Commercial Duck Production for Bird Welfare, Environmental Benefits and Efficiency
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Foreword

With the continued growth of the human population and the associated demand for high quality animal protein, there remains a need for increased animal production efficiency. Duck accounts for 5% of world poultry production, with around 87% of this being produced in regions of Asia. In the period 1993 to 2003, world duck production doubled. Compared to broiler production, the duck industry in Australia is small, but continues to grow at around 10-12% per year. The industry slaughters eight million birds annually, and is worth an estimated $100 million.

The aim of this project was to increase knowledge to assist in the efficient production of a uniform product, that is of high quality and safety, and meets or exceeds standards for wellbeing (health, diet, housing and care), and environmental stewardship.

The key findings and recommendations from this report are that:-

- the energy content of the present commercial diets is adequate for optimal growth rate, however, the protein content is too high and can be reduced to 17.5%.

- there is an opportunity to implement a three stage feeding program, with the introduction of a finisher diet in weeks five and six of production.

- sorghum can account for at least 50% of the grain components of the duck diets without affecting performance.

- water consumption of ducks is high. Limiting intake by installing meters on water lines alleviates the reduced growth rate of ducks in summer. This depression is currently costing the duck industry 4.5 days of extra feed for the ducks to reach market weight.

This project was funded from RIRDC core funds, provided by the Australian Government. Industry partner, Pepe’s Ducks Pty. Ltd., (Windsor, NSW, Australia), provided funds to support this project.

This report is an addition to RIRDC’s diverse range of over 2000 research publications and it forms part of our Emerging Animal Industries R&D program, which aims to develop new opportunities.

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.

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About the Author

Dr Jeff Downing moved from CISRO Division of Animal Production to the Faculty of Veterinary Science, University of Sydney, in 1996. He is presently employed as Senior Lecturer and teaches Poultry and Pig husbandry to students in the Veterinary Science and Animal Veterinary Bioscience degrees. Presently, areas of 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.
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PEPE’S Ducks Pty. Ltd., as the industry partners were strongly influential in all aspects of the project and so thanks to John Houston and Peter Brown for their contributions and overall enthusiasm.
Abbreviations

AA  Amino acid(s)  
ADP  Apparent Protein Digestibility  
AME  Apparent Metabolisable Energy  
AMEn  Apparent Metabolisable Energy adjusted to zero nitrogen retention  
ANR  Apparent nitrogen retention  
Calc  Calcium  
CL  Total caecal length  
CP  Crude protein  
CV  Cherry Valley  
DL  Duodenum length  
DM  Dry matter  
DL-MD  Duodenum to Merkle’s Diverticulum  
FBR  Feed to breast muscle ratio  
FCR  Feed Conversion Efficiency  
GF  Grimaud Frères  
GIT  Gastrointestinal tract  
kJ  kilo Joule  
LW  Liveweight  
ME  Metabolisable energy  
MD-ICJ  Merkle’s Diverticulum to the ileo-caecal junction  
MJ  Mega Joule  
MHA  Methionine hydroxy analogue  
NRC  National Research Council  
Phos  Phosphorus  
SI  Small intestine  
TME  True Metabolisable Energy  
TMEn  True Metabolisable Energy adjusted to zero nitrogen retention  
TRN  True nitrogen retention
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Executive Summary

Who is the report targeted at?

This report is targeted at duck producers. The beneficiaries will in the first instance, be the integrated industry agencies that contract duck production to individual growers. More efficient production will assist contract growers to remain economically viable. The success of producers depends on supplying product with the best efficiency both at the farm and processing level. To meet the needs of the Asian restaurant trade the producers need to supply whole duck carcasses with the right proportions of meat and fat to ensure good flavour and the skin needs to be of high cooking quality. Meeting these challenges with the strains and housing available to local producers is challenging, and to remain financially viable the economics of production requires the highest efficiency.

The duck industry is relatively new and the volume of research specific to Australian conditions is scarce. Even in countries, such as France and the UK where the industry has been well established the volume of research available is nominal in comparison to the broiler chicken (Baeza et al., 2000). Of the research available from Europe, much is of limited relevance to Australian conditions because of the difference in climatic conditions and type of housing used. The inherent physical and physiological differences between broilers and ducks, limits the relevance of extrapolating research data from broiler studies to duck production. For the Australian industry there is an urgent need for relevant information on growth rates, feeding efficiencies, diet composition, welfare and factors limiting processing efficiency.

The report details the results of five studies that investigated the effects of genotype, sex, pen-sex, season and nutrition on performance of Pekin ducks under Australian conditions. The research efforts attempted to address some of the factors limiting efficiency in the local duck industry.

Background

Domestic poultry consumption was estimated to be 37.4 kg per person for 2008 (ABARE, 2009). Around 95% of Australia’s total poultry production is consumed domestically (ABARE, 2009) with duck meat consumption being 0.5 kg per person per year (Micheal, 2001). While this is small, the industry is expanding at 10-15% annually (PEPE’s Ducks, personal communication). The industry slaughters 8 million birds annually and is worth an estimated $100 million.

In the Australian market, the consumer expectation is for a bird grown to a liveweight of 2.85 kg at processing and having a high breast muscle yield (PEPE's Ducks, personal communication). Further, consumers also require a uniform product, and for a health conscious population, the correct amount of carcass fat.

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 the developing South East Asian countries including China, Thailand, Vietnam and Bangladesh (Micheal, 2001). As it develops, the duck meat industry has started to address issues of animal wellbeing, industry sustainability and food safety. Due to the high demand of breast meat, an important research objective is to increase the proportional size of the breast and thus increase profitability without altering the overall size of the carcass.

The duck industry is relative new and the volume of research specific to Australian conditions is scarce. The inherent physical and physiological difference between broilers and ducks limits the
relevance of extrapolating research data from broiler studies to duck production. For the Australian industry there is an urgent need for relevant information on growth rates, feeding efficiencies, diet composition, welfare and factors limiting processing efficiency.

The main strains of Pekin ducks used in Australia for commercial production are the Cherry Valley (CV) and Grimaud Frères (GF). These strains have been developed overseas to meet local needs and they are not ideally suited to the specific requirements of the Australian market. With these strains not ideally meeting the local market requirements, the project investigated the performance of crosses of these main strains to determine if they might be more suited to market needs.

In Australia, during the six-week production period, a two stage feeding program is currently used. A starter diet is fed from days 1-14 and grower diet from days 15-42, or until slaughter. This may not be the most efficient feeding program. The broiler industry uses a much more complex range of dietary formulations, and there seems good reason to believe that the duck industry could increase efficiency if there was a more detailed understanding of the nutrient requirements of commercial duck strains. Of special interest is protein requirements, and the project investigated the protein needs of ducks at different stages. Most of the energy needs of ducks are met by using wheat as the main grain source in diets. Wheat prices are likely to increase, and eventually there will be strong economic pressure to use alternative grains. The broiler industry has spent a lot of research effort examining the use of sorghum as a replacement grain for wheat in chicken diets. This has not happened in the duck industry and so the project examined the replacement of wheat with sorghum in commercial duck diets.

The efficiency at which poultry absorb nutrients is of great importance. Feed conversion ratio (FCR) is commonly used to describe feed efficiency. The feed conversion ratio in ducks is significantly higher than in chickens (Havenstein et al., 2003). In the Australian broiler industry, 65% of costs are feed related. Key issues to address in relation to performance include growth, feed efficiency and the rate of muscle depositions. The project investigated the effects of genotype, season and sex on FCR in commercial ducks. There will also be evaluation of different procedures for determining efficiency of nutrient utilisation.

Reasons given for rearing ducks as single sexes vary. However, the main one is that the proposed competition results in differences in growth rate between males and females (Farrell, 1999; Normand et al, 1996). Males are more efficient, having an improved FCR between six and seven weeks of age (Normand et al, 1996) and reduced carcass fat (Normand 1997). The project investigated the performance of different genotypes reared as single or mixed sex groups under Australian conditions.

**Aims/objectives**

The ultimate objective, is the efficient production of a uniform product, that is of high quality, safe, and meets or exceeds standards for wellbeing (health, diet, housing and care), and environmental stewardship.

In summary the key objectives were to:

1. Develop growth models to more precisely predict market ages for the desired market weight, and the highest yield of high-value muscle (i.e. breast meat); balanced to meet or exceed consumer expectations with regard to quality, food safety, animal wellbeing and environmental sustainability.

2. Use dietary intervention to provide more uniform market weights, higher yield of breast meat, and reduce feed input costs. Potential to also develop niche markets based on modifying the duck tissue profiles through the use of specific nutrient ingredients.
If the duck industry is to meet its potential there needs to be a research capability established to meet industry challenges, especially those relating to product quality, welfare and production efficiency. The project improved our understanding of the environmental and husbandry requirements for good welfare outcomes of intensively produced ducks. The beneficiaries will in the first instance, be the integrated industry agencies that contract duck production to individual growers. More efficient production will assist contract growers to remain economically viable. Meeting the correct nutrient requirements of ducks will prevent wastage of feed resources, and minimises the nutrient wastage expelled into the environment. An economically sustainable industry will continue to support allied industries and employment. Development of a ‘cut-up’ market and potential expansion into an export market will provide increased export earnings and industry expansion.

Methods used

Five experiments were undertaken as part of the project. All studies were performed using 48 individual floor pens in a tunnel ventilated shed at the University of Sydney’s Poultry Research Unit.

Study one (Chapter 4): The objective of the study was to assess the effects that strain and sex have on the growth rates of Pekin ducks grown under Australian summer conditions. The effect of single sex rearing is also compared to the normal commercial rearing practice of mixed sex rearing.

The treatments consisted of four strains of Pekin duck reared as single sexes (males and females), or as mixed sex groups (equal numbers of males and females). The strains used were the Cherry Valley (CV) and Grimaud Freres (GF), and the reciprocal crosses of these two strains, these being the CV male X GF female and the GF male X CV female. The four strains were produced by appropriate matings, at a commercial breeding farm owned 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 as single sexes (females or males) or mixed sexes (equal numbers of males and females). Ducks were reared under normal commercial conditions. Individual liveweights were recorded weekly. Carcass growth measurements were taken on days six, 13, 20, 27, 34 and 41 from an individual duck selected at random from each pen. On days six, 20 and 34 males were taken from the mixed pens in blocks one and two of the shed and females were taken from the mixed pens in blocks three and four. Liver, proventriculus and gizzard were removed and weighed. The GIT was removed and the length of individual segments, were then measured. On days 20 (week three) and 34 (week five) the carcasses and all body parts used for growth measurements were retained. The carcasses were autoclaved, homogenised and after freeze-drying the crude fat, protein and ash were determined. At day 14, four ducks were randomly selected and removed from each pen of the growth trial. Equal numbers of males and females were taken for the mixed sex pens. The ducks were placed in 48 metabolism cages and fed ad libitum the same commercial grower diet supplied to the ducks in the growth trial, with the addition of an insoluble ash marker, Celite, at a concentration of 10 grams per kilogram of feed. The AME and nitrogen retention were determine using the acid insoluble ash (AIA) procedure.

Data was stored in Microsoft Excel® and unless stated otherwise, statistically analysis was conducted using the REML linear mixed model function of Genstat® 11th edition. Data was first tested for equality of variance using residual plots. When the equality of variance could be improved using a loge transformation, data was transformed. The fixed model included the effects of Sex, Pen-sex, strain and week and the random model included the effects of block, pen and tag. For the proximate carcass analysis and the metabolism study, differences between treatments were determined using ANOVA (SAS: Statview, version 5).

Study two (Chapter 5): The objective of this study was to assess the effects that strain and sex had on the growth rates of Pekin ducks grown under Australian winter conditions. The effect of single sex rearing is also compared to the normal commercial rearing practice of mixed sex rearing.
Again the treatments consisted of four strains of Pekin ducks reared as single sexes (males and females) or mixed sex groups. The strains used, and rearing, were the same as in study one. Exactly the same measurements were made as in study one. Statistical analysis was the same as described for study one.

**Study three (Chapter 6):** The objective of the study was to investigate the performance of commercial ducks strains fed diets with lower protein concentrations than was presently being used in industry, and whether part of the wheat component of the diet could be replaced with sorghum, without compromising performance.

There were 12 different treatments consisting of four strains and three separate diets. The strains were the same as used in studies one and two, all reared as mixed sexes.

Diets were formulated and supplied by Inghams Pty Ltd. The three dietary treatments were:

- **Control Diet:** this was the commercial diet fed as starter on days 1-14 (formulated to contain 21.7% protein and 12.5 MJ/kg ME), and grower diet fed on days 15-41 (formulated to contain 18.1% protein and 12.8 MJ/kg ME). For this treatment the grain component of the starter was, wheat 50% and sorghum 15.5% and for the grower diet was 50% wheat and 24% sorghum.

- **Low protein diet:** this was fed as starter on days 1-14 (formulated to contain 19.1% protein and 12.5 MJ/kg ME) and grower on days 15-41 (formulated to contain 15.7% protein and 12.8 MJ/kg ME). For this treatment the grain component of the starter was wheat 50% and sorghum 20%, and the grower diet was 49.9% wheat and 27.5% sorghum.

- **High Sorghum diet:** this was similar to the control diet fed as starter on days 1-14 (formulated to contain 21.7% protein and 12.5 MJ/kg ME) and grower on days 15-41 (formulated to contain 17.8% protein and 12.8 MJ/kg ME). For this treatment the grain component of the starter was, wheat 31% and sorghum 31% and grower diet was 36% wheat and 36% sorghum.

The performance and carcass measurements were the same as for studies one and two. At day 14 (week two), four ducks were randomly selected and removed from each pen of the growth trial. Equal numbers of males and females were taken. The AME and nitrogen retention were determined using the AIA and total faecal collection procedures. Data were analysed using the mixed model REML procedure in GenStat 10. For the proximate carcass analysis and the metabolism study, differences between treatments were determined using ANOVA.

**Study Four (Chapter 7).** The objectives of this study were to evaluate the performance of commercial Peking ducks fed diets differing in protein and energy, and the form of the wheat grain fed.

There were 12 different treatments consisting of three strains and four diets. The strains used were Grimaud Freres and Cherry Valley, and the reciprocal cross between the Grimaud Freres (male) and Cherry Valley (female), all reared as mix sexes.

The dietary formulations used were:

- **Control Diet:** this was the commercial diet fed as a starter days 1-14 (21.6% protein and 12.3 MJ/kg ME) and grower fed days 15-41 (17.8% protein and 12.5 MJ/kg ME). For this treatment the grain component of the starter was ground wheat 44% and sorghum 20%, and the grower diet was 43.5% ground wheat and 30% sorghum.

- **Low protein diet:** was fed as starter days 1-14 (21.6% protein and 12.3 MJ/kg DE) and grower diet fed on days 15-28 (17.8% protein and 12.5 MJ/kg ME) and a finisher diet fed from days 29-41 (17.0% protein and 12.8 MJ/kg ME). For this treatment, the grain component of the starter diet was
ground wheat 50% and sorghum 20%, and the grower diet was 49.9% ground wheat and 27.5% sorghum. The finisher diet was 48.5% ground wheat and 30.0% sorghum.

High energy diet: fed as starter diet days 1-14 (22.3% protein and 12.8 MJ/kg ME) and grower diet fed days 15-41 (18.6% protein and 13.0 MJ/kg ME). For this treatment the grain component of the starter was, ground wheat 49% and sorghum 20%, and grower diet was 48% ground wheat and 30% sorghum.

Whole wheat diet: fed as starter on days 1-14 (21.6% protein and 12.3 MJ/kg ME) and grower fed on days 15-41 (17.8% protein and 12.6 MJ/kg ME). For this treatment the grain component of the starter was, ground wheat 29.0%, whole wheat 15% and sorghum 20.0%, and grower diet was 28.5% ground wheat, 15% whole wheat and 30% sorghum.

The same measurements were made as described in the previous studies including the metabolism study. The same statistical analysis was also performed.

**Study Five (Chapter 8).** The main objective of this study was to investigate the amount by which the protein content of the finisher diet could be reduced without impacting on growth and performance of ducks. This study also investigated the performance and carcass composition of three different strains of duck during the summer to determine whether a new CV line could better meet market needs.

There were 12 different treatments consisting of three strains and four diets. The strains were one line of Grimaud Freres and two lines of Cherry Valley, with all lines reared as mixed sexes.

The diets were formulated and supplied by Inghams Pty Ltd. A starter crumble was fed to all ducks from day 1 to day 14 and had a protein content of 21.5% and energy density of 12.6 MJ/kg ME. The grower diet was fed as a pellet to all ducks from day 15 to day 28 and had a protein content of 17.5% and energy density of 12.5 MJ/kg ME. Pelleted finisher diets were fed over days 29-41 and had the following specifications: Diet A: Protein 16.8% and 12.5 MJ/kg ME, Diet B: Protein 16.1% and 12.5 MJ/kg ME, Diet C: Protein 15.4% and 12.5 MJ/kg ME, Diet D: Protein 17.5% and 12.5 MJ/kg ME. Diet D was considered to be the control as it contained the same specifications as the grower diet.

Briefly, on days 14, 21, 28, 35 and 41 (week six) all ducks were individually weighed. On days six, 13, 20, 27, 34 and 41 growth measurements were taken from an individual duck selected at random from each pen. Carcass and GIT measurements were made as described for the previous studies. On day 27 (week four) and 41 (week six) the carcasses and all body parts used for growth measurements were retained. At day 14 (week two), two ducks (one male and one female) were randomly selected and removed from each pen of the growth trial. Ducks from two pens of the same strain were grouped (four ducks) and were moved to 24 metabolism cages and fed *ad libitum* the same commercial grower diet supplied to the ducks in the growth trial, with the addition of an insoluble ash marker, Celite, at a concentration of 10 grams per kilogram of feed. In this study analysis was carried out using both the total collection and AIA procedures. The statistical analysis of data was the same as described for the first four studies.

**Results/key findings**

**Study one.** For reasons of ‘commercial in confidence’ the strains have been designated as Strain A, Strain B, and the crosses as A x B and B x A. Predicted liveweight means at 41 days ranged from 2724 g for Strain B X A to 2963 g for Strain B. Strain A X B out performed strain A but not B. Strains A and B X A, at six weeks, did not differ significantly. In summer, these strains would require longer than six weeks to achieve the desired market weight. There were no apparent signs of heterosis for liveweight in either of the crosses. On average males were 200 g heavier than females (range
142g to 272 g for different strains). In practical terms only three of the sex and strain combinations achieved the desired market weight at 41 days.

