farm to processing</td>
<td>4.65±0.23&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.23±0.21&lt;sup&gt;b&lt;/sup&gt;</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>From processing point to dry eviscerated weight</td>
<td>22.9±0.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>24.3±0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.005</td>
</tr>
<tr>
<td>From processing point to wet eviscerated weight</td>
<td>21.8±0.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>23.4±0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.001</td>
</tr>
<tr>
<td>From farm to dry eviscerated weight</td>
<td>26.1±0</td>
<td>26.8±0.4</td>
<td>0.26</td>
</tr>
<tr>
<td>From farm to wet eviscerated weight</td>
<td>25.3±0.3</td>
<td>25.9±0.3</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Note: Values within rows not having the same superscripts are significantly different (P<0.05)

9.4. Discussion

9.2.1. Trial A

Attempts to run experimental studies on commercial farms often create circumstances which are not anticipated and which often result in less than favourable conditions for the purpose of the experiment. An underlying goal of the current study was to determine the role electrolytes could have in controlling bird dehydration during transport and lairage during periods of high temperature. The limitation of the current work was that it needed to be undertaken at a predetermined time, principally when the birds were at market age. Disappointingly, on the farm pick-up day, the ambient temperature was moderate and within the birds thermoneutral zone and there were persistent rain showers resulting in high RH. However, the combination of temperature with the high RH would be sufficient to be mildly stressful for ducks.

Also, because of a problem on the farm, the timing of the initial weighing at farm pick-up was different for the two treatments and so it was difficult to compare the treatments directly. To offset this, the predicted weight losses during transport and processing were compared. It was not possible to obtain a measure of the electrolyte intake on-farm because some was lost from the main reservoir.
During the treatment period on-farm, the electrolyte-treated birds increased in liveweight, while the control flock birds did not. This resulted in the electrolyte-supplemented birds having greater liveweight at farm pick-up. On arrival at the processing plant, and at the last weight before processing, the electrolyte-treated birds maintained a higher liveweight. For both treatments, the percentage weight loss during transport was high and this is probably largely due to excreta loss as the birds cleared the GIT. During lairage there was a significant linear relationship between time and the carcass weight loss expressed as percentage. Lairage time will affect bird dehydration.

The electrolyte-treated birds had higher weight loss during transport and lairage, but it should be noted that they were loaded into transport crates earlier than the control birds. However, when this is calculated as a predicted weight loss, the same difference remained. It is probable that higher carcass weight loss of the electrolyte-treated birds is related to greater gut water weight, which is lost early after transfer to transport crates. The predicted weight loss indicated that once birds are in lairage, the rate of weight loss was similar between the treatment groups. In lairage, the birds dehydrated at the same rate. At this point birds may continue to clear the GIT of waste but much of the water loss will be through evaporation. This would be especially true during periods of high temperature.

The percentage carcass weight loss from processing through evisceration was higher in the electrolyte-treated birds. It possible that these birds are more hydrated, and that removal of the viscera removed some of this water, resulting in higher weight loss. While the percentage weight loss of the electrolyte-treated birds was greater than that of the controls from farm pick-up to the final wet eviscerated carcass weight, they still had a higher final weight. This is even accounting for the fact that they were loaded 90 min earlier than the control birds. While the final wet eviscerated weight is the economic measure of the treatment effects, the differences is weight loss indicates that the supplemented birds were better hydrated and it is probable that they experienced less physiological stress. The final carcass weight was around 90 g heavier for electrolyte-treated birds.

Electrolyte supplementation for 32 hours resulted in higher carcass weight from the farm through to processing during periods of moderate ambient temperature. It would be reasonable to suggest that this effect would have increased benefit during periods of high ambient temperature.

9.4.2. Trial B

The birds which were supplied with electrolytes and betaine before farm pick-up and then during transport and lairage had higher liveweight at the processing point. The birds without the electrolytes lost a higher percentage of their liveweight during the nine hours from farm pick-up to processing point. This difference is probably due to a lower rate of fluid loss from the supplemented birds. The heavier liveweight at initial processing was not realised after evisceration, where carcass weights were similar for the treatments. The fact that the continuously supplemented birds lost a higher percentage of their weight during evisceration suggests that the extra weight recorded prior to processing is probably gut water, with this being removed during evisceration. At the thermoneutral temperature experienced during the study, no advantage was gained in processing weight by supplementing birds during transport and lairage and the higher loss of weight during evisceration indicates greater gut water content but not greater tissue hydration. The value of the supplementation in transport and lairage to the birds’ welfare could not be determined.

9.4.3. General conclusion

Even with the limitations experienced working on the commercial farm, the evidence supports the hypothesis that supplementation with electrolytes and betaine prior to processing increased bird hydration and this increased yield during processing.
Results

Strategies to alleviate the depressed growth rate of ducks under Australian summer conditions

Objective

In summer months, it can take current duck strains 4–6 days longer to reach market weight compared to in winter (Downing 2010). The adverse effects triggered by exposing poultry to constant high temperature are more severe than exposing them to cyclic HS. Under Australian conditions, ducks are more likely to have to deal with cyclic HS, rather than constantly high temperatures. For this reason, the experimental studies concentrated on cyclic HS. The project investigated ways to alleviate the depressed growth rate of ducks during the Australian summer and reduced the physiological stress impairing their welfare. A range of strategies have been used to help broilers cope with HS and some of these are discussed in Section 1.3. In the current project, three experimental studies investigated different strategies, and the refinement of specific strategies

Experimental results

Chapter 2

The experiment consisted of rearing commercial CV Pekin ducks and subjecting them to cyclic high temperature during Weeks 5 and 6 of age. The strains used where the CV and an industry selected line from the parent CV strain named P2.

As a starting point, six treatments that had previously been used in broilers with varying degrees of success were applied. The performance of the birds was evaluated when the following treatments applied to both strains:

- control diet and water alone
- control diet and water supplemented with vitamin C at 125 mg/L
- control diet and water supplemented with betaine at 400 mg /L
- control diet and betaine supplemented in the diet at 950 mg/kg
- feed withdrawal during the period of high temperature (08:30–17:30 h daily)
- control diet and water supplemented with electrolyte salts (sodium chloride 1.57 g/L, sodium bicarbonate 1.71 g/L and potassium chloride 0.884 g/L and betaine at 400 mg /L).

All treatments were applied over Days 29–41, except the last. There were concerns how long a high electrolyte water supplement could be supplied before there were adverse physiological effects, such as acidosis. For this reason, the electrolyte water treatment was applied during Days 36–41 only.