The proportion of breast muscle was low at an early age and reached its peak at a later age than did the development of the leg and thigh muscle. The most rapid rate of increase occurred from day 27 to day 41. The predicted mean for the proportion of breast muscle at market age ranged from 8.52 to 9.44 % with females having a higher % (9.64) than males (8.50). The low yield of breast muscle at market age is a limitation faced by the Australian meat duck industry. It indicates the bird is still maturing when it reaches market weight, with processing occurring prior to maximum rate of breast muscle deposition.

The FCR increases significantly from week five to six and this is largely the result of the continued increase in feed intake and decrease in liveweight gain at this time. In the present study, the FCR for the entire production period ranged from 1.90 for to 2.00. The FCR was better for strain A and B X A than for strains B and A x B. These differences are most likely related to the higher maintenance energy requirements of strain B and A X B which are significantly heavier and have higher feed intakes. These heavier strains produced more total breast meat and it would seem, to be more appropriate to determine efficiency of production as the feed required to produce a unit of saleable breast meat. This would take into account the higher maintenance requirements of larger animals.

In the Australian meat duck industry, it is common practice to raise ducks in mixed sex pens. In the current study, the liveweight and the proportion of muscle deposition did not differ significantly between ducks reared as single or mixed sexes.

The total composite water to feed ratio was around 3.3:1. The high water to feed ratios observed in ducks highlights the necessity to maintain adequate access to water at all times.

Carcass composition is economically important. The carcass analysis failed to identify any significant differences in the carcass composition between males and females at week five.

The experimentally determined AME values ranged from 13.0 to 13.28 MJ/kg, with this being 0.2-0.5 MJ/kg higher than the diet formulated value of 12.77 MJ/kg. This was a difference of approximately 1.5-4%. Strain and pen-sex rearing had no effect on the calculated AME. The apparent ileal nitrogen digestibility ranged 71.3 to 76.2 % for the different strains and 72.6 to 74.1 % for the different pen-sex groups. The ileal digestibility was lower for strain A than for other strains. The nitrogen retention rate ranged from 50.0 to 51.2 % for the different pen-sex groups and ranged from 46.8 to 52.9 % for the effect of strain, with strain A having a lower nitrogen retention rate than other strains. The low nitrogen retention rate is suggestive that dietary protein content of the grower diet is too high and that protein is being wasted. This finding was the basis of other work detailed in this report.

**Study two.** The results from this study are compared to those seen in study one. These are comparable studies, with study one being in summer, and study two being in winter. Forty one day processing weights were higher in winter than in summer. In both summer and winter the order for the strains having the greatest weight was the same, namely strain B, A X B and B X A then A. Of significance to our main objective, is the observation that neither cross out performed strain B, but the liveweight of these crosses was higher than for strain A. In summer, only strain B, achieved the desired market weight (2.85kg) by day 41 while in winter three strains achieved market weight. The lower growth rate in the summer is a considerable problem for the industry.

As in summer, males (3137 ± 19 g) were heavier than females (2942 ± 18 g). The differential was 195g which was similar to the difference of 202 g seen in summer. While there may be processing advantages with single sex rearing the data generated in the present study clearly supports the conclusion that single sex rearing provides no growth advantage to either sex.
While in general, the pattern of liveweight gain was similar between summer and winter the decrease from maximum gain to end of production was different. In both summer and winter maximum liveweight gain was achieved in weeks three and four. In summer there was significant decrease in gain in week five, and it remained similar in week six. In winter, the decrease in liveweight gain in week five was minimal, but a significant decrease occurred in week six.

The FCR was lower in summer than winter with the difference being 5-8%. Feed intake and liveweight were greater in winter and the difference in FCR could be related to the higher maintenance requirements of larger birds and the increased energy required for thermoregulation. As was expected, water intake was higher in summer but not excessively higher being approximately 2L or 50 ml/day/bird. With the average feed intake higher and water intake lower in winter the water to feed ratio was lower in winter than summer (3.3 Vs 2.7).

Unlike in summer, where no effects of strain on breast weight as a percentage of liveweight were recorded, in winter there were significant effects. The major differences in winter occurred in weeks five and six, where there was a definite pattern to the strain effects. The breast % was highest in strain B then B x A, A x B and finally strain A. A point of importance is that the crosses did not out perform strain B, although there might be some advantages over strain A. The effects of pen-sex on breast % were complicated by the significant sex x pen-sex interaction. Females reared as single sexes had a higher breast % than females reared in mixed sex pens. However, this effect was the reverse in males. Females had a higher breast % than males just as was seen in summer.

The summer and winter differences in liver, proventriculus and gizzard weights expressed as % of liveweight were minimal. The pattern of being high in week one and decreasing each week thereafter was the same in both seasons. As a general observation, strains A and B x A had longer relative small intestine segment lengths than did strains B and B x A, in both winter and summer, but there were some discrepancies. There is a question over how physiologically relevant the measure used (length/100 g) really is. Strains A and B x A were the lightest strains in both summer and winter. So is the difference between the strains just due to the difference in weights? If the differences in relative length are related to metabolic efficiency then the measure is important but there is really no evidence that this is the case. In general females had shorter relative small intestine segment lengths than males, but again, females were lighter than males in both summer and winter. Again, as general comment, pen-sex had no effect on relative small intestine segment lengths.

There were similarities in carcass composition for summer and winter. In both seasons no effects of strain were recorded. In winter, there were pen-sex effects not seen in summer. Carcass protein content was higher for birds reared in mixed sex pens than in single sex pens. Also, in winter females tended to be fatter than males, but this was not detected in summer. This could be related to the higher liveweight of females in winter.

The calculated AME, ileal nitrogen digestibility, and nitrogen retention were similar to the values determined for the summer study. In both seasons strain and pen sex had no effects on AME. Again, the nitrogen retention rates are low, as was seen in the summer study. The low nitrogen retention in both summer and winter suggest that the protein content of the grower diet is too high.

**Study three.** The objective of the study was to investigate the performance of commercial ducks fed diets with lower protein concentrations than was being used by industry, and whether part of the wheat component of the diet could be replaced with sorghum, without compromising performance.

Strain A and B are the strains presently being used in commercial practice. Strain B was persistently heavier throughout all the production period. The crosses were intermediate in terms of the growth rate seen in the parent lines, with strain A x B being superior to B X A. These observations are in line with the results reported in studies one and two.
The pattern of differences in liveweight and feed intake resulted in the composite FCR for the production period being similar for all strains (2.10 to 2.16). The differences in the pattern of water intake were similar to the feed intake with it being higher for strains B and A X B than for strains A and B X A. The differences in feed and water intake resulted in there being no difference in the water to feed ratio (2.8-2.9), when the strains are compared.

Right from week one of the study, ducks on the low protein diet were lighter and at the end of the production period the difference amounted to around 70-80 g compared to the control and high sorghum diets. This amounted to roughly a 2.5% reduction in final liveweight. The difference was much greater in week two (approximately 6%) and week four (approximately 5%). This suggests that there was some degree of compensatory growth with the effect of low dietary protein being most detrimental during the earlier stages of the production period. This is supported by the pattern of weekly liveweight gain. At weeks one to four, ducks on the low protein diet had significantly lower weekly liveweight gain. However, in week five there were no differences in gain and then in week six, the gain for ducks on the low protein diet was significantly greater than for ducks on the control or high sorghum diets. Males were persistently heavier than females for all strains and when fed the different diets. At the end of the production period the average difference between the sexes was 214 g. This difference was similar to that noted in the earlier studies.

The breast weight as % of liveweight ranged from 8.25% for strain A to 8.97 % for strain B. As a general observation the male line seemed to have an influence on the breast % because it was similar between strains A and A x B and between strains B and B x A. The low protein diet resulted in a lower breast to liveweight %. When the differences in final liveweight are taken in to account the average breast weight for the low protein diet was 232 g compared to 274 g for the control diet and 265 g for the high sorghum diet. While the females had a higher breast weight to liveweight % than the males when the differences in final liveweight are taken into account, the average breast weight was similar for females (257 g) and males (254 g).

There were some differences in the ratios of organ and GIT weight to liveweight. The most frequent differences related to diet, with the low protein diet being different to the other diets. The relevance of these differences is difficult to interpret. If they influence performance then it would be expected that the relative % would be smaller for ducks fed the low protein diet. However in most cases, the differences were larger for the ducks on the low protein diet and this could simply be due to the differences in liveweight.

Following the low nitrogen retention rates reported in studies one and two using the AIA procedure it was considered relevant to evaluate both the AIA and total collection procedures for determining AME and nitrogen retention in the current study. There were some differences in the AME and AMEn values determined using the two procedures. AME and AMEn were in general higher using the AIA procedure. There were no effects of diet or strain on AME calculated using the total collection method. When the AIA procedure was used to calculate AME, strain was found to have an effect but not diet. Ileal nitrogen retention for strain effects ranged from 81.8-83.9% and for diet ranged from 80.7-84.1 %. The diet effect was significant with the ileal nitrogen digestibility being lower for the sorghum diet compared to the control diet with low protein diet being intermediate. Using the AIA procedure the nitrogen retention rate ranged from 72.6 to 75.3 % for the different diets and 69.1 to 77.8 % for the different strains. Strain A had a lower retention rate compared to the other strains. Using the total collection procedure the nitrogen retention rate ranged from 80.8 to 82.9 % for the different diets and 81.8 to 82.6 % for the different strains. Neither diet nor strain had a significant effect. The nitrogen retention rate using the total collection procedure is high being similar to values determined for ileal nitrogen digestibility. This is not feasible and suggests that there is a problem with the total collection method for determining nitrogen retention.

There does not appear to be any studies comparing Australian grown sorghum to Australian grown wheat as a grain source in duck diets. In the present study, alteration in the grain component did not
affect duck performance as ducks on the higher sorghum diets performed just as well as those fed the commercial control diets. The calculated AME and AMEn values were similar for all diets. Replacing wheat with sorghum had no effect on energy metabolism. There was a decrease in ileal nitrogen digestion when the sorghum content was increased and a tendency for the nitrogen retention to be slightly lower but these differences had no effect on performance.

**Study Four.** The objectives of this study was to evaluate the performance of commercial Peking ducks fed diets differing in protein, energy and the form in which the wheat was fed.

Strain B had superior day 41 processing weight and this is the same strain as performed best in all earlier studies. Strain C (the cross) was heavier than strain A in all weeks. All strains achieved at least market weight (2.85 kg) at 41 days. The average difference between males and females was 204 g and this was similar to the difference observed in all previous studies. While there were some dietary effects, there was no discernible pattern. A very relevant finding was that on day 41 there was no differences in processing weight between different dietary treatments. Feeding the low protein diet on days 29-41 produced similar results to feeding the higher protein control diet.

The pattern of liveweight gain was influenced by strain with the differences being of the same pattern seen for absolute liveweight. Transfer of ducks from the control grower diet to the low protein finisher diet resulted in a significant decrease in liveweight gain in week five. However, this rebounded in week six and the ducks on the low protein diet recorded a significantly higher liveweight gain in week six. The total liveweight gain in weeks five and six were similar for all diets. The dietary effect on liveweight gain in weeks five and six resulted in higher FCR in week five and lower FCR in week six for ducks fed the low protein diet in the finisher phase. Over the 41 days there was no effect of diet on total FCR. The FCR ranged from 2.06 to 2.08 and this was similar to the values achieved in the earlier winter study (Chapter 2).

Diet had no effect on the breast to liveweight % with it being around 9.5%. Strain A had a lower % than the other strains. The differences in breast % and liveweight resulted in strain A having 45-78 g less total breast meat at day 41. There were no effects of diet on the digestive organ (liver, proventriculus and gizzard) weight to liveweight %. There were no significant effects of strain, sex or diet on carcass composition.

As identified in study three, the values determined for AME and AMEn are slightly higher when using the AIA procedure than the total collection method. This might be associated with the loss of some volatile components (volatile fatty acids) during the oven drying process. There were no diet or strain effects on AME or AMEn, ileal nitrogen digestibility or nitrogen retention using the AIA procedure. Using the total collection method, strain had no effect on AME but the high energy diet had a higher value than the whole wheat diet. When adjusted for zero nitrogen retention the AMEn for the high energy diet was higher than for the control and whole wheat diets. There were no diet or strain effects on ileal nitrogen digestibility for either determination method. There were no diet or strain effects on nitrogen retention using the AIA procedure. Unlike the large differences in nitrogen retention seen for the two procedures in study three, the difference in the present study was only 2-3%.

**Study five.** The main objective of this study was to investigate the amount by which the protein content of the finisher diet can be reduced without impacting on growth and performance. Results from previous chapters suggested that excessive levels of protein are being fed in weeks five and six in commercial production. This project also investigated the performance and carcass composition of three different strains of duck during the summer to determine whether a new CV line could better meet consumer needs. For reasons of ‘commercial in confidence’ the strains have been designated as Strain A, Strain B, and C.
As allocation effects confounded the effect of protein content of the finisher diet on liveweight, it was more appropriate to compare weekly liveweight gain. In week five, weekly gain was significantly greater for ducks on the 16.8 and 17.5% protein diets than those fed on the 16.1% and 15.4% protein diets. In week six, this was reversed and the weekly gain was significantly greater for ducks fed the 16.1% and 15.4% diets. While for the low protein diets there was a decrease in liveweight gain following the feeding of the finisher diets in week five, there appeared to be a degree of compensatory growth in week six. This compensatory growth was also observed following the feeding of the low protein diet in study three (chapter sex). When we combined the liveweight gain for weeks five and six, there were significant differences. The birds fed the 16.1% protein diet had lower combined gain than birds on the other diets and birds fed 15.4% protein had lower total week five plus six gain than those fed 17.5% protein. In terms of 41 day final weight, the only difference was where birds on the 15.4% diet had a lower weight than those on 17.5% protein diet. The data indicate that there is the potential for the introduction of a three phase feeding program in commercial duck production with the finisher diet having a protein content of 16-17%.

In the present study, a new ‘Producer-selected’ strain was compared to the two the Pekin strains used in commercial production. Strain B and C out performed strain A, having higher liveweights at days 41. It is know that the GF strain achieves higher final liveweight than the CV but the results indicate that one CV line is performing as well as the GF strain. It appears that through selection, producers could improve the growth rate of the CV strain. Total FCR over the whole six week period was also significantly improved, as indicated by the significant decrease in FCR from 2.06 ± 0.01 for duck of strain A to 1.99 ± 0.01 for the Strain C.

Although there were differences in breast muscle yield between the three strains, the same pattern was observed, whereby breast muscle development increased rapidly after week four. This late deposition of breast muscle seen in ducks suggests that protein in the diet may be more important at this stage than earlier on in the production period. Yet the present study found that protein content of the diet in weeks five and six had no effect on breast muscle yield. There was also no effect of protein content in the diet on carcass crude protein content in weeks five and six. This suggested that feeding as little as 15.4% crude protein in the diet has no effect on breast muscle yield or carcass protein content.

Not only did strain C have high growth performance it also had improved carcass composition when compared to strain A and B. Of significance is the improvement in breast muscle yield. Breast muscle yield on a liveweight basis was significantly greater for ducks of strain C than the other two strains from day 20 to day 41. At market age, the predicted mean for the proportion of breast muscle for ducks of strain C was 12.03 ± 0.03% which was substantially higher than for ducks of strain A (8.71 ± 0.03%) and strain B (9.36 ± 0.03%). Despite ducks of strain C having greater breast muscle development than ducks of strain B from weeks three to six, the feed intakes were not significantly different. This suggests that ducks of strain C more efficiently convert feed to breast muscle than ducks of strain B. Ducks of strain C yielded a mean of 364 ± 0.9g of breast muscle which was 75.8 ± 0.9g more than ducks of strain B and 119.8 ± 0.8g more than ducks of strain A. Ducks of strain C had a carcass crude fat of 15.1 ± 0.4% which was significantly lower than the mean carcass crude fat level for ducks of strain B (17.1 ± 0.5%).

The present study found a relationship between poorer performing animals and longer intestinal lengths to bodyweight proportions which concurred with earlier observations. For both the length of the DL and combined caeca, ducks strain A had the longest, followed by ducks of strain B strain and then ducks strain C. This might suggest that ducks with shorter gut lengths as a proportion of liveweight may be more efficient in assimilating nutrients from the ingested food.

Strain had no effect on the excreta derived or, the marker derived AME and marker derived AMEn. However, the strain effect on excreta derived AMEn just reached significance. Strain C had an AMEn higher than strain B with strain A being intermediate.
The % ileal nitrogen (protein) digestibility using the marker procedure was not different for the three strains. Strain had no effect on the % nitrogen retention using either using total excreta collection method or the insoluble ash marker procedure. However, as seen in study three, there were large differences in the calculated nitrogen retention rates using the two procedures. Again it was much higher using the total collection method. The values calculated using this method are similar to the ileal nitrogen digestibility values and as mentioned in chapter six this can’t be correct. This difference was not noted in the winter trial described in chapter seven.

**Implications for relevant stakeholders:**

There is limited research on duck production under Australian conditions. With the industry expanding at 10-12% annually there is an urgent need for relevant research to support this growth. The research undertaken and forming the basis of this report was aimed at investigating aspects of production related to performance of existing genotypes and nutritional strategies to improve growth, efficiency and meat yield. The duck industry is small and the main beneficiaries of the research will be the integrated companies and growers involved in duck production.

The research will support the duck industries continued high annual growth, and with this expansion, employment in this rural sector should grow. The industry has yet to extend into the ‘cut-up’ and export markets. These opportunities won’t be realised unless further research is undertaken to support this expansion. The change to develop an export market is clear to the duck industry, and when this happens, benefits support the Australian economy.

**Recommendations**

The duck industry is constrained because it relies on overseas genotypes developed for markets which don’t have the same requirements as those in Australia. The industry has worked hard at managing these overseas strains to better meet their market needs, but they are still faced with significant limitations. Crossing the existing strains will not produce a line that provides any advantage to the industry. There will be a continued need for the industry to identify a strain which meets its specific needs. This might be done through selection from within the current strains, or identifying new genetics from overseas. There is sufficient variation in the CV strain for selection to improve growth rate and especially breast yield. Whether such selected lines perform in commercial practice would need to be determined. Rearing ducks as separated sexes has no benefits in terms of performance. There could be advantages at the processing end, and through being able to provide sex-specific diets, but these benefits would need to be evaluated against the cost of vent sexing and maintaining different flocks of males and females.

Growth rate of ducks is lower in summer. With the type of housing presently being used this will continue to be an industry problem. There is a need to identify nutritional or physiological strategies which help to limit the growth retardation occurring in summer. Having to grow birds for an extra 4-6 days in summer just to reach market weight is costing the industry substantially in added feed costs.

Water intake of ducks is higher than broilers. Limiting water intake will decrease feed efficiency and so it is important for producers to maintain adequate water intake. Maintaining litter quality is much more difficult with ducks than broilers. There is a tendency for producers to limit water intake in an effort to maintain litter quality. This is false economy, and producers should have monitors on the water lines to measure water use, and ensure supply is adequate.

The industry currently uses a two phase feeding program. The research detailed in this report indicates that a three phase feeding program might be more suited to the nutritional requirements of commercial Pekin ducks. The research has identified that the protein content of the grower diet (19%) is too high, and that substantial savings could be made by reducing this, even if a two phase feeding program continues to be used. The energy needs of ducks under Australian conditions have not been
investigated extensively. The present research has indicated that increasing the energy content of the existing diets has no effect on performance. This has at least identified that the industry recommendations for energy content of the starter and grower diets are adequate, although it hasn’t investigated whether these are the optimal. The metabolism studies have given support to the formulated AME values of the diets being correct in terms of energy availability to the birds.

The duck industry, as the broiler industry has previously recognised, will need to find new sources of grain, and move away from their reliance on wheat. Wheat availability will decrease as human requirements increase. Sorghum is an alternative that the broiler industry is researching extensively. Currently, wheat and sorghum are used in formulation of duck diets at a ratio of 2:1. Increasing the ratio to 1:1 had no negative effects on duck performance. So it is possible to use more sorghum in duck diets. The industry has reservations about this because of effects on pellet stability. Ducks feed in a manner different to broilers. Correct pellet size and low levels of fines is important for good performance. For the industry to use more sorghum in diet formulations, pellet quality would need to be maintained. It is important that the industry consider what alternative grains are suitable, because this is an issue it will have to face and deal with soon. Use of whole wheat has become common practice in the broiler industry. The energy costs for processing is a substantial cost in feed preparation. These energy costs can be reduced by using whole grain. In the current work, adding 15% whole wheat grain to the diet had no advantages or disadvantages in terms of performance. The data do suggest that adding more than 15% might have a detrimental effect on protein digestibility and AME.
1. Introduction

1.1 The Australian duck industry

With the continued growth of the human population and the associated demand for high quality animal protein, there remains a need for increased animal production efficiency (Adeola 2006). Ducks account for 5% of world poultry production with around 87% of this being produced in regions of Asian (Michael, 2004). China remains the main producer of duck meat (Evans, 2004).

Domestic poultry consumption was estimated to be 37.4 kg per person for 2008 (ABARE, 2009). Around 95% of Australia’s total poultry production is consumed domestically (ABARE, 2009) with duck meat consumption being 0.5 kg per person per annum. While this is small, the industry is expanding at 10-12% annually (PEPE's, personal communication). The industry slaughters eight million birds annually and is worth an estimated $100 million (Brown, 2010). Eighty-five percent of these birds are produced by two largely, vertically integrated companies (Michael, 2001). These being the NSW based PEPE’S Ducks Pty. Ltd. and Luv-a-Duck, located in Victoria.

In the Australian market, the consumer expectation is for a bird grown to a liveweight of 2.85 kg at processing and having a high breast muscle yield (Brown, 2010). Further, consumers also require a uniform product and for a health conscious population, the correct amount of carcass fat. The majority of the demand for duck meat in Australia comes from the Asian restaurant trade or during special occasions such as Easter, Christmas and Chinese New Year.

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 the developing South East Asian countries including China, Thailand, Vietnam and Bangladesh (Micheal, 2001). Australia’s low production costs and use of superior genetics would make it competitive in these high demand areas. Australia is also free of the main exotic diseases, such as avian influenza (Iwami et al., 2007). The low risk of disease in Australia provides considerable marketing advantage over product produced by many of the Asian countries. Australia’s close proximity to the Asian region also provides a geographic advantage over other duck producing nations including France and the United Kingdom.

Conventional broiler sheds are the prominent type of housing being used for growing ducks in Australia (see Figure 1.1. and 1.2.). As it develops the duck meat industry has started to address issues of animal wellbeing, industry sustainability and food safety. Due to the high demand of breast meat, an important research objective is to increase the proportional size of the breast and thus increase profitability without altering the overall size of the carcass. Ducks are naturally fat animals (Scott & Dean 1991). Excessive fat content is not desirable and a further industry objective has been to produce a leaner carcass.

1.2 Breeds used in commercial duck production

The Pekin duck is the most common breed used for commercial duck meat production. There are others including the Muscovy, Aylesbury, Rouen, Duclair and Elizabeth. Crosses such as the Muscovy X Pekin and Aylesbury X Pekin are also common. The Pekin is fast growing with current genetic strains reaching a market live weight of 3.4 kg at seven weeks of age. Commercial egg laying strains such as the Khaki Campbell achieve an adult weight about 40% that of the Pekin (Scott & Dean, 1991). In addition to its high growth rate the Pekin breed is highly fecund and fertile capable of producing 230 eggs over a 40 to 42 week production period with a hatchability of around 80-85% (Brown, 2010). The Pekin breed has low mortality and this is attributed to the high level of disease resistance (Nowland, 2004). Some common health problems are leg weakness, foot problems,
cholera, and internal and external parasites (Nowland, 2004). Ducks are routinely vaccinate against, Duck Viral Hepatitis (DVH), Duck Viral Enteritis (DVE) and Cholera (Cherry Valley Farms, 2006).

Figure 1.1. Conventional housing type used for production of ducks in Australia – Brooding phase.

1.2.1 Commercial strains of Pekin ducks

The main strains of Pekin ducks used in Australia for commercial production are the Cherry Valley (CV) and Grimaud Frères (GF). The Cherry Valley Breeding Company was established in the UK in 1960. An intensive breeding program identifying growth rate, breast muscle yield (with low fat deposition) and optimal feed efficiency as key criteria have produced this Pekin. Important reproductive traits (egg numbers, fertility and embryo viability), liveability and processing attributes are also given consideration in the breeding programs. The CV strain can attain a market weight of 3.3 kg at 47 days of age with a FCR of 2.35 and breast meat yield of 20% processed weight (Cherry Valley Farms, 2006). The Grimaud Frères breeding company (France) have a Pekin strain which can achieve a body weight of 3.5kg with a FCR of 2.4 at 49 days of age (Grimaud Frères, 1998). Unselected lines of ducks achieve live weights of 1.2 kg with a FCR of 4.63 at 63 days of age (Park et al. 1988).
1.3 Relevance of current research knowledge

The duck industry is relative new and the volume of research specific to Australian conditions is scarce. Even in countries, such as France and the UK where the industry has been well established the volume of research available is nominal in comparison to the broiler chicken (Baeza et al., 2000). Of the research available from Europe, much is of limited relevance to Australian conditions because of the difference in climatic conditions and type of housing used. The inherent physical and physiological differences between broilers and ducks, limits the relevance of extrapolating research data from broiler studies to duck production. For the Australian industry there is an urgent need for relevant information on growth rates, feeding efficiencies, diet composition, welfare and factors limiting processing efficiency.

Ducks are documented to have similar nutrient requirements to chickens (Elkin 1987). Considering there are differences in growth rates, carcass composition, digestive anatomy and rate of passage of feed through the gut between the two species, it should be expected that their nutritional requirements would differ (Siregar & Farrell 1980). While there is documented evidence from overseas on the nutritional requirements of ducks (Oluyemi & Fetuga, 1978; NRC, 1994; Xu et al., 2002; Adeloda 2006); the information is often contradictory and scarce for Australian conditions. The question remains as to how relevant overseas observations are to Australian conditions?
1.4 Gastrointestinal development and function

Development of the intestinal tract is a major factor limiting the early growth of birds (Konarzewski et al., 1989). The intestinal tract needs to maintain an appropriate uptake of nutrients to meet the increased demand during growth (King et al., 2000). It has been suggested that the physical development (size and surface area of the intestinal tract) rather than the physiological development that most limits early body growth (Sell et al., 1991). In Pekin ducks, the morphological and functional growth of the intestinal tract is completed by seven weeks of age (Watkins et al., 2004). Research has demonstrated that the development of the intestines is directly related to age mediated increases in metabolic rates (Lilija, 1983; King et al., 2000).

The duck, although similar anatomically to other avian species, has some differences. A main difference is the absence of distinct crop, replaced by a widening of the oesophagus (Elkin 1987). It’s thought that the pseudo-crop is responsible for the faster rate of passage of food found in ducks when compared to chickens of similar ages (Adeola et al., 1997). The oesophagus terminates at the proventriculus or glandular stomach (Adeola, 2006; McDonald et al., 2002). The gizzard is located at the posterior end of the proventriculus (McDonald, 2002). It has similar function as in broilers, grinding feed into a smooth paste (Adeola, 2006). Flow of digesta to the small intestine occurs once the particles are small enough. The duodenum is the proximal portion of the small intestine (McDonald, 2002). It forms a loop around the pancreas and receives secretions via hepatic and pancreatic ducts. These secretions are responsive for hydrolysing starch, proteins, and fat into smaller units for transport and absorption (Adeola, 2006). The jejunum is the next portion of the small intestine which extends from the duodenum to the Meckels Diverticulum (DM: remnant of the yolk sack). This is the principal site for absorption of the end products of digestion (Adeola, 2006). The ileum is the last segment of the small intestine which extends from the Meckel’s Diverticulum to the ileo-ceco-colonic junction. It functions as both an absorptive site as well as supporting some microbial digestion for enzyme-resistant feeds (Adeola, 2006). Posterior to the ileum is the relatively short colon and two long caeca which act to absorb remaining nutrients in the digesta before being expelled from the gastrointestinal tract (GIT). Important nutrients absorbed here are electrolytes, volatile fatty acids (mostly from microbial fermentation) and water (Adeola, 2006). The rectum is short and indistinguishable from the colon in the duck and terminates at the cloaca. The cloaca is a three compartment organ (coprodeum, ureodeum and proctodeum) that combines the function of both the rectum and bladder by storing both urine and faeces prior to excretion (Adeola, 2006; McDonald, et al., 2002).

The ability of the intestines to absorb nutrients is mainly dependent on the mucosal surface area, the permeability of the epithelium and the properties of nutrient transporters in the brush border and basolateral membranes (Ferrer et al., 2003).

Jamroz et al. (2001) recorded the absolute values and relative measures based on metabolic live weight of different sections of the gastrointestinal tract of ducks. The study found that in relation to metabolic live weights (calculated as kg^{0.67}), the total length of the tract was significantly higher in chickens and geese than in ducks at day 21, but all three species had similar lengths at day 42. Intestine weight was less for ducks compared to both chickens and geese at both day 21 and 42 (Jamroz et al. 2001). This does not correlate well with the phenomenal growth rate expressed by the duck up to 42 days of age.

Applegate and colleagues (2005) provided evidence that anatomical development of the small intestines is more rapid in ducklings than in the turkey poult. This difference in development was reflected by the weight and length of small intestines, but also by the villus height measurements of the ileum and jejunum which was 2.5 times higher and had crypts 5 times deeper in the ducklings than turkey poults. By day seven of age, the jejunum/ileum of Pekin ducklings is 2.7 times heavier, 1.6 times longer and 2.3 times more dense, than that of the turkey poult.
Although selection in chickens has increased the mass specific development of the intestinal tract (Jackson & Duke, 1995), this does not appear to be the case in ducks. Watkins et al. (2004) found that as a percentage of liveweight the intestinal tract of the Pekin duck decreased from 14% at two days of age to 4% at maturity, while its wild ancestor, the Mallard, showed a similar decrease from 15% at two days of age to 5% at maturity. Watkins et al. (2004) confirmed that selection had a positive effect on overall body weight gain and absolute intestinal mass. However, when intestinal mass was evaluated as a proportion of body mass from 3 to 5 weeks of age, it was found that the values were 45% to 66% higher in Mallards than Pekin ducks. Therefore, the authors concluded that the higher growth rates evident in the Pekin duck were likely to be attributed to a significantly higher relative intestinal surface area and enzyme activities rather than intestinal mass. The authors also suggested that the low intestinal mass of the domesticated duck may be a result of the mucosa wall being thinner to facilitate improved nutrient transport or because the processed nature of the commercial diet required less development of the smooth muscles in the intestinal lining. If intestinal development was measured in terms of length instead of mass the effects of these factors would be excluded. Although the majority of organs in the domesticated duck have shown a proportionate decline in size and weight when compared to those of its ancestor, the Mallard, the liver has actually increased in relative mass by 40% (Watkins et al., 2004). This reflects the importance of its role in feed metabolism. 

(King et al., 2000) demonstrated that the efficiency of the intestinal mucosa to transport free amino acids into enterocytes from the intestinal lumen directly affected protein utilisation by the animal. Intestinal efficiency is maximised through the development of intestinal villi for increased surface area. Watkins et al. (2004), found that for Pekin ducks, that while the height of the villi increased in the first 21 days of growth, their density decreased over this same period.

The difference in feed efficiencies between broilers and layers could be due to the larger mass-specific area of the intestinal tract in broilers (Mahagna et al. 1996). In Pekin ducks the mass of the intestinal tract increases with age (King et al., 2000). However, when the intestinal surface area is represented as a proportion of the body weight, it undergoes substantial decline with age. King et al. (2000) found that the ratio of intestinal surface area (cm²) to body weight (g) decreased from 1:2 at one week of age to 1:7 at seven weeks of age. Improving the development of the ducks’ gut could lead to increases in growth and improve feed efficiency. However, existing knowledge on the development of the duck gastrointestinal tract and its relationship with nutrient utilisation is very limited.

1.5 Nutritional requirements of meat ducks

Research on the nutritional requirements in ducks is limited and the majority of information used by the Australian industry has been sourced from overseas. Because there is relatively limited information on energy utilization of feed ingredients by ducks, diet formulations often employ metabolisable energy (ME) values determined in broiler chickens. As energy utilization studies have shown that there are significant differences in energy requirements of ducks and chickens, the ME values for efficient growth of ducks need to be better defined (Elkin, 1987; Adeola, 2003, 2006; Niu, et. al., 2008). Since genetics and environmental conditions are known to influence nutrient requirements it is likely that some of the information used from overseas is not fully applicable to commercial conditions in Australia. A better understanding of the nutritional requirements of ducks under Australian conditions is needed in order for the duck industry to reach its potential. In particular, recommendations for energy and protein are crucial as they economically, have the most influence on profitability (Xu et al., 2002).

In Australia, during the six-week production period, a two stage feeding program is currently used. A starter diet is fed from days 1-14 and grower diet from days 15-42 or until slaughter. Data from the published literature are given in Table 1.1, and provides an overview of the range in energy and protein contents of starter and grower diets fed to ducks. Differences in recommendations can vary according to species, genotype, environment and husbandry (Adeola, 2006).
Table 1.1. Metabolisable energy (MJ/kg) and crude protein (%) concentrations used in duck starter and grower diets.

1.5.1 Energy Requirements

The energy component of the diet is a major cost and so there is an economic prerequisite to provide the optimal energy concentration in duck diets (Adeola, 2006). Determining energy requirements is complex because rather than being a single chemical entity, it is a physical measure related to a wide range of compounds in the feed including carbohydrate, fat and protein (Hunton, 1995).

Ducks will consume an amount of energy needed for maintenance, physical activity and growth if provided with the opportunity. Ducks are capable of adjusting their feed intake to meet their energy requirements (Siregar et al. 1982b; Wiseman, 1987; Scott & Dean 1991; Hunton, 1995; Adeola, 2006; Richards, 2007; Cherry and Morris 2008). While this means a range of dietary energy levels in the diet can support rapid growth it does not negate the need for research aimed at identifying the optimal level of energy for ducks. This knowledge is crucial for improving FCR and increasing the precision of feed formulation and preventing excess energy being stored as undesirable fat.

Scott and Dean (1991) reported on the relationship existing between dietary energy and the feed conversion ratio (FCR) in ducks. As the ME energy content of the diet increases, FCR is improved.
The same relationship is found in broilers (Dozier et. al., 2006, 2007; Ghaffari et al., 2007). Siregar et al. (1982b) reported that increasing the energy density of duck diet decreased feed consumption and improved s FCR. The mechanism by which this occurs is unknown but regulation of feed intake is by the central nervous system and peripheral tissue mechanisms in poultry (Hunton, 1995: Richards et. al., 2007). If improvement in FCR is largely due to a decrease in feed intake, and with FCR being a measure of efficiency, there are good reasons to have FCR calculated on an energy intake basis rather than the total feed intake. This is probably a better measure of efficiency.

During their first seven days, Pekin ducks were found not to consume more than 350g feed and providing a starter diet containing more than 12.6 MJ/kg ME, had no effect on growth rate (Adeola 2006). Feeding ducks to 42 days of age, with increasing dietary energy from 10.0 to 12.5 MJ/kg ME, caused a decrease in cumulative feed intake of 230g and an increase in bodyweight gain of 70g for each MJ increase in ME (Cherry and Morris, 2008). When dietary energy was increased from 10 to 12.5 MJ/kg ME, the FCR improved by around 0.3 units. Variations in dietary protein content were found to have no consistent effect on feed intake in these studies. The same workers reported that when the dietary energy increased from 12.6 MJ/kg or 14.0 MJ/kg ME, while crude protein (CP) was maintained at 16%, feed intake decreased by around 10% over days 35-48 of age. However, the birds on both diets were found to have achieved similar total energy intakes.

Fan and colleagues (2008) reported on what effects changing the dietary energy had on performance and carcass composition of Pekin ducks. Diets differing in energy concentration, ranging from 10.9-13.0 MJ/kg AME, and having the same protein concentration of 18% were fed to ducks during weeks three to six (grower phase). Weight gain increased significantly and this was accompanied with significant decrease in feed intake and FCR when the energy concentration of the diet increased from 10.9 to 13.0 MJ/kg AME. Using regression analysis, the authors predicted that the optimal energy concentration for the grower diet to achieve maximum performance was 12.6-12.7 MJ/kg AME when the protein content was 18%. Adeola (2006) reported no improvement in gain or feed efficiency when diets containing more than 12.6 MJ/kg ME were fed to commercial strain of Pekin ducks.