During Week 5, all treatments applied increased daily LWG compared to the control birds. The statistical power of the analysis identified subtle differences in LWG of around 2–4 g/d (14–28 g/week) and this was only identified as an improvement in total liveweight at the end of Week 5 for the birds given betaine in water. In Week 6, the use of electrolytes and betaine-supplemented water had a positive effect on LWG, and this resulted in significantly heavier liveweight at the end of the production cycle. The poor LWG in Week 6 for birds supplemented with vitamin C, betaine in water and with feed withdrawal needs to be viewed with caution as the differences, while identified as significant, remain small.

The pattern of cyclic high temperature used here, with a maximum of 32°C for nine hours, might be expected to cause moderate HS. The lengthy period of lower temperature each day could provide the birds with sufficient time to compensate, at least to some extent, for any effects the high temperature had on performance and duck welfare. This is supported by the fact that there were no differences in
feed intake between treatments. The effect of treatment on feed to gain was marginally non-significant (P=0.06). In Week 6, birds treated with electrolytes plus betaine tended to have better feed to gain. This trend helped to account for the significantly improved total feed to gain seen for these birds compared to the control birds. While feed efficiency is routinely determined as the feed weight to LWG, a better measure would be the feed consumed to produce consumable meat, and especially the high quality breast meat. Treatment and had no effect on efficiency of feed use to produce breast meat.

The treatments applied here have been successful when used in broilers and could be useful strategies under conditions of high ambient temperature which cause severe HS. Under conditions of cyclic moderate HS, as used here, the only strategy that showed it could have a positive influence on performance and physiological stress was the supplementation of water with electrolytes and betaine.

The P2 strain has been selected from the parent CV strain for increased liveweight and breast muscle development. This selection is an obvious reason for the differences observed between these strains. Interestingly, the earlier difference in LWG between these strains is not seen in Week 6, where LWG was similar. The P2 ducks are heavier in Week 6, and the effects of the high temperature, could be more severe for these heavier birds. Strain CV had a poorer feed to gain over the full production cycle. Strain has an effect on the feed to breast weight ratio, with the P2 strain producing more breast muscle and doing this with increased efficiency. This difference in yield is to be expected as the P2 strain has been selected for increased breast yield, but it is a further economic advantage when it is achieved with improved efficiency.

Up until Week 2, male and female ducks had similar daily LWG. After this, the LWG of the males was greater than the females, with this difference being larger for the P2 strain than the CV strain. Because of their greater weight, males would be expected to be more severely affected by HS, especially in Week 6. In the current study, the LWG of the females in Week 6 actually decreased compared to Week 5, whereas that of the males remained similar to Week 5. There is a confounding issue here. Females reach maximum daily LWG earlier than males, as has been reported previously to RIRDC (Downing 2010). The sex differences seen in the normal pattern of growth would naturally see females with a lower LWG than males in Week 6. The sex x treatment interaction for LWG was marginally non-significant (P=0.06). There was a trend for males to benefit from the betaine added to water and the electrolytes plus betaine in water. Any benefit for males would likely be related to their heavier weight.

Chapter 4

After the positive effect of electrolyte supplementation on duck performance during cyclic high temperature reported in Chapter 2, the following questions needed answering:

- what concentration of electrolytes should be used as a water supplement to get the best performance and have the largest affect on physiological stress?
- can the electrolytes be added in the feed to improve these same measures?

The following treatments were applied during Days 36–41 of age to birds of the CV strain fed a grower diet (Weeks 3–6) of low DEB (160) or high DEB (261). The electrolyte solution was used at the concentrations of 50% 100% and 150% of that used in the study detailed in Chapter 2. Betaine is regularly added to commercial duck diets, but there is no clear indication as to its value during thermoneutral or cyclic HS conditions and so this was included as further treatment. The treatments were:

- water only
- electrolytes at 50% + betaine in Week 6 (E50)
- electrolytes at 100% + betaine in Week 6 (E100)
- electrolytes at 150% + betaine in Week 6 (E150)
- betaine in grower feed (Days 22–41)
- electrolytes at 100% + betaine 36 hours before transport (E100-36h).

The performance evaluation was conducted in two separate periods. The first was Weeks 3–5 of age, when birds were maintained in thermoneutral conditions and the treatments applied, were grower diets of high or low DEB and a sub-sample of pens on each diet where betaine had been added to the feed. The second was during Week 6, when the cyclic HS was applied and the water supplements also used.

Betaine addition to the feed had no effect on LWG or final liveweight during Weeks 3–5, when the temperature was kept in thermoneutral range, or in Week 6, when the birds were exposed to cyclic high temperature. Over Weeks 3–5, the betaine supplementation in the feed had no effect on feed intake but there was poorer feed to gain. This was not seen during the period of cyclic high temperature.

The DEB had no effect on LWG in Weeks 3–5, when the temperature was kept in thermoneutral range. The low DEB diet supported the same LWG as the high DEB diet. Therefore, the low DEB being used in commercial grower diets is adequate when the temperature is in the thermoneutral range. During the cyclic HS period, in Week 6 there was a marginally non-significant interaction between treatment and DEB (P=0.07). The trend for the control birds on the high DEB to have a higher LWG than those control birds on the low DEB suggests that the increased need for electrolytes at the high temperature could be supplied in the feed. On the low DEB diet, birds supplemented with electrolytes tended to have higher LWG than the control birds, with this trend being stronger when the E150 or E100-36h treatments were used. This trend was not evident when birds were fed the high DEB diet. These trends could account for the differences in final liveweight. Females supplemented with E150 and males supplemented with E100-36h had higher final liveweights compared to the control females and control males, respectively.

Over Weeks 3–5, the DEB had no effect on feed intake but there was marginally non-significant effect on feed to gain. On the high DEB diet, no treatment had an effect on feed to gain. On the low DEB diet, supplementation with E150, E100 and E100-36h tended to supported better feed to gain. The improvement seen in Week 6 was sufficient for the E150 treated birds to have a better total feed to gain compared to the control birds.

At processing, there was a marginally non-significant interaction between DEB and treatment for the effect on eviscerated dry carcass weight. On the low DEB diet, providing E100 for 36 h before farm pick-up trended to increased dry carcass weight, while on the high DEB diet supplementation with E150 tended to increase dry carcass weight. The treatments had no effect on carcass meat and fat percentages. A possible reason for these effects on carcass weight is a greater hydration rate in the supplemented birds. Increased water retention during HS and transport would reduce physiological stress and reducing this would improve welfare.