Fats became commonly used as an ingredient in poultry feed in the late 1940s (Wiseman, 1984). Other than supplying essential fatty acids, the first advantage of using fats in poultry diets is the additional caloric value they provide (Patrick & Schaible, 1980, Wiseman, 1984). This is especially advantageous as some fats are cheap and readily available. Secondly, after the addition of certain fats to diets, growth and feed conversion ratio were improved in chickens and ducks (Patrick & Schaible, 1980, Wiseman, 1984, Storey and Maurer, 1986). These improvements were attributed to an increased utilization of dietary energy as a result of oil supplementation.

According to Wiseman (1984), poultry diets need to include at least 0.9% linoleic acid. The National Research Council (NRC, 1994) recommends 1%. This provides sufficient n-6 fatty acids for synthesis of longer chain fatty acids such as arachidonic acid, which is essential for the synthesis of phospholipids (Klasing, 1998). A deficiency of essential fatty acids results in retarded growth, fatty livers, dermal, and reproductive problems. Scott and Dean (1991) and Patrick and Schaible (1980) recommend 3.29% and 3.4% fat respectively, while the industry limits fat to 5%. Pellet life is severely reduced with the addition of fats over 3%. This is especially true when the less stable unsaturated fats are used. However, this may be overcome by spraying feed evenly, post-pelleting, with fats, just prior to consumption (Scott & Dean 1991).
1.5.1.1. Factors affecting energy metabolism

The utilisation of nutrients in feed ingredients, such as amino acids and energy, may vary according to the age, genotype and gender of the duck (Mohamed et al., 1984; Zhang et al., 2007). Ducks perform better than chickens when fed low energy diets (Dean, 1991). Strains of ducks selected for growth rate and FCR have reduced cumulative feed intake to attain the same bodyweight as unselected lines (Cherry and Morris 2008). In comparing two lines of Pekin ducks, one selected for growth rate and FCR and the other for breeding performance, the time to slaughter weight was 9 days less for the line selected for growth performance and the total cumulative feed consumed was 30% less (Cherry & Morris, 2008).

As ducks age the ability to metabolise dietary energy decreases (Siregar and Farrell, 1980). These authors used respiration chambers to determine energy utilisation at 5-8, 12-15 and 19-22 days. When a high energy diet was fed (14.85 MJ/kg ME), energy utilisation efficiency during these days were 0.79, 0.79 and 0.75, respectively. When the dietary energy content was 11.9 MJ/kg ME the energy utilisation efficiency was .074, 0.71 and 0.70 over the same corresponding days.

Cherry and Morris (2005) reported the maintenance requirements of Pekin drakes to be 523kJ/kg metabolic bodyweight (W<sup>0.75</sup>) at 26°C and that at 10°C this increased to 583 kJ/kg W<sup>0.75</sup>. As ambient temperature increases it is more difficult for ducks to dissipate heat and in an effort to maintain homeostasis ducks reduce feed intake as a strategy to decrease the metabolic heat load. In an effort to maintain performance under high temperatures and in the face of a decrease in feed intake, diets with higher energy content can be fed. When ducks were maintained at temperatures ranging from 26-30°C and fed diets containing either 12.4 MJ/kg or 13.2 MJ/kg ME and 18% protein, they were found to have similar daily energy intakes but the feed intake was lower for birds fed the 13.2 MJ/kg ME diet (Cherry & Morris, 2008). If the ME content of the diet is too low, the ducks’ intake will not compensate for the effect of the high temperature. This was observed by Cherry and Morris (2008) when they offered ducks a diet with an energy content of 10 MJ/kg ME and found that the birds were not able to match the cumulative energy intake of birds fed a diet containing 12.5 MJ/kg ME under conditions of high temperature.

Scott and Dean (1991) reported that diets supplying less than 10.9 MJ/kg ME depressed growth rate. However, these diets were not pelleted and the authors felt that this helped to limit feed intake, as pelleted diets improve duck performance (Patrick & Schaible, 1980; Farrell, 1999).

The type of dietary ingredients included in a mixed diet will influence energy metabolism. Overseas studies have calculated ME values for a variety of feed ingredients for ducks (McNab & Blair, 1988; King et al., 1997; Adeola, 2005). Unfortunately the availability and costs of feed ingredients usually means that information gathered from most studies are not as relevant to diet formulation under Australian conditions.

Crude fibre is not digested by poultry (Scott et.al., 1959; Dean and Scott, 1969; Siregar et al., 1982a). Normally poultry diets contain 50-70g crude fibre. Siregar and colleagues (1982a) fed isoenergetic and isonitrogenous diets containing 40, 80 or 120 g/kg acid-detergent fibre (ADF) to ducks and found weight gain was similar, but feed intake and ME intakes were higher and FCR poorer on the diets with the highest fibre content. Dietary AME and nitrogen retention was found to be lower as the ADF content increased. Efficiency of energy utilisation declined as the ADF content of the diets increased.
1.5.2 Protein Requirements

Rather than there being a requirement for crude protein per se, ducks require a quantity of essential amino acids and sufficient substrate for synthesis of the non-essential amino acids (Hunton, 1995; Adeola, 2006). The range of recommendations identified in Table 1.1, indicate that 18-23% protein is needed in the starter diet, normally fed days 1-14 and 15-18% protein is needed in the grower diet. With this degree of variation it is difficult to determine the ideal protein concentration needed for the most efficient growth of ducks. Scott and Dean (1991) suggested that the inconsistencies in the reported data may be a result of using different strains and rearing under different environmental conditions. These authors recommend that the producer should formulate the dietary protein content to the ducks needs, taking into consideration factors such as market age, climate, and strain. Having insufficient dietary protein will limited protein accretion while excess protein in the diet will be metabolised and used as a source of energy (Siregar, et al. 1982a). In Australia, under commercial conditions, ducks receive a starter diet containing around 22% protein and a grower diet containing 19%.

While there are a small number of reports identifying duck protein requirements under Australian conditions, these were done some time ago and may not be relevant to the genotypes presently being used in commercial production. Early work by Bagot and Karunajeeva (1978) recommended diets for a particular strain of Pekin duck should contain 25% protein when the energy content was 12.17 MJ/kg ME. However, this strain is no longer used in commercial production due to the inferior performance. Research examining the effects of dietary crude protein under Australian environmental conditions, were conducted by Siregar et al. (1982a). These authors suggested that for maximum growth rates, ducks needed a crude protein content of 18.7% in the starter diet and 16% in the finisher diet. Again these recommendations may not be relevant for the modern strains of Pekin duck.

Scott and Dean (1991) stated that a starter diet should contain 21.5% crude protein, while earlier publications by Leclercq et al (1987) and Patrick and Schaible (1980) recommended 19% when the diet energy content was 12.55 MJ.kg ME, and 18% with the same dietary energy content, respectively. Adeola (2006) suggested that ducks fed lower protein than required, early in life would compensate later in life. The practical problem faced when feeding low protein diets early in growth, is whether the ducks will have sufficient time for full compensatory growth before processing at six weeks of age.

Cherry and Morris (2008) summarised the results from a number of trails where ducks were fed different diets from day 15 to 42-48 days of age. They identified that liveweight increased in a curvilinear manner when protein content of the diet increased from 14 to 24%. The FCR decreased by approximately 1.3% for each 1% increase in protein. Feeding a low protein diet of 15.7% with 12.9 MJ/kg ME from 1 to 42 days of age decreased total feed intake and reduced growth rate to 28 days of age (Cherry & Morris 2008). In the same study, when the protein content of the starter diet (days 1-14) was increased to 21%, the rate of gain was significantly higher up to 35 days of age. It is obvious that the young birds have a high protein requirement. Compared to ducks fed 21% protein from day old to 17 days age, those fed 16% protein diets for the first 6, 8 or 10 days of age and then 21% protein until day 17 and the same grower diet, took an extra 1, 2 and 4.5 days to reach market weight, respectively (Cherry & Morris 2008).

Protein quality is measured by the availability of amino acids (AA). The diet needs to provide sufficient of the essential amino acids. As we use the same ingredients in duck and broiler diets it understandable that the same amino acids are likely to be limiting. Kluth and Rodehutscord (2006) showed that amino acid digestibilities were lower in ducks than in turkeys and broiler chickens and thus digestibility values determined with broilers should not be used in formulating diets for ducks. With the ingredients available to formulate duck diets, lysine methionine, threonine and tryptophan are likely to be the most limiting amino acids. Cysteine needs to be adequate to spare methionine. The advent of free amino acid sources at viable costs has enabled a reduction in the content of dietary
crude protein in poultry diets whilst maintaining well-balanced amino acid composition (Aftab et al., 2006).

Amino acid digestibilities estimated in poultry are influenced by the microbial degradation and utilization in the hindgut (Parsons, 1985). In studies where cecectomized and intact ducks were compared, the effects on the true digestibility of energy or AA acids from different ingredients sources was not consistent (Ragland et al., 1999). The authors concluded that the effect of cecectomy on nutrient digestibility depends on the feed ingredient being assayed.

Adeola (2007) identified methionine as the first limiting amino acid with diets based on corn. Studies at Purdue University identified the methionine and lysine requirements of ducks to be 0.6% and 1.2% at 1 week of age, 0.55% and 1.0% at 2 weeks of age, 0.3% and 10.8% at 6 weeks of age (Adeola, 2006). Increasing the digestible methionine content of the diet from 2.4 to 3.9 g/kg improved bodyweight gain, and food efficiency when fed during 22-42 days of age. Jamroz et al., (2006) fed Pekin ducks diets supplemented with different methionine concentrations ranging from 0.3 to 0.48%. The liveweight of six and 21 day old ducks was improved when the methionine concentration was 0.42-0.48%.

Increasing dietary lysine, arginine and tryptophan has had similar effects in other studies undertaken overseas (Chen and Shen, 1979; Oluyemi and Fetuga, 1978; Wu et al., 1984). Under Australian conditions and the grain sources used, lysine will be the most limiting amino acid. There is very limited research data on the lysine requirements of ducks. The lysine requirements for maximum growth and that for breast yield are different (Xie, et al., 2009). These workers fed a lysine deficient diet to Pekin ducks from seven to 21 days of age and supplemented this with additional lysine. Using regression analysis they determined that the lysine requirement for maximum weight gain was 0.84%, best feed to gain was 0.9% and that for maximum breast yield was 0.98%. The authors highlight that these are higher than the NRC recommendations (NRC, 1994). The higher requirement for breast yield in grower ducks is also supported by Bons et al., (2002).

From day old to 8 weeks of age, Muscovy ducks were fed the same control diet (12.53-12.76 MJ/kg ME and 18.5% CP (Baeza & Leclercq, 1998). In weeks nine to 12, in a series of 3 studies, control birds were fed diets with protein concentrations of 15-16% and their performance compared with ducks fed diets with lower protein concentrations (10.2 to 14.3%) but supplemented with a combination of lysine, methionine, threonine and tryptophan (+ 4 amino acids) or with two combinations of 3 amino acids, these being lysine, methionine and threonine (no tryptophan) or lysine, methionine and tryptophan (no threonine). When the control diet had 15% CP the treatment diet with the 4 amino acids needed to have a CP content of 12.4% for performance to be equivalent to control birds. In the second study, when birds were fed diets with 10.5% CP and supplemented with the 4 amino acids the performance was equivalent to birds on the control diet containing 15.3 % CP. When the control diet had 16% CP performance was similar to diets having 14.2%. 12.4% or 10.5% CP and supplemented with the amino acids. However, breast yield was lower when the diet contained as little as 10.5% CP. It appears from this that the requirements for maximum growth and breast yield are different. In the control diet having 16% CP, the performance of birds on diets with 12.4% CP were similar irrespective of whether threonine or tryptophan were left out of the amino acids mixture used to supplement the low protein diet. However, when threonine was removed breast yield was lower.

Valine requirements of ducks were studied by Timmler and Rodehutsescord (2003). These workers added valine at levels ranging from 6.8-12.7 g/kg to a basal diet and fed it to Pekin ducks from days one to 21 of age. A digestibility study was undertaken using the total faecal collection method for 5 days starting at day 11 of age. To achieve 95% maximum protein accretion and growth birds needed to be fed 7.9-8.0 g/kg valine in the diet. This was similar to the 7.8 g/kg identified as being required by Yu and Shen, (1984). The valine content of 6.8g/kg in the basal diet was insufficient to meet needs of the ducks as they had to be withdrawn from the study as they couldn’t physically stand. If dietary protein was the only source of valine for the ducks it was estimated that the valine requirement should
be 8.24 g/kg (Timmler & Rodehutscord, 2003). Farran and Thomas (1992) also reported that ducks have leg problems when the diet concentration of valine was not adequate.

Digestibility for most of the indispensable AA found in common feedstuffs is above 80% for ducks (Adeola, 2006). When formulating diets, the true digestibilites for many amino acids are additive (Hong et al., 2001, 2002) but there are exceptions with arginine, histidine, lysine, tryptophan and aspartate found not to be additive when digestibilites were determined for canola, soybean and corn (Adeola, 2006).

1.5.3. Protein to Energy Ratio (P/E)

Protein and energy are linked in many respects because excess protein can be used as energy. Nitrogen retained in the body can be catabolized to energy-yielding excretory products that end up in the urine as non-protein nitrogen. Siregar et al. (1982b) demonstrated this when they observed that increasing the amount of protein in the diet subsequently increased the metabolisable energy. As dietary protein and metabolisable energy are linked, they cannot be considered in isolation when formulating diets. Ducks have a propensity to lay down carcass fat, and this needs to be considered when formulating the energy content of the diet (Adeola, 2006).

There is a need to provide the correct P/E to avoid excessive carcass fat deposition (Cherry & Morris, 2008). Fan and colleagues (2008) fed Pekin ducks diets differing in energy concentration ranging from 10.9-13.0 MJ/kg AME while maintaining protein concentration at 18%. This would have provided diets with P/E ranging from 16.5 to 13.8. As the ratio decreased, feed intake decreased and FCR improved. However, no effects on breast or leg muscle yield were observed but abdominal fat increased when the ratio was less than 15.9.

Zhou et al (2001) fed diets to meat-type ducks with 11.7, 12.6 and 13.4 MJ/kg ME energy and crude protein of 14, 16 and 18% during the grower period (weeks 3-6) in a 3 x 3 factorial deigned experiment. The FCR improved as CP increased when 12.6 and 13.4 MJ/kg of ME was fed, that is when the P/E increased. Carcass fat increased as ME of the diet increased (i.e. P/E decreased) and decreased as CP protein increased (i.e. P/E increased). The concentration of liver enzymes involved in fat synthesis decreased as protein concentration of the diet increased.

Chen et al., (2000) using Minnong mule ducks, studied the optimum P/E ratio for the starter (weeks 1-3) and grower (weeks 4-8) periods. In the starter period, P/E was modified by feeding the same dietary ME (11.51 MJ/kg) and altering the CP content from 15 to 21%. This gave a P/E ratios ranging from 13.04 to 18.26. In the grower phase (weeks 4-8) the energy content was 11.91 MJ/kg and the CP varied from 12-18% and this gave P/E ranging from 10.08 to 15.11. Best growth rate, FCR and carcass composition was achieved when the P/E was 15.65 in the starter phase and 12.5 in the grower phase. There is a much higher protein content need in the starter phase.

When Beijing ducks were fed to eight weeks of age diets varying in energy (10.88-12.13 MJ/kg ME) and protein content (14-22% CP), best performance was achieved with the combination of 11.71 MJ/kg ME and 20% CP (Yunyan et al., 1989). This was a protein/energy ratio of 17.0. While ducks need higher protein in the first three weeks of growth, 20% CP in the grower phase is excessive. When A44 ducks were fed similar diets in the first three weeks of age and then fed diets varying in crude protein and metabolizable energy contents during weeks four to eight of age, optimum performance (growth rate and FCR) were achieved by providing 13-16% CP and 10.1-11.1 MJ/kg ME (Mazanowsli et al., 1991). This equated to having a P/E of 12.8-14.4.

The optimum dietary protein and energy content for starter (up to 3 weeks) and grower (4-8 weeks) diets was determined for Tianfu ducks by He et al., (1994). Peak growth rate was achieved using a starter diet having 12.75 MJ/kg ME and 17% CP (P/E = 13.3) and grower diet with 12.66 MJ/kg ME and 16.97% CP (P/E = 13.4). Maximum breast yield was observed when the CP content of the starter and grower diets were 21.23% and 16.23% and both diets contained 11.82 MJ/kg ME (P/E of 17.96
and 13.7, respectively). While the optimum P/E will differ for individual duck strains it would seem that the P/E ratio providing best growth rate was lower than that needed to achieve the best breast muscle yield and this is most evident in the starter diet.

Leclercq and Carville (1976) in two experiments, fed Muscovy ducks diets containing 12.35 MJ/kg ME and CP contents varying from 17.7 to 24.5% or diets with 19.3% CP and different energy contents varying from 10.4 to 13.3 MJ/kg. The differences in protein and energy had no effect on liveweight gain or FCR. With diets containing 19.3% CP feed intake fell as the energy content increased.

1.5.4 Alternative grain sources

Since feed costs contribute to more than 65% of total production costs for duck meat production within Australia, an increase in grain prices will substantially increase production costs. It is anticipated that grain prices will continue to increase in the future (Anderton & Kingwell 2008). Factors influencing grain prices include, extended drought conditions in Australia, increased demand for food from countries such as India and China and most importantly, the diversion of grain sources away from animal production and towards production of ethanol as an alternative fuel source (Anderton & Kingwell 2008). Large increases in the price of crude oil since mid 2004, as well as uncertainties for the future of fuel prices have encouraged many countries to invest in biofuel production (Anderton & Kingwell 2008). In particular, cellulosic ethanol production can result in a fuel possessing with a net energy yield that is very close to CO₂ neutral (Anderton & Kingwell 2008), making it increasingly desirable as a gasoline alternative.

Presently, the main grain sources for poultry diets are corn and wheat. This will need to change as the human demands for these grains sources continue to increase. Alternative grains are sorghum, rice hulls, oats, rye and barley. One of the main constraints in using these alternatives is the presence of anti-nutritional factors including the fibre content (King et al., 1997). King et al., (1997) studied the AME and TME values for some of these alternatives in Pekin ducks. The low ME of whole oats 10.5 MJ/kg (Scott et al., 1982) have excluded it from poultry diets. The TMEn for dehulled oats in ducks was 15.2 MJ/kg and this suggests that it could be an alternative grain source for ducks. Rye had a TME of 11.0 MJ/kg but has been found to have problems when fed to chickens (Lee & Campbell, 1993).

Wheat and sorghum are the most common grains used by the Australian poultry industry (Black et al. 2005), with wheat making up 70 percent of the total grain component of commercial duck-meat diets within Australia. Sorghum accounts for the other 30 percent, and it is a cheaper alternative to wheat. The two grains appear nutritionally similar (see table 1.2.) (Adams 1999). This has given rise to the assumption that one can be substituted for the other, allowing sorghum to replace the wheat component of duck diets. However, no trials have been conducted to determine the viability of this assumption. Alternatively, literature exploring the use of sorghum within broiler diets is readily available (Okoh et al. 1989, Kumar 1996, Jacob et al. 1997, Black et al. 2005, Ebadi et al. 2005, Reddy et al. 2005). In Australia, the chicken meat industry have invested considerable research effort into overcoming the problems with using sorghum in broiler diets.

While sorghum is a good source of CP, the protein may not be completely available to the animal (Okoh et al. 1989). The low digestibility of sorghum protein is believed to be due to anti-nutritional factors which limits its potential as a feed ingredient for poultry (Jacob et al. 1997). Black et al. (2005) compared wheat and sorghum for their use with poultry. The AME content was considerably higher for sorghum in both layers and broilers. Layers offered sorghum based diets consumed 13 percent more AME daily than those offered wheat based diets. However, for broilers, daily intake of AME was similar for sorghum and wheat based diets. Despite a similar daily intake of AME, broilers offered wheat based diets grew 20 percent faster and used 17 percent less feed than those offered sorghum based diets. This was attributed to a low availability of amino acids, with arginine possibly the first limiting amino acid, due to the low digestibility of sorghum proteins (Black et al. 2005).
Contradictory to this, results from other studies show the first and second limiting amino acids to be methionine and cysteine, respectively (Ebadi et al. 2005).

<table>
<thead>
<tr>
<th></th>
<th>DM (%)</th>
<th>DE (MJ)</th>
<th>CP (%)</th>
<th>Fibre (%)</th>
<th>Calc (%)</th>
<th>Phos (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>90</td>
<td>6.57</td>
<td>14.4</td>
<td>2.7</td>
<td>0.05</td>
<td>0.37</td>
</tr>
<tr>
<td>Sorghum</td>
<td>90</td>
<td>6.62</td>
<td>11.2</td>
<td>2.0</td>
<td>0.04</td>
<td>0.32</td>
</tr>
</tbody>
</table>

Table 1.2. Nutrient composition of Wheat and Sorghum grains (Adams 1999).

Reddy et al. (2005) acknowledge sorghum to satisfactorily occupy the whole grain component of a poultry diet. When sorghum was included at 0, 50 or 100 percent of the grain component of poultry diets, the highest reduction in feed costs occurred when sorghum was included at 100 percent of the grain component (Reddy et al. 2005). Sorghum can completely replace the maize component of the grain in layer diets without negatively affecting performance and quality of egg production (Reddy et al. 2005).

Although sorghum may not be seen as an ideal source of grain for broiler diets, it may be a sufficient source of grain for duck diets. A study by Elkin and Rogler (1991), assessed the differential response of ducks and chicks to dietary sorghum tannins. The study, found depressed growth rates and feed efficiency when feeding ducklings a high tannin sorghum diet compared to a low tannin sorghum diet, as was found with chicks. However, upon comparing results between species, the negative effects of dietary sorghum tannins on weight gain and feed efficiency are less severe in ducks than in chicks (Elkin & Rogler 1991). King et al. (2000) investigated the effect that tannins have on the nutrient utilisation on the White Pekin ducks. The study similarly concluded that high tannin sorghum grains lowered nutrient utilisation from the diet, and hence better performance can be obtained from a low tannin sorghum grain.

There appears to be no studies comparing Australian grown sorghum to Australian grown wheat as a grain source in duck diets. Hence, no definite conclusions can be made as to whether sorghum can be used to replace wheat as the grain component in Australian duck meat diets, in an attempt to save feed costs for the industry. When the project was undertaken (2007/8) the price of wheat was $428/tonne and sorghum $343/tonne.

### 1.6 Feed efficiency

The efficiency at which poultry absorb nutrients is of great importance. Feed conversion ratio (FCR) is commonly used to describe feed efficiency. The feed conversion ratio in ducks is significantly higher than in chickens (Havenstein et al., 2003). In the Australian broiler industry 70% of costs are feed related. Key issues to address in relation to performance include growth, feed efficiency and the ratio of various tissue depositions. Feed efficiency can be defined as the ability of an animal to convert feed into live body weight. However, it is more economically important to define feed efficiency as the conversion of nutrients in feed to high value protein for human consumption.

Although the Pekin duck is acknowledge to have superior growth rates, it is not considered to be an efficient performer in terms of feed conversion when compared to broilers especially if efficiency is gauged on the breast yield. In overseas studies, Pekin ducks are shown to have an FCR of 1:2.18 at six weeks of age (Normand, 1997). The feed efficiency of the duck declines with age (Farhat & Chavez, 2000). *Ad libitum* feeding will also influence the age related changes in FCR (Campbell et al. 1985). This is related to the higher nutrient requirements as liveweight increases. Farhat & Chavez, (2000) report that feed efficiency declines at six weeks age, while Grow (1972) identified eight weeks as the
critical age. The difference is likely related to the genotypes used. Farhat and Chavez (2000) demonstrated that feed conversion ratios in ducks increase by up to 14% from five to six weeks of age.

The change in feed conversion ratios in ducks is also associated with a change in the growth allometry, as the duck changes from muscle accretion to fat deposition. This is further supported by the findings of Farhat and Chavez (2000), where the percentage of carcass crude protein was found to decreased from week six to seven of age, while the percentage of fat increased over the same period.

1.7 Measuring digestibility

To more accurately predict performance, feed formulations need to be based on digestibility and not the total content of amino acids and energy in the available feedstuffs. Therefore, when formulating poultry diets nutritionalists need to have access to digestibility measures for energy and protein in the feedstuffs available to them.

Adeola (2006) has summarized the methods being used in poultry to measure digestibility of feed ingredients. The main procedures are;

1. Direct method – where diets are formulated so that the test ingredient provides the sole source of the nutrient being tested. It has limitations when evaluating low quality ingredient such as barley.

2. Difference method – where a basal and test diet (a mixture of basal diet and the test ingredient) are formulated and compared, with the digestibility being determined by the difference between these. It assumes that there is no interaction between the ingredients in the basal diet and the test diet.

3. Regression method – basal and test diets are mixed in graded levels to form a series of assay diets. The resulting data are fitted to simple linear regressions. A prerequisite here is that there is a large enough difference in digestibility of ingredients in the basal and test diets.

Apparent digestibility is determined as the difference between total intake of ingredients less total faecal ingredient output. While it is relatively easy to measure there is an inherent error in the calculation because it fails to take account for the endogenous losses of the ingredient that is measured in the faeces. True digestibility is measured as the total ingredient intake minus the total faecal ingredient output plus the endogenous ingredient losses. True digestibility is a more precise measure of the ingredient digestibility but it is much more difficult to measure. Total endogenous losses will be low relative to intake if the intake is high but relatively high if the intake is low (Lemme et al., 2004). When measuring apparent metabolism energy (AME) and true metabolisable energy (TME) it is common practice to adjust for nitrogen retention giving an AMEn and TMEn (Adeola, 2006). This is based on the concept that for the bird to remove body protein as uric acid, energy is needed. So birds that retain more nitrogen use less energy to remove nitrogen as uric acid. The general practice is to adjust the ME value back to zero nitrogen retention (AMEn and TMEn). The correction factor used is 34.39kJ/g nitrogen as determined by Hill and Anderson (1958). Conversion of AME to AMEn made a difference of 7-8% in the study of Adeola et al., (2008) and 9% in the study of Hong et al., (2001).

Determination of the differences between feed ingredient intake and total faecal ingredient output continues to be the method most commonly used for determination of nutrient digestibility in poultry. There are inherent problems with this method (McNab, 2000). These include feed wastage, loss of excreta material, contamination with spilt feed, feathers and down and digesta regurgitated by the bird as well as fermentation during the collection period. These problems are even worse in ducks because
of the very liquid excreta and often it’s forceful ejection (Adeola, et al., 1997). For these reasons it is now generally agreed that the analysis of ileal digesta is more appropriate than using excreta to assess amino acid digestibilities in ducks ( Kluth & Rodehutscord, 2006; Huang et al., 2007).

The use of an insoluble marker mixed with the feed overcomes the need to accurately measure feed intake and excreta output. A range of markers has been used with common ones being acid-insoluble-ash (AIA), chromium oxides and titanium dioxide (see review: Sales and Janssens, 2003). Acid-insoluble-ash is the mineral content left after digestion with hydrochloric acid and then ashing in a furnace (Shrivastava & Talapatra, 1962). To increase the dietary AIA content, Celite can be added to provide a higher AIA content and increase the accuracy of the extraction and ash determination. The reported success of using AIA as a marker varies. Tillman and Waldroup, (1988a & b) using broilers found greater variation in ME and AA digestibilities than when using the total excreta output method. For ducks less variation was found in DM digestibility using the AIA method compared to total excreta output evaluation (Farrell & Martin, 1998). Farrell and Martin (1998) found that values for energy, DM, phosphorus and calcium digestibility were lower using the AIA marker procedure.

Ileal digestibility is used as measure of protein suitability for poultry. Caecal fermentation can have varying effects (Ravindrian et al., 1999). Jamroz et al., (2001) reported that the average AA digestibility in chickens, ducks and turkeys were 76, 69 and 56%, respectively. The differences in AA digestibility between the species could be due to differences in endogenous losses or absolute digestibility differences. The true AA digestibility needs to account for the endogenous losses but efforts to account for this lead to large variations. Kluth and Rodehutscord (2006) fed chickens, ducks and turkeys the same diets for seven days and used a marker (Titanium dioxide) procedure to determine digestibilities. The relationship between AA intake and digestibility at the ileum was linear for all species. The calculated slopes using regression analysis can be used as partial digestibilities for the dietary protein without correcting for endogenous losses as these are given as the intercepts at zero nutrient intake (Rodehutscord et. al., 2004). There were differences in the AA digestibility between the species. Ducks had lower AA digestibilites than did broilers and turkeys with the degree of difference depending on the feed ingredient and individual AA being considered. The authors concluded that AA digestibility values for broilers should not be used in formulating diets for ducks.

Jamroz et al. (2002) reported that the average digestibilities for AA at 14, 28 and 42 days for ducks was 44, 62 and 60 % and at the same ages was 70, 73 and 73% for broilers. Kluth & Rodehutscord, (2006) also found differences and these are not due to differences in intake or endogenous losses. The digestibilities of methionine, lysine, and threonine and crude protein from soybean meal for ducks were 76%, 70%, 66% and 74%, respectively. The energy efficiency was 71-75%. For rapeseed meal the values for methionine, lysine, and threonine and crude protein were 80%, 66%, 64% and 69%, with energy efficiency being 72-77%. The AA digestibility coefficients were higher in the reports of Adeola (2005) and Nyachoti et al., 2004 but these workers used older birds, and calculated the values using total excreta collection and different test feeding levels.

1.8. Nitrogen retention

Fasting losses of nitrogen will vary with time and for individual birds (NcNab & Blair, 1988). Mohamed et al., (1984) found an endogenous nitrogen loss of 760mg/bird/24 h for ducklings. For a Cherry Valley commercial strain, nitrogen retention was 63.7 ± 1.4 % when fed a control grower diet and was 58.3 ± 1.3 and 55.6 1.3 % when aflatoxin affected diets were fed (Han et al., 2008).

Using a 54h sampling period, the mean (SD) endogenous nitrogen losses for ducks from two separate studies was 1.015 ± 0.46 g and 0.614 ± 0.60 g (Adeola, 2003). The corresponding mean endogenous energy losses were 70.6 kJ and 60.9 kJ. There were large individual variations in energy losses with the range being 56.5-98.7 kJ and 37.5-129.0 kJ for separate studies detailed by Adeola, (2003). The level of nitrogen retention for corn was 36% and soybean meal 47%. This is low but in these studies the assay system uses a fasting protocol and force-feeding of 60 g of feed and so the birds were losing weight. Forced feeding only uses the test ingredient and this may influence digestion and the act of
fasting birds could be a relevant factor in measuring digestibility and nitrogen retention (Lemme et al., 2004). The low nitrogen retention rates are associated with protein being used as an energy source with the nitrogen then secreted as uric acid.

Apparent nitrogen retention (ANR) rates for ducks of 65.9% for wheat, 55% for dehulled oats and 9% for corn were reported by King et al., (1997). Adjusting for endogenous losses the true nitrogen retention values (TNR) were 88% for wheat, 83% for dehulled oats and 51% for corn. In this study the fasting loss of endogenous nitrogen was 0.29 ± 0.11g and for energy 50.6 ± kJ over the 54 h collection period. In a second study, the ANR for oats was –36%, rye –20% and corn –82%. Endogenous nitrogen loss was 1.09 ± 0.4 g/ per 54 h and for energy was 79.1 ± 21.3 kJ per 54 h. After the appropriate corrections were made, the TNR were 64.8% for Rye, 91.7% for rice and 80.3% for corn. Of interest, is the very large difference in endogenous losses between the two studies 0.29 ± 0.11g and .09 ± 0.4 g. This clearly indicates that when calculating TME the endogenous losses need to be determined for every individual bioassay. Fed deprived duck of 3.7 and 3.8 kg liveweight, voided 3.9 ± 0.45 and 6.48 ± 0.63 g dry excreta in 54 h (King et al., 1997). There was very large individual variation and so again for any TME assay fasting losses need to be determined for each individual assay.

Adeola et al., (2008) in two experiments where Pekin ducks were fed a starter and grower diets based corn and soybean meal found the nitrogen retention to be 70% and 74% for starter and 73% and 76% for grower in experiment 1 and 2, respectively. Apparent amino acid digestibility was high in experiment 1 (77-90%) and 2 (66-86%) but actual nitrogen retention was poor. With the same diets, AME values for the starter were 14.04 and 13.18 MJ/kg and for the grower diet, 14.04 and 13.40 MJ/kg in experiments 1 and 2, respectively. These values were determined in birds force-fed after a 48h fasting period.

A large reduction in the protein content of a finisher diet had no significant effect on growth rate or carcass composition, but it did increase nitrogen retention (Baeza & Leclercq, 1998). This suggests that feeding excessive protein in the finisher diet reduces nitrogen retention and would be inefficient use of feed.

### 1.9 Three stage feeding program

Marica and Blaha (2006) compared feeding Pekin ducks of three different genotypes either a two stage feeding program or three stage program. Females and males of all genotypes were reared separately. All birds were fed the same starter diet (12.32 MJ/kg ME and 22.6% CP) for the first 21 days and then changed to a grower diet (12.33 MJ/kg ME and 18.1%CP) up to day 49 (control) or the grower diet to day 35 and then changed to a finisher diet days 36-49 containing 12.2 MJ/kg ME and 16.3 % CP or finisher a diet on days 36-49 containing 12.2 MJ/kg ME and 15.3 % CP. Males ducks of all strains had higher LW at 49 days when fed the finisher diet contain 15.3% CP. Females of only one strain had higher LW at 49 days when fed the finisher diet contain 15.3% CP while the females from the other strain had similar LW to the control birds. The three stage dietary programs gave better FCR, 2.6-2.65 and 2.58-2.63, than did the two stage feeding schedule (2.85-2.92). While performance was improved the absolute abdominal fat weight was greater when the three genotypes were fed the finisher diets but when this is represented as % of carcass weight there was, essentially no differences.

### 1.10 Water intake

Because they evolved from an aquatic habitat, eating marine plants and insects, it is not surprising that ducks consume more water than most other poultry species (Ragland et al., 1997; Joy, 2005; Adeola, 2006). Scott and Dean (1991) reported the water to feed intakes in ducks to be 4.2:1 while in chickens it was lower at 2.3:1. Ducks should never have access to feed without water, otherwise GIT impaction can occur (Morishita, 2004). While the majority of the water consumed by ducks is excreted, it is believed that maintaining high water consumption is necessary to attain good feed digestibility.
Therefore, if ducks do not have sufficient access to water and become dehydrated this will affect their FCR.

Currently many producers are hesitant to provide unrestricted access to water because it results in higher levels of wastage, which increases the labour requirements necessary to maintain litter condition. Some management systems shut off feed and water at night to help maintain litter inside buildings in a dry condition (Dean & Sandhu, 2008). In these systems plenty of clean drinking water should be available at least 8-12 hours per day (Morishita, 2004). Wet litter has negative impacts on duck production, leading to increased ammonia production, poor heat transfer and insulation, and caking of bedding. Poor hydration also makes the carcass more difficult to process. Research on water consumption in ducks is limited but what is available indicates that decreasing water consumption will lower production efficiency.

1.11 Meat yield

The main efforts in selection are to increase liveweight at slaughter age, increase breast yield and decrease carcass fat. Breast meat yield is considered to be as important as FCR (Baeza & Leclercq, 1998). Selection has increased protein accretion by ducks and this is associated with improved FCR (Timmller & Jeroch, 1999). Baeza, et al., (2002) compared an unselected line of Muscovy duck with a commercial line selected for growth rate and found that an indirect effect of the selection was to increase breast yield and increase carcass fat. Selection increased the protein and mineral content and decreased water content of breast muscle but had no effect on muscle fibre type. The overall effects of selection on meat quality were relatively moderate. Muscle development was greatest between weeks eight and ten were it increased by 108-152%. At 12 weeks, the carcass fat was 2.8% of LW in the selected line and 1.5% in unselected line.

The most accurate means of measuring breast yield is to dissect out the breast tissue. As this is not possible on the live animal, another means to aid selection is to find easily measured factors that show high correlation with breast yield (Kleczech et al., 2006). Efforts to find correlations between morphological measures and carcass composition revealed that live weight is highly correlated \( r = 0.701 \) to 0.857 \) with the weight of all tissue components (Kleczech et al., 2006). In both sexes carcass lean content was correlated with leg (drumstick) length (0.52 males; 0.28 females) and with chest girth (0.65 males and 0.57 females). Because of the degree of sexual dimorphism displayed in Muscovy ducks, regression analysis needs to be done on data collected from individual sexes and only applied to the relevant sex (Kleczech et al., 2006). The composition of breast meat from Mule ducks was 74% water, 21.1% and 2.2% fat (Paci et al., 1993). Proportion of red muscle fibre present in the breast meat of Muscovy ducks is 90% (Baeza et al., 1999) and Pekin duck is 84% (Gillie and Solomon, 1998).