Overall, formulating duck grower diets to have low a DEB is not detrimental to achieving good on-farm performance under thermoneutral conditions, but a higher DEB would be beneficial during moderate HS. Changing to a high DEB is not a good management option for duck producers because of the increased difficulty of managing litter quality. There were strong enough trends to indicate that providing electrolytes and betaine as a water supplement could be a more practical option. The higher electrolyte concentration of 150% gave equal, but depending on sex and DEB, in some instances better performance than the concentration of 100%. The results from the treatment using the 50% concentration, suggest that it’s too low to be effective. The trends in the data suggest that the use of electrolytes and betaine for the 36 hours before farm pick-up for processing needed to be further investigated.

**Chapter 7**

Of the strategies tested to help commercial ducks during periods of high temperature, the use of electrolyte and betaine supplemented water offered the best opportunity to achieve improvements in performance and bird hydration. Under Australian summer conditions, ducks can be exposed to
periods of HS for short periods lasting one to three days, although there are some instances where heatwaves can last longer. The use of electrolytes during short periods of cyclic HS is an easily managed option for producers, although it would still require regular filling of a header tank linked to the shed drinker lines. If the supplementation could be applied during only part of the day, it might be possible that the filling of a header tank is required only once daily.

The objective of the study was to assess the effects of continuous or intermittent electrolyte supplementation on the performance of Pekin ducks exposed to short periods of high ambient temperature during Week 5 and Week 6 of the production cycle.

Two strains of Pekin ducks, CV and P2, were used. The following four treatments were applied to both strains:

1. Water alone
2. Electrolyte supplementation in water
3. Electrolyte plus betaine supplementation in water
4. Electrolyte plus betaine supplementation provided 08:00–1700 h during Heat Period 1 (Days 30–32) and 17:00–08:00 h during Heat Period 2 (Days 40–42).

During the first period (Days 30–32), the continuous supplementation with electrolytes or electrolytes plus betaine improved LWG compared to the control birds. Supplying the electrolytes plus betaine only during the period of high temperature was not sufficient to have any effect on LWG. This means that a short period of supplementation is not adequate to best hydrate the birds and reduce physiological stress.

In the second heat period (Days 40–42), all the electrolyte supplemented groups had superior LWG compared to the controls, but there were differences between the electrolyte groups. Birds on electrolytes alone had a LWG that was superior to the other electrolyte treatments, followed by those birds on the electrolytes and betaine continuously and then by birds on this treatment given for the thermoneutral period only. The differences in LWG gain were sufficient for there to be significant differences in final liveweight. All electrolyte-treated groups had greater final liveweight than the controls, and this ranged from 70–180 g. This significant improvement resulted in a higher carcass processing weight of 60–80 g, with this being a 3–4% improvement in carcass yield over the controls. The improvement in LWG is probably due to greater hydration of the birds which would reduce the physiological stress. Supplementation of the electrolytes and betaine only during the thermoneutral period of Days 40–42 was sufficient time to help alleviate the effect of HS but it was not as successful as supplying them continuously.

There is an inherent sex effect for LWG, and this is seen in the present study. The difference between males and females was greater for the heavier P2 strain. In both heat periods, the reduction in LWG gain was similar for males and females.

Feed and water intake differences tended to be related to the differences in LWG, with them being higher for the treatments with superior LWG. Supplying the electrolyte and betaine supplements during the thermoneutral period over Days 40–42 significantly depressed water intakes, when compared to other treatments. The reason for this is not clear, but could be related to palatability of the supplement and the regular changes from supplement to water for this treatment.

During the high temperature periods, the feed to gain of the control birds was poor, especially over Days 40–42. In Heat Period 1 (Days 30–32), the birds given electrolytes, or electrolytes and betaine, had superior feed to gain compared to the control birds and to those given electrolyte and betaine during the heat period only. In the second heat period (Days 40–42), all treatments gave better feed to gain compared to the controls. Birds supplemented with electrolytes and betaine all day had the best feed to gain, while it was similar for the groups given electrolytes all day and electrolytes and betaine during the thermoneutral period only.
After processing, the control birds had a lower carcass weight compared to the electrolyte treatment groups. This was probably not as a result of increased intercellular water retention in the muscle as there were no differences in water holding capacity of the muscles tissues collected from the males of the control compared to the males continuously supplemented with electrolytes and betaine. In the faster growing P2 strain, the electrolyte treatments had no effect on the percentage yield of carcass components, but electrolyte supplementation affected the slower growing CV strain. The effects seen in the CV strain resulted in a higher carcass muscle percentage in the birds with electrolytes all day compared to other treatments, with it being similar for ducks treated with electrolyte and betaine all day and the controls, but higher than the birds treated with electrolytes and betaine for a limited time. The treatment effects on the total carcass fat depended on the strain. In both strains, it was the electrolytes and betaine treatments that resulted in a higher carcass fat percentage. In the CV strain, when the combined treatment was given continuously, it gave the highest carcass fat percentage, and in the P2 strain it was when the treatment was given for the limited period.

**Factors involved in feather pecking and strategies to reduce the incidence of the damage caused**

FP is a general term used to describe damaging behaviours directed towards feathers of other birds. While there has been extensive research into FP in laying hens, there is a decided lack of research into duck behaviour in Australian production systems. This lack of knowledge on FP and its causes in commercial ducks needs to be addressed if solutions to the problem are to be identified and implemented.

The detrimental effects caused by this behaviour are relayed to cost of production and bird welfare. Occurrence of FP has been attributed to a number of factors, including genotype, physiology, nutrition, light intensity, group size, stocking density, stress, floor type and early rearing environment. Observations made during a previous project ‘Efficient, environment and bird friendly duck production’ (Downing 2010), suggested that there are genetic (the CV strain is more prone to FP than GF strain of Pekin ducks), seasonal (incidence of FP is greater in winter than summer) and age (beginning at around 3–4 weeks of age) components to this behaviour. What is clearly lacking in the literature is any detailed long-term study of duck behaviour in intensive housing systems. There is limited research on FP in ducks, and there is little understanding as to what factors predispose birds to FP. Obviously, if this is unknown, the solutions remain obscure.

**Experimental results**

**Chapter 3**

The objective of the study was to assess the effects of stocking density and light intensity on the growth performance and extent of FP in CV and GF Pekin ducks. A further objective was to identify if there were differences in behaviour that might help account for the strain effects on FP seen in commercial sheds.

The experimental treatments consisted of two strains: CV and GF, two light intensities (high, >60 lux and low, <5 lux) and three stocking densities, low density (4.4 birds/m²), medium density (5.2 birds/m²) and high density (6.0 birds/m²).

Eight pens in the high light intensity section of the shed were used to evaluate the behaviour of the two strains. The number of pens observed was determined by resource constraints. The eight pens were continuously monitored by two video cameras per pen. Observations were made on each pen at five minute intervals for a 24 hour period at 3, 4, 5 and 6 weeks of age.

**Behaviour study**

Ducks spend 65–75% of their time resting, a further 12% of their time alert but sitting, and between 15–20% involved in general activity. The level of general activity is much higher in Weeks 5 and 6.
This pattern might be significant in commercial duck sheds because if other environmental conditions predispose ducks to higher FP activity, the increase in general activity might help perpetuate the problem by increasing the potential for social transmission. Ducks spend a moderate amount of time self-preening, about 6–7%, and the tendency is for this to increase as the birds age. They spent very little time preening other birds or involved in mutual preening. The probability that ducks would be involved in aggressive grooming that resulted in some form of negative response from other birds was low. This activity might be part of those resulting in FP damage. Strain and stocking density had no effect on this form of grooming.

FP activity, where feather were actually pulled at, was seen at a frequency of around 0.06% of the time. The incidence does increase in Weeks 5 and 6. At the time when damage is directed at the wing, Weeks 3 and 4, the FP activity is low with a probability of it occurring only 0.02–0.05%. It needs to be remembered that the probabilities are determined from the number of birds engaged in the activity of the total number of birds in the pen. The observations cannot tell if the same bird is involved in the FP activity at different observation times. A low probability might mean that few birds are involved in the activity or that one bird might be involved with regular frequency.

Strain and stocking density had no effects on grooming or the incidence of FP. The only real difference was the higher probability that the GF ducks would be resting.

**Feather pecking damage**

Feather damage was evaluated at the end of Week 3 (Period 1) and the end of Week 4 (Period 2). There is a distinctive period of FP damage directed at the wing around the time of feather emergence, which is commonly around the end of Week 3 of age. In Period 1, the damage directed at the wing region was more severe than that directed at the thigh. This was not the case in Period 2. It follows that there is likely some attraction which directs the ducks to the wing area. It is proposed that the attraction is the red blood that can be seen in the feather shaft at the time of feather emergence. While this might be the initial attraction, blood from damaged feathers is smeared on the thigh and this could further attract the ducks to this area. Only about 8% of the birds had FP damage. The incidence of FP damage could indicate that only a few individual birds are involved in the activity. While the difference was only seen at the second evaluation period, the GF birds did have a lower incidence of FP damage.

Stocking density had an effect of the degree of FP damage, but this was only seen when the evaluation was made in Period 2. The damage seen for birds housed at the medium density was greater than for birds at the low density. The difference between the damage in birds at the medium density and at high density was marginally non-significant, but the trend was for it to worsen in the medium density treatment. The general consensus is that damage from FP increases with group size, and as the density increases. The pattern seen in this study does not seem to hold to this concept. If individual birds have different propensities to be involved in FP, the densities used in the current study may have little influence because the group size and enclosure are small.

In this study, we did not observe FP damage directed at the back area. This probably accounts for the much easier removal of feathers at the processing plant, as relayed by staff at PEPE’s Pty Ltd. This difference can be identified by the need, or not, to wax duck carcasses to remove the pin feathers during processing. This casual observation is important because it suggests that the better environmental control experienced in the experimental facility might have a role in FP activity directed to the back region.

**Production performance**

In Weeks 5–6, the LWG was lower when birds were kept at the high stocking density compared to the lower densities. The differences in LWG resulted in differences in final liveweight at processing age, with it being higher for birds housed at the lowest density compared to the highest density. While the
analysis indicated that the final liveweight was not different between birds at the medium and high densities, it was close as the difference in average weight between the low and medium density was only 3g.

In Weeks 3–4, the LWG was superior for birds in the low light intensity but this was not seen in Weeks 5–6. In the behavioural study, under high luminance ducks rest more at 3–4 weeks than at 5–6 weeks, and engage in less general activity. The effect of low light could add to the level of inactivity in Weeks 3–4, and could help account for the LWG effects seen at this time. Light intensity and stocking density had no effect on the LWG or final liveweight of the two strains or the different sexes.

The feed to gain was better for birds at the low light intensity until the end of Week 4, but not in Weeks 5–6, but the overall feed to gain for the entire production cycle was not any better. The stocking density had no effect on feed to gain. Strain GF was more efficient than strain CV with better feed to gain in all weeks.

When the efficiency of production was determined as the ratio of feed to breast yield there were no stocking density or light intensity effects. The GF strain had greater breast weight and was more efficient with the feed weight to breast weight being better. At low and medium stocking densities, the breast percentage was higher for the GF strain but not at the higher density. Birds at the higher density had lower liveweight, and this might indicate that the reduced weight is partially lost breast muscle.

Using trial and error, over a long period the industry has settled on 5.2 birds/m² as being the density most suited to their housing conditions. The results from the current study indentified 5.2 birds/m² as the maximum density to achieve the best LWG. The effect of density on FP is not conclusive. It was higher at 5.2 birds/m² than at 4.4 birds/m², but only in period 2, and the fact that the extent of FP did not increase at 6 birds/m² makes it difficult to interpret what effect the density has on FP.

Chapter 6

While FP is considered a multi-factorial problem, the fact that the wing damage occurs at a reasonably precise time in ducks suggests that there might be a more specific reason for its occurrence. Our observations suggest that the FP behaviour occurs at the time of early feather emergence when blood is easily recognised in the feather shaft. One approach to determine if this is the case was to disguise the feather shaft and measure the effect on FP behaviour. In the present experiment, the strategies used to disguise the blood feather were to colour the wings with blue spray marks and to rear the birds under BL. To distract the birds at the time of feather emergence, SB were provided in the pens.

It is proposed that the conditions which cause stress to the birds could predispose them to FP. PL quality has been suggested by producers to be an environment stressor that can cause birds to engage in FP. Stress results in the release of corticosterone in birds. Elevating plasma corticosterone has been used as an experimental model to simulate stress in laying hens and broilers. Corticosterone can be administered in the feed or water to elevate plasma corticosterone concentrations. If stress-provoking stimuli do predispose ducks to FP, then elevating plasma corticosterone would be a strategy to mimic this. In commercial practice, ducks are reared as mixed sexes. Currently there is no clear indication whether males or females have a higher propensity to engage in FP. The effect of single sex rearing of males and females on FP was a further objective of the current experiment.