A limiting factor to marketing Pekin ducks at six weeks of age is the poor yield of breast meat. There is a strong correlation (0.7-0.8) between breast meat yield and breast depth (Dean et al., 1987; Farhat & Chavez, 2000). A line selected for increased breast thickness had superior liveweights at six weeks (Farhat & Chavez, 2000). The selected line had significantly higher carcass yield, breast muscle thickness, higher eviscerated carcass protein (31.3 vs 27.94 %) and lower carcass fat (64.6 vs 60.7 %) determined on a DM basis. The selected line had higher plasma glucose and in an earlier study, the selected line had higher plasma IGF-1 (Farhat & Chavez, 1999). Selection for muscle thickness has resulted in a leaner carcass and higher growth to six weeks and better FCR to seven weeks.

There are strong correlation between liveweight and carcass fat and meat weight in Pekin ducks (Rymkiewicz & Boncho, 1999, Bochno et al., 2000). Genotype has an influence on carcass lipid content (Chartrin et al., 2006 b). Pekin ducks have higher total lipid, triglyceride and phospholipid content than does the Muscovy breed (Chartrin et al., 2006). Four generations of selection for growth rate improved FCR by 0.54 and decreased carcass fat by 2.5% (Pingel & Hemipold, 1984). Differences between ducks of a fat and lean line were studied by Farhat and Chavez (2001). Lean ducks had less carcass fat and more carcass protein. Lean ducks retained more dietary nitrogen than
fat ducks but no differences in AME or AMEn were observed. The fat line had a 15.7 % higher excretion of nitrogen than the lean ducks. Saunderson and Whitehead (1987) got a 15% higher AA oxidation in fat broilers. Using a control line and one selected for increased breast muscle thickness, there was a significant increase in breast muscle thickness (7 to 10.8 mm) from weeks six to seven and this was associated with a 14% increase in feed intake in week seven (Farhat & Chavez, 2000).

Age and sex affect meat quality. As birds’ age the muscle lipid content increases (Baeza et al., 2002). Carcass fat % increases but not protein in both sexes of Peking ducks between six and ten weeks of age (Abdelsamine and Farrell, 1986). Baeza et al., (2000) found a lack of sexual dimorphism for LW in mule ducks. Up to eight weeks, FCR was higher for females than males but from eight to 13 weeks it was higher for males than females Growth rate slows rapidly after ten weeks of age. The breast meat weight increased in weeks eight to ten by 73% for females and 74% for males. Although at all ages the breast weight was higher in males this was not significant (Baeza et al., 2000). Breast muscle water content decreased with age but protein and lipids increased. In general, ash content remained unchanged with age or sex. Water content of the breast muscle was negatively correlated with fat and protein. The increased lipid content of breast muscle as birds’ age was due to increased accumulation of triglyceride deposits (Baeza et al., 2000). When Muscovy males were slaughtered at 12 weeks and females at ten weeks, males were found to have more carcass meat (% BW) and less carcass fat (% BW) than females (Kleczek et al., 2006). Carcass fat % increases but not protein in both sexes of Peking ducks between six and ten weeks of age (Abdelsamine & Farrell, 1986).

Research must also address the effect of diet on meat quality. It is well documented that diet can be used to influence poultry meat quality (Bartos, 2004). Despite growth advantages of high energy diets, contrary to consumer preferences, high dietary energy cause a significant increase in abdominal fat. Fan and colleagues (2008) fed Pekin ducks diets differing in energy concentration (10.9-13.0 MJ/kg AME), and having the same protein concentration of 18% during weeks three to six (grower phase). Increasing the dietary energy had no effect on breast or leg muscle yield but when the concentration of energy was above 11.3 MJ/kg ME carcass fat increased. Siregar et al. (1982b) suggested that the undesirable amount of carcass fat in ducks is a result of high energy diets not being accompanied by corresponding changes in dietary protein to keep the energy to protein ratio optimal. Overfeeding results in accumulation of triglycerides with high monounsaturated fatty acid chains (Baeza et, 2006). Feeding fish oil increases omega-3 content of meat but sensory acceptance is low (El-Deek et al., 1997; Schiavove et al., 2004).

Selection for reduced carcass fat content needs to be done with adequate concern for aspects related to meat quality. Selection against carcass fat in broilers reduced eating quality (Dranfield & Sosnicki, 1999). Pekin ducks selected for low fat tend to have lower intramuscular fat than unselected line (Powell 1992). Breast meat of ducks for selected for growth rate were found to have less red muscle fibres (Baeza et al., 1997).
1.12 Mixed or single sex rearing

Reasons given for rearing ducks as single sexes vary. However, the main one is that the proposed competition results in differences in growth rate between males and females (Farrell, 1999; Normand et al, 1996). Males are more efficient, having an improved FCR after six to seven weeks of age (Leeson & Summers, 1988; Normand et al, 1996) and reduced carcass fat (Normand 1997). Because of the differences in development another reason advanced for rearing ducks as single sexes is to increased uniformity of product and the possibility of reducing the slaughter time as sexes reach market weight at different times (Farhat & Chacez., 2000).

Leeson and Summers (1997) found that at a slaughter age of six weeks, males were 300 g heavier than females. Scott and Dean (1991) reported the difference between males and females was 100 g. Normand (1997) identified that the growth rate of the two sexes differentiated at week five of age. Pekin ducks show a sharp decrease in FCR after week six. This is related to the higher energy needed for maintenance and increased propensity to deposit fat.

Farhat and Chavez (2000), compared the performance of Pekin ducks from a control line with those from one selected for increased breast muscle thickness when reared as single sexes or as mixed sexes. At two and four weeks there were no differences. Between weeks five and six when sexual dimorphism appeared birds reared in single sexes had higher liveweights than those reared as mixed sex group. These workers concluded that separate rearing was more suitable because it allowed separate sex feeding and processing of males at an earlier age. Males consumed significantly more feed to six weeks of age than females and had slightly better FCR at six weeks (2.18 Vs 2.24) but a significantly better one at seven weeks (2.48 Vs 2.62) when feed intake was higher but not significantly so for males (Farhat & Chavez, 2000).

In Mule ducks the degree of sexual dimorphism for liveweight was found to be small. Up to eight weeks, FCR was higher for females than males but in weeks eight to 13 weeks was higher for males than females (Baeza et al., 2000). Breast meat weight increased during weeks eight to ten but the change was similar for females (73%) and males (73%). Although at all ages the breast weight was higher in males it was not significantly greater than for females. These observations suggest that raising sexes together is not a problem (Baeza et al., 2000).
## 2. Objectives

As stated in the project submission the following objectives were identified. As with all projects there need to be consistent evaluation of the objectives in light of the results from the project and new information gathered from other researchers or the industry partners PEPE’S Ducks Pty. Ltd.

Following each of the studies undertaken as part of this project revision and some modifications of the objectives were made in consultation with the RIRDC program manager for the project.

The project objectives were identified in collaboration with PEPE’S Ducks Pty. Ltd., to develop guidelines/models for growth rate (market weight and age), feed and water intake, feed efficiency, carcass composition using the imported genetic lines used in commercial duck production. The successful marketing of ducks relies on meeting the consumer expectation for high quality meat especially breast muscle. The allometric (study of change in proportion of various parts of an organism as a consequence of growth) development of breast meat in ducks is not well understood, particularly as to how it relates to market ages/weights for the commercial lines and those ingredients commonly available in Australia for poultry diet formulation. From a research standpoint, the project provided opportunities to assess the anatomical development of organs (primarily digestive) necessary to support tissue development (the principle one being breast muscle) and investigated dietary strategies to maximise these developments.

The project was to explore the potential for utilising diet to enhance the niche, functional and nutraceutical value of duck meat. As duck meat is considered a speciality item by many consumers it would be of benefit to capitalise on consumer’s expectation with respect to the product being green (i.e. no antibiotics, reduced nutrient excretion), having consistent portions and quality, flavour and healthy. Upon further evaluation of the project objectives during the project more emphasis was placed on dietary composition and its influence on feed and breast meat yield. It was decided that development of niche markets for duck meat is a low priority for the industry and that development of a cut-up’ and export market are more appropriate developments.

The intake of water to feed in ducks is almost twice that for chickens or turkeys, as a consequence there appears to be more serious negative effects of water and feed withdrawal before processing on product yield and meat quality. There is some success in other species with the use of electrolytes (in water and feed) prior to processing in maintenance of muscle/body hydration; no information has been identified relative to the potential for ducks. This may also be of importance with respect to self-life of the product. While this is an industry issue, it was decided that the research effort of the current project should be directed at production efficiency.

The ultimate objectives is the production and efficiency of a uniform (consistent bird:bird growth, and predictable market weights at the desired market ages) duck meat that is of high quality, safe and meets or exceeds standards for wellbeing (health, diet, housing and care) and environmental stewardship.

In summary the key objectives were:

1. Develop growth models to more precisely predict market ages for the desired market weight and the highest yield of high-value muscle (i.e. breast meat); that is balanced to meet or exceed consumer expectations with regard to quality, food safety, animal wellbeing and environmentally sustainability.

2. Use dietary intervention to provide more uniform market weights, higher breast yield of breast, and reduce feed input costs. Potential to also develop niche markets based on modifying the duck tissue profiles through the use of specific nutrient ingredients.
3. Methodology

3.1. Duck Growth Trials

All the experimental procedures 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.

3.1.1. Experimental shed

The housing used was a tunnel shed with evaporative cooling (see Figure 3.1.). Shed fans were automated to cool the shed when it exceeded the desired temperature. The shed had 48 individual pens (1.5 x 3 m) laid out as shown in figure 3.2. All studies were conducted using a completely randomised design with blocking. The blocking was used to account for any inherent variation in shed conditions, especially those related to differences in temperature and rate of ventilation. The pens were number sequentially and divided evenly into four blocks. In all studies there were 12 treatments with one being randomly allocated to one pen in each block. 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. The shed was lit with fluorescent lighting. Lighting was maintained for the full 24 hours of each day.

Figure 3.1. The tunnel ventilated experimental shed used in the study
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<tr>
<th>Pen 1</th>
<th>BLOCK 1</th>
<th>Pen 25</th>
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<tbody>
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<td>Pen 2</td>
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<td>Pen 3</td>
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<td>Pen 8</td>
<td>BLOCK 2</td>
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<td>Pen 13</td>
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<td>Pen 23</td>
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<td>Pen 47</td>
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<tr>
<td>Pen 24</td>
<td></td>
<td>Pen 48</td>
</tr>
</tbody>
</table>

Figure 3.2. Pen layout in the tunnel ventilated shed
3.1.2. Breeding and Incubation

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

![Day old ducklings on arrival.](image)

**Figure 3.3.** Day old ducklings on arrival.

3.1.3. Brooding

Supplementary heat was provided with a temperature of 35°C, as measured directly beneath the brooder lamp, at day 1 (see Figure 3.3). The temperature was reduced to 28°C by day 7, to 26°C by day 14 and then 24°C by day 21.

3.1.4. Bird identification

On day 6 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 imbedded in the surrounding tissues.
3.1.5. 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 commercial production 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. Details of these commercial diets are shown in table 3.1. 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 used in the studies reported here were not made available. In studies detailed in chapters one and five these commercial starter and grower diets were used. For studies detailed in chapters six to eight modifications to these diets were made and specifics are given in individual chapters.

At the start of the study one feeder was made available in each pen. At day 21 an additional feeder was installed in each pen.

3.1.6. Watering

Each pen had its own water supply so the water intake could be recorded (see Figure 3.4). A row of 4 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.

Figure 3.4. The pen setup at the time of bird placement
<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Starter (0-14 days)</th>
<th>Grower (14-41 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein (%)</td>
<td>22</td>
<td>19</td>
</tr>
<tr>
<td>Energy (MJ/kg)</td>
<td>12.14</td>
<td>12.77</td>
</tr>
<tr>
<td>Methionine (%)</td>
<td>0.50</td>
<td>0.40</td>
</tr>
<tr>
<td>Methionine + Cystine (%)</td>
<td>0.85</td>
<td>0.70</td>
</tr>
<tr>
<td>Lysine (%)</td>
<td>1.00</td>
<td>0.80</td>
</tr>
<tr>
<td>Threonine (%)</td>
<td>0.75</td>
<td>0.60</td>
</tr>
<tr>
<td>Tryptophan (%)</td>
<td>0.23</td>
<td>0.16</td>
</tr>
<tr>
<td>Cellulose (%)</td>
<td>4.00</td>
<td>5.00</td>
</tr>
<tr>
<td>Fats (%)</td>
<td>5.00</td>
<td>7.00</td>
</tr>
<tr>
<td>Minerals (%)</td>
<td>6.50</td>
<td>6.00</td>
</tr>
<tr>
<td>Calcium (%)</td>
<td>1.00</td>
<td>0.90</td>
</tr>
<tr>
<td>Available Phosphorous (%)</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>Vitamins:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A (UI/kg)</td>
<td>13500</td>
<td>12000</td>
</tr>
<tr>
<td>D (UI/kg)</td>
<td>3000</td>
<td>2000</td>
</tr>
<tr>
<td>E (UI/kg)</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 3.1. The nutritional composition of duck starter and grower diets (Inghams Pty Ltd 2007).
3.1.7. Mortalities and culls

Ducks were culled if they appeared unhealthy or lame to an extent that affected their ability to feed, and subsequently, their ability to grow normally. Culls were euthanased with a lethal injection of phenobarbitone into the femoral vein of the leg. All culls and mortalities were recorded.

3.1.8. Performance measurements

Unless identified in the individual experimental chapters the following procedures were performed in all studies.

3.1.8.1. Liveweight measurements

At placement a group pen weight was recorded. On days 7 (week 1), 14 (week 2), 21 (week 3), 28 (week 4), 35 (week 5) and 41 (week 6) all ducks were individually weighed.

3.1.8.2. Feed intake

Feed was weighed in and out with intake determined weekly on a pen basis.

3.1.9. Carcass growth measurements

On days 6, 13, 20, 27, 34 and 41 carcass growth measurements were taken from an individual duck selected at random from each pen. If the pens contained mixed sexes, equal numbers of males and females were taken from treatment pens at each sampling. The selection of males and females was alternated at different weeks so that in one week a male was randomly selected and then the next week it was female. After selection, ducks were individually weighed and then euthanised.
3.1.9.1. Muscle sampling

The skin was cut away from midline of the ventral aspect to expose the abdominal cavity and breast muscle. Scissors were used to cut through the ribs and both the right and left clavicles. The sternum and adjoining breast muscle were removed from the body and a scalpel was used to dissect the left and right pectoral major from the carina and pectoral minor. The left and right pectoral minor were also dissected from the sternum. The combined weights of the pectoral major and the pectoral minor were recorded.

Skin was dissected away from the legs to expose the thighs and drumsticks. The legs were detached from the body using a knife to dissect away the muscle tendons, which append the femur to the ilium and the pubis. The tendons connecting the thigh muscles to the patella and condyles of the femur were also dissected. All muscles removed from the femur were weighed collectively and recorded as the thigh weight. The ligaments appending the femur to fibula and tibia were dissected. The muscles on the fibula and tibia were removed, weighed collectively and recorded as the leg muscle (drumstick) weight.

3.1.9.2. Liver and abdominal fat sampling

All vessels connected to the liver were dissected away so the liver could be removed from the abdominal cavity. The liver weight was recorded. At day 7 there is very little or no discernible abdominal fat. On days 13, 20, 27, 34 and 41 the abdominal fat (also known as cod fat) was removed from the abdominal cavity and the weight recorded.

3.1.9.3. Gastrointestinal tract (GIT) sampling

The intestinal tract was excised following a cut proximal to the crop and another distal to the caecal-ileal junction. A further cut was made at the gizzard to isolate the proventriculus. The proventriculus was cut longitudinally and washed to remove undigested material. After drying the weight was recorded. A cut distal to the gizzard isolated the gizzard from the remaining intestinal tract. Any fat surrounding the gizzard was removed and included as abdominal fat. The gizzard was cut longitudinally and washed to remove undigested material. After drying the weight was recorded. The remainder of the intestinal tract was straightened. The duodenal length (DL) was taken from where the tract had been removed from the gizzard to the end of the pancreatic loop. The upper small intestine (jejunum) length was taken from end of the pancreatic loop to the Meckel’s diverticulum (DL-MD). The lower small intestine (ileum) length was taken from the Meckel’s diverticulum to the ileal-caecal junction (MD-CJ). The caecal length (CL) was taken as the distance between the distal ends of the outstretched arms of the caeca.