The objective of the study was to determine what conditions could potentially predispose Pekin ducks to FP. The effect of the different strategies on bird performance was also evaluated.

CV Pekin ducks were exposed to the following eight treatments:

1. Control, reared as mixed sexes
2. Females reared as single sex
3. Males reared as single sex
4. PL quality, reared as mixed sexes
5. Wings coloured with blue spray marks, reared as mixed sexes  
6. SB included in the pen, reared as mixed sexes  
7. Birds reared under filtered BL, reared as mixed sexes  
8. Corticosterone-treated water, reared as mixed sexes  

**Production performance**

A notable observation was the failure to detect any increase in plasma corticosterone concentration when ducks were given corticosterone-supplemented water. While this was the case, there were definite measurable physiological effects on the ducks. There was a significantly depressed LWG in the birds supplemented with corticosterone. Although the corticosterone was supplemented in Weeks 3-5, the effect on LWG was severe enough to significantly depress liveweight at market age. The final liveweight was around 400 g lower than the control birds. Males were heavier than females under all treatments, but this difference was less for the birds treated with corticosterone. In fact, in Week 5 there was no difference. The pattern of feed intake in the corticosterone-treated birds was also unique. They had the highest feed intake in Weeks 3–4 and the lowest in Weeks 5–6, with the overall the total feed intake being similar to all other treatment groups. Differences in feed and water intake resulted in the corticosterone-treated birds having the worst feed to gain and highest water to feed ratio. The changes in carcass composition for the corticosterone-treated ducks provide further support that the dose of corticosterone administered was sufficient to cause physiological perturbations. The corticosterone-treated ducks had lower total carcass muscle percentage and higher total carcass fat percentage.

Rearing birds under BL resulted in lower LWG over Weeks 3–4 compared to controls and similar LWG in Weeks 5–6, but the earlier effect was sufficient to depress the final liveweight compared to the controls. Compared to the controls, providing SB or colouring the birds’ wings had no effect on any performance measure. While there were some differences between controls and birds on PL during the treatment period these were not consistent and overall there were no differences in final performance measures. The treatments had no effect on total carcass muscle and fat percentage compared to the control birds except, as has already been discussed for the corticosterone-treated birds.

**Feather pecking damage**

Overall, the extent of FP in the experiment was low and this is an obstacle to investigating this problem in ducks. There is no way of predicting how extensive FP will be under the experimental conditions being employed. Because the treatments were designed to limit FP, or test if FP could be increased under some conditions, the comparisons of treatment effects were made to the control birds rather than comparisons between the treatments applied.

Compared to the control birds, those with CW had lower wing damage scores than the control birds on Day 30, but not on Day 35. There was a trend for the birds reared under BL to have lower scores than the controls, with the difference being marginally non-significant on Day 30. It should be noted that higher scores for the wings were recorded for birds on PL and males reared in single sex pens, but these differences failed to reach significance.

The use of supplementary corticosterone certainly affected performance, but had no effect on FP damage. In the study, litter quality was kept in poor condition and in fact was considered to be as poor as it would ever get in commercial sheds. Birds on the PL performed well, and based on plasma corticosterone levels, were not stressed. The PL treatment had no effect on FP damage.

Colouring the wings blue would act to disguise the blood in the emerging feather shaft, and so the lower FP seen at day 30, would suggest that the hypothesis identifying the blood feather as an attractant to other ducks would seem to be valid.
Chapter 8

The earlier studies detailed in Chapters 3 and 6 investigated some aspects considered to be potential contributors to FP in commercial ducks. Evidence for the role that the attraction to the blood in the feather shaft played in FP damage to the wing area was provided in Chapter 6. Further confirmation of this was undertaken in the experiment described here. Further evaluation of the inclusion of SB was also included in the current experiment.

TRP has a role in brain turnover of serotonin. Increased rates of FP are associated with low serotonergic neurotransmission. If aggression is a component of FP behaviour in ducks, then feeding increased dietary TRP is a strategy to test this. The extent of FP on commercial farms is higher in winter than summer. Again, observations provided by PEPE’s Ducks Pty Ltd and commercial producers suggested that air movement in the shed during the cold winter increased the extent of FP. The objective of this study was to further investigate factors that could be involved in FP in commercial CV ducks.

The P2 industry-selected strain of CV Pekin ducks was used and the following treatments were applied:

1. Control=P2 strain reared as mixed sexes
2. Wings coloured with blue spray mark
3. SB included in the pen
4. TRP added to the diet
5. Increased AF.

**Production performance**

The TRP-treated birds had lower LWG at Week 4 and while this difference was not seen at Week 6, the overall effect was for the TRP birds to have lower final liveweight at the end of the production cycle. The significantly lower liveweight of the TRP birds observed on Day 42 was also seen on arrival at the processing plant, and was reflected in a lower hot carcass weight. The birds exposed to increased AF had higher LWG in Week 6 compared to other treatments, and this resulted in higher final liveweight compared to the controls. The control birds had a lower hot carcass weight than the birds exposed to the AF.

While there were no obvious LWG differences between the birds with CW and the controls, the final liveweight was lower in the control birds. This resulted in a much poorer feed to gain in the same periods and an overall total poorer feed to gain. The better feed to gain for the birds with SB in Weeks 5–6 resulted in better total feed to gain for these birds, compared to the controls.

Treatment had no effect on the breast, drumstick, cod fat or total meat expressed as percentage of the hot carcass weight. The control birds had lower subcutaneous fat percentage compared to other treatments and the TRP birds had lower percentage than the birds with SB. These differences help account for the differences seen in the total fat percentage.

**Feather pecking damage**

This was the first study where the two different forms of FP occurred. There was no significant effect of treatment on FP damage to the wing area. The positive effect of colouring the wings identified in chapter 6 was not replicated here. Damage directed to the back occurs towards the end of the production cycle and can result in the feather removal from the back area. This is a concern for the ducks welfare and also creates problems for processing as the remnants of the damaged feather are difficult to remove during processing. The experimental facility used has much better environmental control than is possible in commercial sheds. Because this was the first time that back damage had been observed through the three years of these studies, there is a hint that environmental conditions in the shed could be related to the form of FP activity. The treatment effects were not significant,
although it did appear as though the increased AF might be involved, but this would need further evaluation. Males had more damage to the back region than females.

The degree of FP seen in individual pens varies greatly. It appears from the current work that FP, if it occurs, is seen on all ducks in individual pens or is not seen at all. This does raise the possibility that FP could be initiated by individual birds and that in the small pen enclosures used here, these individual perpetrators cause most of the damage or that once started, social transmission extends to incidence.

**The effect of transport and lairage on the carcass weight loss during processing**

Because feed is removed three hours before farm pick-up for processing, and ducks have no access to water during transport and lairage, they lose weight prior to processing and this causes physiological stress and if serve would affect their welfare. While some of this the initial loss is excreta expelled as the birds empty the GIT, the later loss is due to dehydration. This is especially the case during summer, when birds can be exposed to high ambient temperatures. Dehydration is a welfare concern for the bird and an economic concern for the industry because of the reduced carcass yield and the effect on meat quality.

**Overall objective**

The objective was to determine the rate of weight loss during transport and lairage and to investigate whether the use of electrolytes and betaine supplementation could help to alleviate the effects of transport and HS.

**Experimental studies**

**Chapter 5**

The objective was to determine how relevant transport and lairage were to weight loss and whether providing electrolytes and betaine supplementation during the lairage period could reduce processing weight losses by limiting dehydration. Birds used in the study were randomly collected from the main flock on a commercial grow-out farm at the time of pick-up for processing at 42–43 days of age.

The treatments were:

- ducks processed as soon as possible after arriving at the processing plant
- ducks that were transported and then held in lairage and processed at a later time
- ducks that were transported and then held in lairage and processed at the later time, but during lairage were provided with water supplemented with electrolytes and betaine.

All treatment groups lost similar amounts of weight during transport, with this being less than 2% of the farm weight. The weight loss during lairage was different. It was significantly greater for birds processed later and having no access to electrolytes. In lairage, delayed processing resulted in a 3.5% loss of farm liveweight while supplying electrolytes limited this to 1.1% and was similar to the birds processed early, at 1.5%. When the birds were processed, the weight loss during evisceration was lower for the birds processed later without electrolytes. This suggests that the extra weight recorded for the early-processed and electrolyte-supplemented birds was due to the greater gut weight, which is probably fluid in the gut. While providing the electrolytes may have helped the birds cope by limiting the effect of transport and temperature, it had no benefit on processed carcass weight. This indicated that the increased weight was water being held in the gut. This would act as a heat sink to help ducks cope with the temperature and physiological stress. An alternate would be to supply the electrolyte supplementation before transport.
Chapter 9

The objective of the experiment was to test whether providing ducks with electrolytes and betaine supplementation for 32 hours before pick-up could help to reduce dehydration and weight loss during transport and lairage and benefit the birds’ welfare, especially during high temperature periods, and result in higher processed carcass yield.

The study was completed on a commercial duck farm in southwestern Sydney. Birds were at the end of the grow-out period (42 days of age). A sub-sample of the flock was supplied with electrolytes and betaine for 32 hours before farm pick-up. Half of these treated birds were compared with birds selected from the flock at the time of the pick-up. The remaining half of the on-farm electrolyte-treated birds were transported with either continued access to the electrolyte solution, or with no further access to the supplement. Weight changes were measured during transport, lairage and then processing.

An underlying goal of the current study was to determine the role electrolytes could have in controlling bird dehydration during transport and lairage during periods of high temperature. Working in a commercial production shed limits any control we had over many aspects of the experiment. Disappointingly, on the farm pick-up day, the ambient temperature was moderate and within the birds thermoneutral zone, and persistent rain showers resulted in high RH. However, the combination of temperature and RH would be sufficient to cause moderate stress for these birds.

Before the on-farm treatments, birds had similar liveweight. During the treatment period on the farm, the electrolyte-treated birds increased their liveweight while the control flock birds did not. This resulted in the electrolyte-supplemented birds having a greater liveweight at farm pick-up. Based on the predicted weight loss, the electrolyte-treated birds lost a higher percentage of their liveweight during transport and lairage. Most of this difference occurred early, as from three hours after pick-up the rate of weight loss in lairage for the electrolyte-treated and control birds were similar. In lairage, the birds lost weight at the same rate. At this point, birds may continue to clear the GIT of waste but much of the water loss will be through evaporation and so cause dehydration. This would be especially true during periods of high temperature. While the percentage weight loss was higher in the electrolyte-treated birds, they still had a higher final weight. This is even accounting for the fact that they were loaded 90 minutes earlier than the control birds. The final processed carcass weight was around 90 g heavier for the electrolyte-treated birds.

The birds which were supplied with electrolytes and betaine before farm pick-up and then during transport and lairage had higher liveweight at the processing point compared to those without continued access to electrolytes during transport and lairage. The heavier liveweight at initial processing was not realised after evisceration, where the carcass weights were similar for the two treatments. At the temperatures and RH experienced during the study, no advantage was gained in processing weight by supplementing birds with electrolytes and betaine during transport and lairage. The value of the supplementation to the bird’s welfare could not be determined.

The increased weight of supplemented birds could be due to increased intracellular water retention which acts to limit the extent of dehydration experience by the ducks. This is likely to reduce any physiological stress and in turn benefit their welfare.

Growth performance of the Grimaud Freres Star 43

Objective

The objective was to evaluate the growth performance of a new imported GF strain.
Experimental study

Chapter 8

For the GF strain, maximum LWG was reached by Day 21 and maintained until Day 35, but after this, it decreased rapidly. As has been shown for other strains, the females reach maturity earlier than males, as the reduction in LWG from maximum begins earlier (Downing 2010). The GF strain was heavier than the P2 strain at all times. At Day 45, the GF birds averaged 3,718±37 g. While this might be suitable for the cut market, it is not ideal for the whole bird market. Even at Day 42, the birds were 3,587±36 g, which is still not suitable to meet current market specifications.

In fact, if the birds were to be processed at the correct market weight, they would need to be removed around Day 35 when the liveweight averaged 2,899±29g. While this might seem ideal costwise, it is not practical because of how breast muscle develops in ducks. As identified in a previous RIRDC project, breast development in ducks occurs comparatively late in the production cycle (Downing 2010). While it was not determined here, ideally what needs to be known is the pattern of breast muscle development in the new GF strain, because if this occurs late in development then this strain may not suit market needs.
Implications

Production performance

Stocking density

The stocking densities used were determined from discussions with PEPE’s Ducks Pty Ltd. Under their farming management system, ducks are housed at a density of 5.2 birds/m². The density of 4.4 birds/m² was chosen on the basis that it would be the minimum density that would be economically viable for the production system. The density of 6.0 birds/m² was chosen on the basis that this would be the maximum that could be sustained under summer conditions, using the conventional housing type currently used in production. The results indicate that the highest density for maximum performance was 5.2 birds/m². Using conventional open-sided broiler sheds, the industry is currently at maximum density for best performance.