3.1.10. Preparation for Proximate Analysis of carcass composition

On sampling day 20 (week 3) and 34 (week 5) for the studies detailed in chapters 4 to 7 and on day 34 (week 5) and 41 (week 6) for the study detailed in chapter 8, the carcasses and all body parts used for growth measurements were retained. The carcasses were placed in individual labelled autoclave bags and autoclaved at 124°C for 225 minutes. The carcasses were then weighed and individually homogenised using an industrial blender. Two samples were taken for each carcass. The first sample was used to calculate carcass dry matter. The other sample was freeze dried (FD3 Freeze Drier, Dynavac Engineering) and used to determine crude fat, protein and ash.
3.1.10.1. Dry Matter (DM) and Water Content

A sample of the homogenised duck was weighed into a crucible of known weight and placed into an oven set at 105°C. After 24 hours the sample was removed and reweighed. The percentages of DM and water content were calculated using the following equation.

\[
DM\% = \frac{\text{Final Weight} - \text{Crucible Weight}}{\text{Sample Weight}} \times 100
\]

\[
\text{Water Content} \%= 100 - DM\%
\]

3.1.10.2. Carcass crude lipid content

The crude lipid was determined using a technique derived from that developed by Folch et al. (1957). A known weight of freeze dried sample was combined with 50 mL of Folch I (2:1 (v/v) chloroform/methanol) solution in an Erlenmeyer flask. The mixture was shaken for 30 minutes using a mechanical shaker and then allowed to stand overnight. The homogenate was filtered through a 0.25μm Whatman™ filter paper into a 100mL graduate cylinder. The flask was then rinsed with Folch I solution until the volume in the cylinder was 60 mL. A volume of 12 mL of 0.88% NaCl was also added to the cylinder. The cylinder was inverted twice and then allowed to stand. Once the solution had separated into two distinct phases, the aqueous layer was removed, using a siphon apparatus and discarded. The volume of the remaining chloroform and lipid layer was recorded. Approximately 5 mL of Folch II (3:47:48 (v/v/v chloroform: methanol: 0.88% saline) solution was used to wash the remaining layer. The aqueous layer was then removed, using the siphon apparatus and discarded. A pipette was used to remove 10 mL of chloroform lipid extract to a scintillation vial of known weight. The vial was transferred to an oven set at 40°C and left overnight. The weight of the dried lipid was measured and recorded. The percentage of crude lipid was calculated using the following equations:

\[
\text{Crude Lipid} \% \text{ (of DM)} = \frac{\text{Lipid & Vial (g) - Vial (g)}}{\text{Chloroform & Lipid Layer (mL) / 10 mL}} \times \frac{1}{\text{Sample Weight (g)}} \times 100
\]

\[
\text{Crude Lipid} \% \text{ (of Carcass)} = \frac{\text{DM} \%}{100} \times \text{Crude Lipid} \% \text{ (of DM)}
\]

3.1.10.3. Crude protein content

Crude protein was calculated from the freeze dried sample using a Leco© FO-428 nitrogen analyser and a modification of the technique developed by Dumas (1831). The machine was calibrated using a known set of standards. A pre-weighed sample was placed on the sample tray. The sample was incinerated and the percent of total nitrogen was recorded. The crude protein was calculated using the following equations:

\[
\text{Crude Protein} \% \text{ (of DM)} = \text{Total Nitrogen} \% \times 6.25
\]

\[
\text{Crude Protein} \% \text{ (of Carcass)} = \frac{\text{DM} \%}{100} \times \text{Crude Protein} \% \text{ (of DM)}
\]

3.2. Metabolism studies

The following procedures were used for determination of dietary AME, nitrogen retention and ileal nitrogen digestibility.

3.2.1. Experimental design

Unless otherwise stated for individual studies the following experimental design was used. At day 14 (week 2), four ducks were randomly selected and removed from each pen of the growth trial. Equal numbers of males and females were taken from mixed sex pens. The bioassay trial used the same
treatments as in the growth trial. The ducks were placed in 48 metabolism cages in a separate temperature controlled facility.

The ducks were fed ad libitum with the same commercial grower diet supplied to the ducks in the growth trial, with the addition of an insoluble ash marker, Celite, at a concentration of 10 grams per kilogram of feed. The feed intake for each pen was recorded. Water was supplied via two nipple drinkers in each pen.

### 3.2.2. Excreta collection

On day 21 (week 3), in studies were the insoluble as marker was used to determine AME and protein digestibility, trays beneath the pens were used to collect excreta over a 10 hour period. The faeces were mixed and a sub-sample taken and freeze dried.

For those studies were AME and protein digestibility values were determined using total excreta output, faeces were collected over three days (days 19-21) with the excreta removed each day. The faeces were dried in a hot air oven at 70°C.

### 3.2.3. Ileal digesta collection

Following excreta collection, the birds were euthanised using an injection of phenobarbitone into the femoral vein of the leg. Following death, a ventromedial incision was made to expose the abdominal cavity. The lower small intestines were removed with a cut immediately distal to the Meckel’s diverticulum and another immediately proximal to the caecal-ileal junction. A small volume of distilled water was used to flush excreta from the ileum into a labelled container. Samples from all four birds in each pen were combined as single combined sample for analysis.

### 3.2.4. Acid Insoluble Ash (AIA) determination

The acid insoluble ash (AIA) was calculated for the diet and both excreta and ileal digesta samples. Around one gram of sample was weighed into a test tube and placed in a drying oven at 80°C, over night. The sample was weighed to determine the sample dry weight. The sample was then placed in a muffler furnace for 8 hours at 500°C. Each sample had 5ml of 4M HCL added and stirred on a vortex mixer for 5 seconds. The test tubes were transferred to a block heater, set on 100°C, for one hour. The test tubes were then spun at 2500 rpm for 10 minutes. The supernatant was removed and 5 ml of water was added to each test tube. The test tubes were centrifuged again at 2500 rpm for 10 minutes. A further 5 ml of water was added. The test tubes were centrifuged again at 2500 rpm for 10 minutes. The supernatant was removed. The samples were placed overnight in oven at 80°C. The sample was then placed in a muffle furnace at for 8 hours at 500°C. The sample was weighed and the AIA determined.

### 3.2.5 Apparent metabolisable energy (AME) and the nitrogen corrected apparent metabolisable energy (AMEn) of the diet using the AIA procedure.

The Gross Energy (GE) of the diet and excreta were determined using a Parr (1281) Bomb Calorimeter. Using the insoluble ash marker procedure, AME of the diet was determined using the following equation:

\[
AME_{DM} = \frac{(GE_{diet} / AIA_{diet}) - (GE_{excreta} / AIA_{excreta})}{GE_{diet} / AIA_{diet}}
\]

All calculation were made on a DM basis.
To compensate for different nitrogen retention rates, AME is adjusted to zero nitrogen retention to give the nitrogen corrected apparent metabolisable energy (AMEn). The correction factor is 34.39 kJ/g of nitrogen. If nitrogen retention is positive, the energy value is added to the gross excreta energy value and in this case AMEn will be less than AME. If nitrogen retention is negative, the energy value is subtracted from the gross excreta energy value and in this case AMEn will be greater than AME.

3.2.6. Apparent Digestible Protein (nitrogen) the diet using the AIA procedure

The crude protein (CP) of the diet, excreta (oven dried and freeze dried) and freeze dried ileal digesta samples were determined from the nitrogen content using a Leco® FO-428 nitrogen analyser. The apparent protein digestibility (APD) was determined using the following equation:

\[ APD = \frac{(CP_{diet} / AIA_{diet}) - (CP_{excreta/ileal digesta} / AIA_{excreta/ileal excreta})}{CP_{diet} / AIA_{diet}} \]

All calculation are made on a DM basis.

3.2.7. Apparent metabolisable energy (AME) and the nitrogen corrected apparent metabolisable energy (AMEn) of the diet using the total collection procedure.

The dried faecal subsample was ground. The DM, nitrogen and energy content of the ground samples were determined as described above. The AME was calculated as:

\[ AME (MJ/kg) = \frac{\text{total energy intake (MJ) - total energy excreted (MJ)}}{\text{Total intake (kg)}} \]

All calculation were made on a DM basis.

The apparent protein digestibility (APD) was determined using the following equation:

\[ APD (%) = \frac{\text{total protein intake (g) - total protein excreted (g)}}{\text{Total intake (g)}} \times 100 \]
4. The effects of strain, sex and pen-sex on the performance of commercial ducks under summer conditions

4.1. Introduction

In the Australian duck market, the expectation is for a bird grown to a liveweight of 2.85 kg at processing and having a high breast muscle yield (PEPE's Ducks P/L, personal communication). Further, consumers also require a uniform product and for a health conscious population, not an excessively high carcass fat content.

The Pekin duck is the most common breed used for commercial duck meat production. The main strains of Pekin ducks used in Australia for commercial production are the Cherry Valley (CV) from the United Kingdom and Grimaud Frères (GF) from France. The GF is faster growing and attains a heavier liveweight at six weeks of age. The CV is slower growing but has strong acceptance with the restaurant trade because of its carcass quality and cooking attributes.

Using imported strains of Pekin duck has created some issues for the local duck industry. The overseas breeding companies have created strains of ducks suitable for their local requirements. These strains are breed to achieve a liveweight of 3.4 kg at a slaughter age of seven weeks. As previously stated, the Australian market specification is for a slaughter weight of 2.85 kg at six weeks. Unlike broilers, maximum breast muscle deposition in ducks occurs later in development. So for the strains of Pekin presently used in Australia, a slaughter age of six weeks occurs at a time that doesn’t coincide with maximum breast muscle development.

It is possible that by crossing the GF and CV strains, heterosis might provide crosses that display the favourable attributes of both the GF (higher growth rate) and CV (carcass quality). The desire is to produce a Pekin strain which better meets the very precise Australian market specifications.

The duck industry is relative new and the volume of research specific to Australian conditions is scarce. Even in countries, such as France and the UK where the industry has been well established the volume of research available is nominal in comparison to the broiler chicken (Baeza et al., 2000). Of the research available from Europe, much is of limited relevance to Australian conditions because of the difference in climatic conditions and type of housing used. For the Australian industry there is an urgent need for relevant information on growth rates, feeding efficiencies and meat yields of the duck strains presently being used.

4.2. Objective

The objective of the study was to assess the effects that strain and sex have on the growth rates of Pekin ducks grown under Australian conditions. The effect of single sex rearing is also compared to the normal commercial rearing practice of mixed sex rearing. The effect of season was evaluated by undertaking the present study in summer and the second in winter (chapter 5).
4.3. Material and Methods

4.3.1. Growth study

4.3.1.1. Experimental Design

There were 48 pens allocated to the study. The pens were number sequentially and divided evenly into four blocks. Each treatment was randomly allocated a pen in each block (see section 3.1.1.).

4.3.1.2. Treatments

The treatments consisted of four strains of Pekin duck reared as single sexes (males or females) or as mixed sex groups, consisting of equal numbers of males and females. The strains used were the Cherry Valley (CV) and Grimaud Freres (GF) and the reciprocal crosses of these two strains. These being, the CV male X GF female and the GF male X CV female. The four strains were produced, by the appropriate matings at a commercial breeding farm owned 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 as single sexes (females or males) or mixed sexes (equal numbers of males and females). The twelve treatments are given in table 4.1

4.3.1.3. Husbandry

On arrival, 36 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 six there were 24 birds in each pen with a floor space of 1875cm²/bird. Birds were identified individual with wing tags.

Birds had access to feed and water ad libitum. The nutritional composition of the starter and grower feeds as provided by Ingham’s Pty Ltd is given in section 3.1.5. 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 to day 41.

4.3.1.4. Performance and carcass measurements

At placement birds were randomly allocated to pens with a collective pen weight recorded at this time. Individual liveweights were recorded on days 7 (week one), 14 (week two), 21 (week three), 28 (week four), 35 (week five) and 41 (week six).

Carcass growth measurements were taken on days six, 13, 20, 27, 34 and 41 from an individual duck selected at random from each pen. On days six, 20 and 34 males were taken from the mixed pens in blocks one and two and female were taken from the mixed pens in blocks three and four of the shed. On days 13, 27 and 41 females were taken from the mixed pens in blocks one and two and males were taken from the mixed pens in blocks three and four. The selected ducks were individually weighed and then euthanised. Organs and GIT sections were collected as described in section 3.1.9. On days 20 (week three) and 34 (week five) the carcasses and all body parts used for growth measurements were retained. The carcasses were autoclaved, homogenised and after freeze-drying the crude fat, protein and ash were determined as described in section 3.1.10.

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### Table 4.1. The 12 different strain and sex combinations used in the study.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Strain</th>
<th>Pen Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cherry Valley</td>
<td>Single (Male)</td>
</tr>
<tr>
<td>2</td>
<td>Cherry Valley</td>
<td>Single (Female)</td>
</tr>
<tr>
<td>3</td>
<td>Cherry Valley</td>
<td>Mixed</td>
</tr>
<tr>
<td>4</td>
<td>Grimaud Freir</td>
<td>Single (Male)</td>
</tr>
<tr>
<td>5</td>
<td>Grimaud Freir</td>
<td>Single (Female)</td>
</tr>
<tr>
<td>6</td>
<td>Grimaud Freir</td>
<td>Mixed</td>
</tr>
<tr>
<td>7</td>
<td>Cherry Valley cross Grimaud Freir</td>
<td>Single (Male)</td>
</tr>
<tr>
<td>8</td>
<td>Cherry Valley cross Grimaud Freir</td>
<td>Single (Female)</td>
</tr>
<tr>
<td>9</td>
<td>Cherry Valley cross Grimaud Freir</td>
<td>Mixed</td>
</tr>
<tr>
<td>10</td>
<td>Grimaud Freir cross Cherry Valley</td>
<td>Single (Male)</td>
</tr>
<tr>
<td>11</td>
<td>Grimaud Freir cross Cherry Valley</td>
<td>Single (Female)</td>
</tr>
<tr>
<td>12</td>
<td>Grimaud Freir cross Cherry Valley</td>
<td>Mixed</td>
</tr>
</tbody>
</table>

#### 4.3.2. Metabolism study

At day 14 (week 2), four ducks were randomly selected and removed from each pen of the growth trial. Equal numbers of males and females were taken for the mixed sex pens. The ducks were placed in 48 metabolism cages and fed ad libitum the same commercial grower diet supplied to the ducks in the growth trial, with the addition of an insoluble ash marker, Celite, at a concentration of 10 grams per kilogram of feed. The AME and nitrogen retention were determined using the AIA procedure (see section 3.2.)

#### 4.3.3. Statistical analysis

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

The fixed model included the effects of sex, pen-sex, strain 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 chi-square 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 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 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.
The analysis of the carcass composition and data from the metabolism study was conducted by ANOVA with significance set at (P < 0.05). Where main effects were detected as significant, pairwise comparisons were made using LSD procedures (LSD = 2 × SED).

4.4. Results

For reasons of ‘commercial in confidence’ the strains have been identified as strain A and B with the crosses being A X B and B X A, with no particular order designated.

4.4.1. Liveweight

There were highly significant effects of strain (see Figure 4.1), sex (see Figure 4.2) and pen-sex (see Figure 4.3) on liveweight but these effects changed over time, as indicated by the significant strain × week, sex × week, and pen-sex x week interactions (all P < 0.001). There were no significant strain x sex (P = 0.06), sex x pen-sex (P = 0.08) or pen-sex x strain (P = 0.60) interactions. The standard errors of means have not been included in the figures as they are too small to plot. The extremely large sample size results in these very small standard errors, hence fairly subtle biological effects are being detected as being statistically significant.

On every week there were significant differences, in mean liveweights. Strains A and B x A were lighter (P < 0.05) than strains B and A X B in all weeks except week one were stains A and A X B were similar. In weeks four to six strain B, was heavier (P < 0.05) than strain A X B. In all weeks males were heavier than females (P < 0.05). Despite the significant pen-sex x week interaction the only difference was in week one were birds reared in mixed sex pens were heavier (P < 0.05) than those reared in single sex pens.

At 41 days the mean (± SEM) liveweights for strain A, A X B, B and B X A were 2705 ± 33 g, 2844 ± 34 g, 2963 ± 39 g, 2724 ± 32 g, respectively. At the same time females had a mean (± SEM) liveweight of 2708 ± 30 g and males 2910 ± 32 g. For ducks reared in mixed sex pens the mean (± SEM) liveweight was 2793 ± 34 g and those reared in single sex pens was 2821 ± 31 g.
Figure 4.2. The mean liveweight for the effect of sex over the six week production period.
There was significant sex x week interaction ($P < 0.001$). In all weeks male ducks were heavier than female ducks ($P < 0.05$).

Figure 4.3. The mean liveweight for the effect of pen-sex over the six week production period.
Despite the significant pen-sex x week ($P < 0.001$) interaction the only difference was in week one where birds reared in mixed sex pens were heavier ($P < 0.05$).

4.4.2. Liveweight gain

The effect of strain on weekly gain is shown in figure 4.4. The effect of strain changed overtime as indicated by the significant strain x week interaction ($P = 0.002$). There were no differences between strains A and B x A or between strains B and A X B at any week. Strain A had lower weekly gain ($P < 0.05$) than strains B and A x B in weeks three to five but not other weeks. Strain B X A had lower ($P < 0.05$) weekly gain than strain A X B at weeks two to six but higher gain in week six ($P < 0.05$). Strain B X A had lower weekly gain ($P < 0.05$) than strain B at all weeks except week six.
The effect of pen-sex on weekly gain is shown in figure 4.5. The effect of pen-sex changed with time as seen from the significant pen-sex x week interaction (P < 0.001). Males tended to have a greater weekly gain than females but the differences (P < 0.05) were only significant in weeks two and six. Male pens had a higher (P < 0.05) weekly gain than mixed sex pens in week six only, with differences between female and mixed sex pens not different.

### 4.4.3. Feed Intake

The effect of strain on feed intake (see Figure 4.6) changed over time with the strain x week interaction (P < 0.001) being significant. The weekly feed intake was lower for strains A and B X A (P < 0.05) than strain B and also lower (P < 0.05) than strain A x B except in week one. The intake was higher for birds of strain B (P < 0.05) than strain A x B in week six only. Total feed intake for strain A was 5.36 ± 0.06 kg, for strain A X B was 5.80 ± 0.06 kg, for strain B was 5.91 ± 0.06 kg and strain B X A was 5.33 ± 0.06 kg. The effect of strain was significant (P < 0.001) with strains A and B X A (P < 0.05) having lower total intake than strains B and A x B.

The effect of pen-sex (see figure 4.7) on feed intake changed over time with a significant pen-sex x week interaction (P < 0.001). Males pens had a higher intake (P < 0.05) than females pens in weeks two and six only. There were no differences between mixed sex pens and male or female reared pens. The average total feed intake for males pens was 5.64 ± 0.08 kg, for female pens was 5.59 ± 0.09 kg and mixed pens was 5.67 ± 0.08 kg with there being no differences (P = 0.75).

![Figure 4.4](image_url)

**Figure 4.4. The mean weekly liveweight gain for the effect of strain over the production period.**

There was a significant strain x week interaction (P = 0.002).
Figure 4.5. The mean weekly liveweight gain for the effect of pen-sex over the six week production period.
There was significant pen-sex x week interaction (P < 0.001).

Figure 4.6. The mean weekly feed intake for the effect of strain over the production period.
The strain x week interaction was significant (P < 0.001).
4.4.4. Feed Conversion ratio (FCR)

The effect of strain on weekly FCR is shown in figure 4.8. There was a significant strain x week interaction (P = 0.04). Up until week six there were no strain effects on weekly FCR. In week six the weekly FCR for strain B X A was lower (P < 0.05) than that for strains B and B X A with strain A being intermediate and not different to other strains.

The effect of pen-sex on weekly FCR is shown in figure 4.9. There was a significant pen-sex x week interaction (P < 0.001). The only differences were seen in week six were male reared pens (P < 0.005) had a lower FCR than both females and mixed reared pens with no difference between the later two treatments.