Betaine

Betaine is regularly added to duck grower diets. The results of this study indicate that there is no advantage to LWG or feed to gain during thermo-neutral conditions, or during cyclic heat stress.

Dietary electrolyte balance

Overall, formulating duck grower diets to have a low DEB is not detrimental to achieving good on-farm performance under thermoneutral conditions, but a higher DEB would be beneficial during even moderate HS. Changing to a high DEB is not a good management option for duck producers, because of the increased difficulty of managing litter quality. Therefore, continued formulation at a low DEB is warranted.

Electrolyte supplementation

Ducks benefit from additional electrolyte provision during periods of high temperature. Under cyclic moderate high temperature, there is a restriction on duck performance. A number of strategies used in broilers during HS were of no benefit to duck performance under these conditions. Ducks benefit from supplementing water with additional electrolytes during periods of high temperature. This is a practical option for producers, as its application can be targeted to specific periods of high temperatures, or when heatwave conditions are anticipated.

As birds age and increase in liveweight they become more susceptible to HS. It follows that the use of electrolytes is more beneficial in the later stages of the production cycle, especially in the last week of production. The effects of HS are going to be most problematic for ducks if they occur in the days just prior to processing as they will not have sufficient time to recover from the setback before processing. The higher electrolyte concentration at 150% gave equal or, depending on sex and DEB in some instances, better performance than the concentration at 100%. The results for the 50% concentration suggest that this is too low to be effective. In general, using the electrolyte concentration at 100% is going to give a good overall improvement in performance. Improvements in performance are coupled with less physiological stress and reduced stress which equates to better welfare.

It would be easier for producers to manage electrolyte supplementation if it could be given only during the high temperature period of each day. The results indicate that this is not an adequate strategy to obtain the desired improvements. While supplementation during the longer cooler part of the day provides some benefit, it is not as successful as continuous supplementation.
Feather pecking and damage

The detrimental effects caused by this behaviour are related to bird welfare and production costs. Occurrence of FP has been attributed to genotype, physiology, nutrition, light intensity, group size, stocking density, stress, floor type and early rearing environment.

It has become clear that there are two distinct forms of the problem in ducks. The first is FP that is directed to the wing, which occurs at a precise time coinciding with the emergence of the true wing feathers around Week 3 of age. The second form occurs later in the production cycle, in Weeks 5 and 6, and is directed at the back region, where there can be removal of the fine feathers.

Under Australian conditions, no definitive reasons for FP have been provided, and this lack of information means there are no tangible strategies to prevent it. FP is difficult to study under experimental conditions because there is a reliance on it being performed at a high rate in control treatments, but this is not always the case. This lack of predictability has been an issue in the current studies. In fact, it was only in the very last study that FP directed to the back region was even observed under the experimental conditions.

Wing-directed feather pecking damage

The role of the blood feather

The results of the project give a better understanding of what might be causing the wing form, but not the back form, of FP. Casual observation suggested that ducks were attracted to the red blood colour in the shaft of the emerging true wing feathers. This is first seen in the feather at the very tip of the wing, and this is where the damage first occurs. Disguising the blood feather using blue spray mark reduced the incidence of this form of the FP damage in one study. There was a tendency for the damage to be less when birds were reared under BL. While this was not significant it does provide evidence that it was not just the colour of the spray that acted as a deterrent. BL was chosen as birds do not perceive BL with the same intensity as red. The observations support the hypothesis that the red colour in the feather shaft has a role in attracting birds to peck at it.

Further casual observations during these studies suggest that individual birds may have a high propensity to engage in PF activity. Individual birds could be seen moving from one penmate to the next, and pecking at the wing feathers. This observation could help explain the pattern of FP damage seen in individual pens. In any pen, FP tended to be an ‘all or nothing’ event. If present, it was normally seen in a high number of birds in the pen; otherwise, it was not present in any of the birds. It could be that in the small group sizes used in the current studies, individual birds were responsible for most of the activity, or that once started by an individual, FP spread by social transmission where other ducks imitate the activity, especially when there is blood present. It has been suggested that so called ‘super-peckers’ exist in laying hens flock and are responsible for severe, aggressive pecking. It could be that a similar situation exists in ducks.

Stocking density

Stocking density of 5.2 birds/m² resulted in more FP damage that when housed at 4.4 birds/m². While this was observed, it might not be of great relevance. In the experiment, only 8% of the ducks had any level of PF damage, and this was minimal, with the damage being scored at 1. Also, the FP damage at the highest density was marginally better than at the 5.2 birds/m², which does not fit with the paradigm in laying hens where FP damage is higher as density increases.

Light intensity

A low light intensity of less than 5 lux had no effect on the extent of FP. Low light intensity is regularly used in laying hens to limit FP and cannibalism outbreaks when they occur. Even if lower intensities than that used in the current study were found to be more successful, they could not be
implemented in the current open-sided sheds used for duck production. Hence, this will not be a solution to the FP problem in ducks under current Australian conditions.

**Strain**

The casual observation made in commercial sheds that FP damage to the wing area is more severe in CV than GF Pekin ducks was confirmed in the current studies.

**Stress**

A poor environment, where birds are exposed to a range of stressors, has been considered a condition predisposing laying hens to FP. A similar role for stress has been suggested by duck producers (PEPE’s Ducks Pty Ltd, personal communication). In this project, the supplementation of water with corticosterone was used to mimic the effects of stress by increasing plasma corticosterone concentrations. A similar experimental model has been used in laying hens and broilers. Interestingly, when ducks were blood sampled during the supplementation, no increase in plasma corticosterone concentrations were detected. It is difficult to provide any explanation for this. While the blood concentrations did not increase, there were significant physiological effects which were the same as those seen in broiler and laying hens. There was a significantly depressed growth rate and poorer feed to gain, as well as changes in carcass composition. As a chronic stress model, it gave similar results to other poultry species but had no effect on the extent of FP damage.

**Poor litter quality**

PL quality has been proposed as a stressor in poultry, especially when combined with cold, wet weather. In this project, PL conditions where simulated in an experimental facility. The litter quality at the end of the study was considered to be worse than it would ever get in a commercial shed (PEPE’s Ducks Pty Ltd, personal communication). Under such conditions there was no increase in circulating corticosterone, and no adverse effect on the extent of FP damage. The birds performed as well as control birds maintained on good litter.

**Dietary tryptophan**

While aggression has been implicated in FP in laying hens and male broiler breeders, the extent of the damage to the wing area of male and female ducks were similar. The use of TRP-supplemented feed to increase plasma TRP concentrations has been proposed to increase serotonin turnover in the brain. Low serotonin turnover has been linked to aggression. In the current project, dietary supplementation with TRP increased plasma TRP concentration and, while there were obvious physiological effects on growth, there were no effects on FP damage.

**Back-directed feather pecking damage**

In the final FP study, damage directed at the back area was observed. Damage to the back occurs towards the end of the production cycle and can result in denuding of the back area. While this ranks as a welfare concern for the ducks it also creates problems for processing, as the remnants of the damaged feather are difficult to remove. While the treatments applied had no effect on the extent of the damage, the role that increased AF over the ducks needs to be further considered. The fact that this form of feather damage was not observed regularly in the experimental facility may provide some circumstantial evidence as to the role of the environment. The experimental facility has much better environmental control than is possible in commercial sheds. The absence of damage to the back region in most of the studies probably accounts for the much easier removal of feathers at the processing plant, as relayed to the author by staff at PEPE’s Ducks Pty Ltd. This casual observation is important because it suggests that the better environmental control experienced in the experimental facility might have a role in limiting FP activity directed to the back region.
FP studies are very difficult to design and implement. Under experimental conditions, only small group sizes are used. Currently, we have no experimental model available which guarantees a high feather pecking frequency which can be used to test alleviation strategies. Experimental studies need to be conducted in large flocks, and this is only possible in commercial sheds, but here there is lack of control over the conditions and potential obstacles to implementing experimental treatments. Under Australian housing conditions, it will be difficult to prevent FP because of the restrictions the housing type imposes on control of the environment, including light. While it was not seen in the experimental studies here, the option of using straw to distract birds in the late stages of the production cycle is worthy of further evaluation in commercial sheds.

**Transport dehydration and stress**

Ducks lose weight during transport and lairage. The initial loss is related to gut emptying after birds are removed from feed. About three hours after farm pick-up, the loss in weight is fairly constant. During this time further weight loss, is most probably water loss from the tissues. The rate of water loss would certainly depend on the ambient temperature and RH. The transport studies undertaken in this project were performed on-farm, and this created some problems due to the limited experimental control. The major issue was the lack of control over the temperature. The studies would have provided greater insight to the problem if they had coincided with a period of higher temperature. Even so, these results can be used to predict the likely relevance of treatment effects during periods of high temperature.

Providing electrolytes and betaine during transport and lairage did have an effect on bird weight prior to processing, but not on carcass yield after processing. The increased weight at processing is probably an increase in gut water. While this might help the bird, it is not a practical option for commercial processors.

The use of electrolyte and betaine supplementation for 32 hours prior to pick-up increased farm weight and weight through to processing, and gave an ultimate increase in processed carcass yield of 3–4%. As some of the increased weight is carried through to the end of processing, it likely that greater water holding capacity of the carcass might be involved. Increased hydration of the ducks during this stress has to be beneficial to them.

Eight million ducks are processed annually, and if these birds are processed at the ideal market weight of 2.85 kg this equates to 22,800 tonnes of liveweight. If it is assumed that the dressing percentage for these birds is 75%, then the total yield of whole carcass weight after processing would be 17,100 tonnes. A 4% improvement in saleable carcass weight would be 684 tonnes, and if a provisional value of $6.30 (PEPE’s Ducks Pty Ltd, personal communication) is placed on one kilogram of dressed carcass weight, this would result in $4.31 million of additional in revenue. If the treatments were only applied during the four months of summer, this would result in $1.44 million of additional revenue. The response seen at moderate temperature would suggest that benefits could be observed in all seasons, not just summer, but probably to a lesser extent.

A further benefit of using the electrolyte and betaine supplements was the improvement in feed to gain. During Days 30–32, the improvement ranged from 0.42 to 0.52 units; when the birds were heavier, the difference was 1.54 to 1.86 units. Over Days 40–42, the control birds used 4.92 g of feed to increase their weight by 1 g. This is a feed cost of 0.25 cents, while the electrolyte and betaine-supplemented birds are doing the same at 0.153 cents. Over Days 40–42, the control birds gained 99 g of liveweight, which would cost 24.75 cents for feed, and the electrolyte and betaine-supplemented birds gained 162 g, which would cost 24.79 cents for feed. Hence the increased value of the carcass weight comes at no additional feed cost. This is a significant economic advantage and reduces the carbon foot print of the production system.
Growth performance of the Grimaud Freres Star 43 strain

The new GF strain out-performed the P2 strain. At Day 45, the birds were far too heavy for the whole bird market (3,718±37 g). In fact, at 42 days they would still be too heavy. If the birds were to be processed at the correct market weight, they would need to be removed around Day 35, when the liveweight averaged 2,899±29g.

While this might seem ideal costwise, it is not practical because of how breast muscle develops in ducks. Processing the GF birds at 35 days is not feasible, as they would not have sufficient breast muscle to meet consumer requirements. The slower growth rate seen in summer might actually benefit the GF strain, as it is more likely to meet the market requirements at 42 days, whereas the CV strain needs to be reared to 44–46 days to achieve this. In the current study, the GF females would better meet the market needs because they are lighter at 42 days, and mature earlier so have better breast muscle development. Ideally, if the sexes were reared separately, the females could be used for the whole bird market and males for the cut-up market. The current problem with this approach is that the industry needs the majority of its current production to meet the demand for the whole bird market.
Recommendations

1. The research generated here is the first that provides information on FP in commercial ducks under Australian conditions. There remains a need for further development of strategies that might help with this problem. The development of suitable experimental models that can be used in commercial sheds is the next step in developing ways of helping producers cope with the problem.

2. The information generated will be of value to those regulators responsible for the development of a new welfare code for poultry.

3. The role of open water access needs to be investigated, both for welfare assessment but also to inform those persons developing the new poultry welfare code.

4. The use of electrolyte supplementation prior to farm pick-up would improve the economic value of duck production, reduce physiological stress on ducks and improve their welfare during transport and lairage.
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Improve the production, efficiency, welfare and processing of commercial ducks

By J. A. Downing
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The duck industry uses genetics from overseas, and much of the knowledge used in production has also been developed from research conducted overseas. Much of this is not relevant to the product specifications needed in the Australian market. To facilitate the profitable growth of the duck industry, key husbandry factors potentially limiting bird growth and welfare on Australian farms need to be better understood.

The report targets the producers responsible for the grow-out of ducks from day olds to market age, which is normally around 42 days of age.

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