The total composite FCR for the production period for the different strains were strain A, 1.95 ± 0.02; strain A X B, 2.00 ± 0.02; strain B, 1.96 ± 0.02 and strain B X A, 1.90 ± 0.02. There was a significant effect of strain on total FCR (P < 0.001). Strain B X A had lower total FCR (P < 0.05) than strains B and A X B. Also, strain A had a lower (P < 0.05) total FCR than strain A X B.

The effect of pen-sex rearing on composite FCR was significant (P < 0.001), with females pens (2.01 ± 0.01) having a higher (P < 0.05) FCR than both mixed pens (1.96 ± 0.01) which was in turn higher (P < 0.05) than male reared pens (1.89 ± 0.01). The strain x pen-sex interaction just failed to reach significance (P = 0.06).
Figure 4.8. The mean weekly feed conversion ratio (FCR) for the effect of strain over the production period.

There was a significant strain x week interaction (P = 0.004).

Figure 4.9. The mean weekly feed conversion ratio (FCR) for the effect of pen-sex over the production period.

The effect of pen-sex changed with time as indicated by the significant diet x week interaction (P < 0.001).

4.4.5. Water Intake

The effects of strain and pen-sex on weekly water intake are shown in figures 4.10 and 4.11, respectively. Both the strain x week and sex x week interactions were significant (both P < 0.001).

The main effects were; strain B X A having a lower (P < 0.05) water intake than strains B and A x B in all weeks and strain A having lower (P < 0.05) intake than strains B and A x B in weeks four to six and with B and A X B not being different at anytime. Male pens had lower (P < 0.05) water consumption than female pens in weeks one, five and six. There were no other effects of pen-sex on water consumption.
Total water intake for strain A was $17.90 \pm 0.23$ L, for strain A X B was $19.88 \pm 0.27$ L, for strain B was $19.71 \pm 0.02$ L and strain B X A was $17.19 \pm 0.22$ L. The effect of strain was significant ($P < 0.001$) with strains A and B X A ($P < 0.05$) having lower total consumption than strains B and A x B. Pen-sex had no significant effect ($P = 0.63$) on total water consumption with those birds reared as mixed sexes consuming $18.68 \pm 0.37$ L, males consuming $18.53 \pm 0.31$ L and females $18.79 \pm 0.43$ L.

**Figure 4.10.** The mean weekly water intake (mL) for the effect of strain over the production period.

The strain x week interaction was significant ($P < 0.001$).

**Figure 4.11.** The mean weekly water intake for the effect of pen-sex over the production period.

The interaction pen-sex x week was significant ($P < 0.001$).
4.4.6. Water to feed ratio

The effect of strain on the water to feed ratio changed with time (see Figure 4.12) with the strain x week interaction being significant (P < 0.001). In week one, the ratio was lower (P < 0.05) in strain B X A than strains B and A X B. In week five, the ratio was higher for strain A X B (P < 0.05) than for strains B and B x A. In week six, the ratio was higher for strain A X B (P < 0.05) than for strains A and B x A.

While the pen-sex x week interaction was significant (P < 0.001), the only difference was seen in week six where female pens had a higher (P < 0.05) water to feed ratio than did the males (see Figure 4.13).

The total composite water to feed ratios for the different strains were strain A, 3.34 ± 0.04; strain A X B, 3.43 ± 0.05; strain B, 3.33 ± 0.05 and strain B X A: 3.23 ± 0.05. Strain had a significant (P = 0.02) on total water to feed ratio. Strain B X A had a lower ratio than strain A X B (P < 0.05). The total composite water to feed ratio for male pens was 3.29 ± 0.04 for female pens was 3.36 ± 0.04 and for mixed sex pens was 3.35 ± 0.04 with the differences not being significant (P = 0.38).

![Figure 4.12. The mean weekly water to feed ratio for the effect of strain over the production period.](image)

There was a significant strain x week interaction (P < 0.001).
Figure 4.13. The mean weekly water to feed ratio for the effect of pen-sex over the production period.
There was a significant pen-sex x week interaction (P < 0.001).

4.4.7. Muscle development and yield

Week had a significant effect (P < 0.001) on breast muscle weight to liveweight % with it increasing in all weeks but the rate of increase was much greater after week four than it was in the previous weeks. The effect of strain, sex and pen-sex on the breast muscle weight to LW %, are shown in figures 4.14, 4.15 and 4.16, respectively. Neither strain (P = 0.22) or pen-sex (P = 0.23) had any significant effect on the breast muscle weight to LW %. Sex had a significant effect on the breast % (P = 0.008) with no significant sex x week interaction (P = 0.25). The breast muscle weight to LW % was higher for females than males (P < 0.05).

At 41 days the mean (± SEM) breast to LW % for strain A, A X B, B and B X A were 8.52 ± 1.24, 9.17 ± 1.34, 9.44 ± 1.38, 9.11 ± 1.33, respectively. At the same time females had a mean (± SEM) breast to LW % of 9.64 ± 1.12 and males 8.50 ± 0.99. For ducks reared in mixed sex pens the mean (± SEM) breast to LW % was 8.92 ± 0.94 and those reared in single sex pens was 9.20 ± 1.20.

The effect of strain on the thigh muscle weight to liveweight ratio expressed as a percentage is shown in figure 4.17. The effect of strain was not significant (P = 0.52). The effects of sex and pen-sex on the % of thigh muscle are shown in figures 4.18 and 4.19, respectively. Neither sex (P = 0.88) or pen-sex (P = 0.92) has an effect on the % thigh muscle. Week had a significant effect (P < 0.001) on thigh muscle weight to liveweight % with it increasing in week one to two, remaining similar in weeks two to four and then decreasing in weeks five and six.
Figure 4.14.  The mean weekly breast muscle weight to LW ratio expressed as a % for the effect of strain over the production period.

There was no significant strain effect (P = 0.22).

Figure 4.15.  The mean weekly breast muscle to LW ratio expressed as a % for the effect of sex over the production period.

The effect of sex was significant (P = 0.008) with females having a higher % than males at all times (P < 0.05).
Figure 4.16. The mean weekly breast muscle to LW ratio expressed as a % for the effect of pen-sex over the production period.

Pen-sex had no significant effect ($P = 0.23$).

Figure 4.17. The mean weekly thigh muscle to LW ratio expressed as a % for the effect of strain over the production period.

There was no significant strain effect ($P = 0.52$).
Figure 4.18. The mean weekly thigh muscle to LW ratio expressed as a % for the effect of sex over the production period.

There was no significant sex effect (P = 0.88).

Figure 4.19. The mean weekly thigh muscle to LW ratio expressed as a % for the effect of pen-sex over the production period.

There was no significant pen-sex effect (P = 0.92).

Week had a significant effect (P < 0.001) on the leg muscle (drumstick) weight to liveweight ratio expressed as a %. The % increased from week one to week two and then gradually decreased, each week thereafter. The effect of strain (see Figure 4.20) was marginally not significant (P = 0.09). The effects of sex and pen-sex are given in figures 4.21 and 4.22, respectively. Neither the effects of sex (P = 0.72) or pen-sex (P = 0.36) had an effect on the leg muscle %.
Figure 4.20. The mean weekly leg muscle (drumstick) to LW ratio expressed as a % for the effect of strain over the production period.

There was no significant strain effect (P = 0.09).

Figure 4.21. The mean weekly leg muscle (drumstick) to LW ratio expressed as a % for the effect of sex over the production period.

There was no significant sex effect (P = 0.72).
There was no significant pen-sex effect ($P = 0.36$).

4.4.8. Abdominal fat yield

Week had a significant effect ($P < 0.001$) on the weight of abdominal fat expressed as % of liveweight. The fat % increased significantly each week over the production period. The effect of strain (see Figure 4.23) was not significant ($P = 0.29$). The values at week six were, strain A, $1.34 \pm 0.14$ %; strain A X B, $1.31 \pm 0.13$ %; strain B, $1.39 \pm 14$ % and strain B x A $1.28 \pm 0.13$ %. The effect of sex on the abdominal fat % is shown in figure 4.24. The effect of sex was not significant ($P = 0.31$). Although it would appear that differences were starting to emerge in week six. At week six, the fat % for females was $1.45 \pm 0.11$ % and males it was $1.21 \pm 0.09$ %. The effect of pen-sex on the abdominal fat % is given in figure 4.25. Pen-sex had no effect ($P = 0.78$) on abdominal fat %.
Figure 4.24. The mean weekly abdominal fat weight to LW ratio expressed as a % for the effect of sex over the production period.

There was no significant strain effect (P = 0.31).

Figure 4.25. The mean weekly abdominal fat weight to LW ratio expressed as a % for the effect of pen-sex over the production period.

There was no significant pen-sex effect (P = 0.78).
4.4.9. Digestive organ weights and gastrointestinal tract measurements

Measurements are given as a percentage of the ratio of organ weight to liveweight.

4.4.9.1. Liver

The effects of strain, sex and pen-sex on the ratio of liver weight to liveweight expressed as percentage is given in table 4.2. There was significant strain x week interaction (P = 0.03). The main differences were seen in week one where Strain A had higher liver % than the other strains (P < 0.05). In week five, strain B x A had a lower liver % than did strain B (P < 0.05). There was a significant sex x pen-sex interaction (P = 0.047). Females reared in single sex pens had a lower (P < 0.05) liver % than females reared in mixed sex pens (4.42 ± 0.06 Vs 4.50 ± 0.07 %) whereas males reared in single sex pens had a similar liver % to males reared in mixed sex pens (4.39 ± 0.06 Vs 4.43 ± 0.07 %).

4.4.9.2. Proventriculus

The effects of week, strain, sex and pen-sex on the ratio of proventriculus weight to liveweight expressed as percentage are given in table 4.3. The effects of strain (P = 0.80), sex (P = 0.09) and pen-sex (P = 0.25) were not significant. The effect of week was significant (P < 0.001). The proventriculus weight to liveweight % was highest in week one and then it declined over then remainder of the production period.

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain A</td>
<td>7.11 ± 0.21&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.22 ± 0.16</td>
<td>4.98 ± 0.15</td>
<td>3.92 ± 0.11</td>
<td>3.39 ± 0.10&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.02 ± 0.09</td>
</tr>
<tr>
<td>Strain AB</td>
<td>6.51 ± 0.19&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.38 ± 0.16</td>
<td>4.92 ± 0.15</td>
<td>4.09 ± 0.12</td>
<td>3.44 ± 0.10&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.21 ± 0.10</td>
</tr>
<tr>
<td>Strain B</td>
<td>6.08 ± 0.18&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.39 ± 0.16</td>
<td>5.01 ± 0.15</td>
<td>3.81 ± 0.11</td>
<td>3.64 ± 0.10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.00 ± 0.09</td>
</tr>
<tr>
<td>Strain BA</td>
<td>6.36 ± 0.19&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.38 ± 0.16</td>
<td>4.94 ± 0.15</td>
<td>3.85 ± 0.12</td>
<td>3.28 ± 0.10&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.14 ± 0.09</td>
</tr>
<tr>
<td>Female</td>
<td>6.27 ± 0.14</td>
<td>5.25 ± 0.12</td>
<td>5.05 ± 0.11</td>
<td>3.90 ± 0.09</td>
<td>3.51 ± 0.08</td>
<td>3.06 ± 0.07</td>
</tr>
<tr>
<td>Male</td>
<td>6.73 ± 0.15</td>
<td>5.43 ± 0.12</td>
<td>4.88 ± 0.11</td>
<td>3.91 ± 0.09</td>
<td>3.39 ± 0.07</td>
<td>3.11 ± 0.07</td>
</tr>
<tr>
<td>Single</td>
<td>6.41 ± 0.12</td>
<td>5.25 ± 0.10</td>
<td>4.86 ± 0.09</td>
<td>3.87 ± 0.07</td>
<td>3.34 ± 0.06</td>
<td>3.05 ± 0.06</td>
</tr>
<tr>
<td>Mixed</td>
<td>6.57 ± 0.17</td>
<td>5.43 ± 0.14</td>
<td>5.07 ± 0.13</td>
<td>3.95 ± 0.10</td>
<td>3.57 ± 0.09</td>
<td>3.11 ± 0.08</td>
</tr>
</tbody>
</table>

Table 4.2: The mean (± SEM) liver weight to liveweight ratio expressed as percentage.

There was a significant strain x week interaction (P = 0.03). Within columns for the effect of strain, values with different superscripts are significantly different (P < 0.05).
Table 4.3: The mean (± SEM) proventriculus weight to liveweight ratio expressed as percentage.

There was significant week effect (P < 0.001). Within columns for the effect of week, values with different superscripts are significantly different (P < 0.05).

4.4.9.3 Gizzard

The effects of week, strain, sex and pen-sex on the gizzard weight to liveweight expressed as % is given in table 4.4. There was a significant week effect (P < 0.001). The gizzard weight to liveweight % was highest in week one and then it decreased thereafter until week five. There was significant sex effect (P < 0.001), with males (3.74 ± 0.05 %) having a higher (P < 0.05) % than females (3.43 ± 0.05 %)

The effects of strain and pen-sex were complicated by there being a significant strain x pen-sex interaction (P = 0.04). When comparing pen-sex effects, there were no differences between single and mixed pen rearing expect for strain B where the gizzard % was higher for mixed pens groups (P < 0.05). The strain effects were more complex. When comparing strains A and A X B, the gizzard % was similar for single pen rearing (3.60 ± 0.07 Vs 3.57 ± 0.07 %) but for mixed pen rearing the % was higher (P<0.05) for strain A (3.72 ± 0.09 Vs 3.39 ± 0.09 %). When comparing strains A and B the gizzard % was similar for mixed pen rearing (3.72 ± 0.09 Vs 3.59 ± 0.09 %) but for single pen rearing the % was higher (P < 0.05) for strain A (3.60 ± 0.07 Vs 3.38 ± 0.06 %). When comparing strains B X A and A x B the gizzard % was similar for single pen rearing (3.65 ± 0.07 Vs 3.57 ± 0.07 %) but for mixed pen rearing the % was higher (P < 0.05) for strain B x A (3.79 ± 0.10 Vs 3.39 ± 0.09 %). When comparing strains B X A and B the gizzard % was similar for mixed pen rearing (3.79 ± 0.10 Vs 3.59 ± 0.09 %) but for single pen rearing the % was higher (P < 0.05) for strain B x A (3.65 ± 0.07 Vs 3.38 ± 0.06 %).
<table>
<thead>
<tr>
<th>Week</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.98 ± 0.09&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.51 ± 0.09&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.59 ± 0.07&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.27 ± 0.06&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.82 ± 0.05&lt;sup&gt;e&lt;/sup&gt;</td>
<td>2.84 ± 0.05&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>2</td>
<td>5.00 ± 0.19</td>
<td>4.44 ± 0.16</td>
<td>3.78 ± 0.14</td>
<td>3.36 ± 0.12</td>
<td>2.85 ± 0.11</td>
<td>2.93 ± 0.11</td>
</tr>
<tr>
<td>3</td>
<td>4.95 ± 0.18</td>
<td>4.46 ± 0.17</td>
<td>3.48 ± 0.13</td>
<td>3.77 ± 0.12</td>
<td>2.78 ± 0.10</td>
<td>2.72 ± 0.10</td>
</tr>
<tr>
<td>4</td>
<td>4.92 ± 0.18</td>
<td>4.59 ± 0.17</td>
<td>3.62 ± 0.13</td>
<td>3.03 ± 0.11</td>
<td>2.70 ± 0.10</td>
<td>2.56 ± 0.09</td>
</tr>
<tr>
<td>5</td>
<td>4.96 ± 0.18</td>
<td>4.54 ± 0.17</td>
<td>3.50 ± 0.13</td>
<td>3.43 ± 0.13</td>
<td>3.04 ± 0.10</td>
<td>3.15 ± 0.12</td>
</tr>
<tr>
<td>6</td>
<td>4.75 ± 0.13</td>
<td>4.30 ± 0.12</td>
<td>3.41 ± 0.09</td>
<td>3.18 ± 0.09</td>
<td>2.69 ± 0.07</td>
<td>2.73 ± 0.06</td>
</tr>
<tr>
<td>Female</td>
<td>5.18 ± 0.14</td>
<td>4.73 ± 0.13</td>
<td>3.78 ± 0.10</td>
<td>3.36 ± 0.09</td>
<td>3.00 ± 0.08</td>
<td>2.93 ± 0.07</td>
</tr>
<tr>
<td>Male</td>
<td>4.96 ± 0.11</td>
<td>4.46 ± 0.10</td>
<td>3.55 ± 0.08</td>
<td>3.24 ± 0.08</td>
<td>2.77 ± 0.06</td>
<td>2.85 ± 0.07</td>
</tr>
<tr>
<td>Single</td>
<td>4.96 ± 0.15</td>
<td>4.56 ± 0.12</td>
<td>3.64 ± 0.12</td>
<td>3.29 ± 0.11</td>
<td>2.92 ± 0.09</td>
<td>2.82 ± 0.09</td>
</tr>
<tr>
<td>Mixed</td>
<td>4.96 ± 0.10</td>
<td>4.56 ± 0.12</td>
<td>3.64 ± 0.12</td>
<td>3.29 ± 0.11</td>
<td>2.92 ± 0.09</td>
<td>2.82 ± 0.09</td>
</tr>
</tbody>
</table>

Table 4.4. The mean (± SEM) gizzard weight to liveweight ratio expressed as a percentage.

There was significant effects of week and sex (both P < 0.001) and strain x pen-sex interaction (P = 0.04). Within columns for the effect of week, values with different superscripts are significantly different (P < 0.05).

4.4.10. Gastrointestinal tract measurements

Measurements of the GIT are expressed as cm per 100 g of liveweight.

4.4.10.1. Duodenum length (DL)

The effects of strain, sex and pen-sex on the length (cm) of the dueodenum (DL) per 100g liveweight is given in table 4.5. The effect of strain was significant (P < 0.00 1). Strains A (2.51 ± 0.03 cm) and B X A (2.54 ± 0.03 cm) had greater DL length (P < 0.05), than did strains A X B (2.36 ± 0.03 cm) and B (2.33 ± 0.03 cm). The effects of sex changed with time as indicated by the significant sex x week interaction (P = 0.03). The sex differences are confined to week two where females have a longer DL length than males (P < 0.05). There was no effect of pen-sex on DL length (P = 0.22).
<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strain A</strong></td>
<td>9.10 ± 0.26</td>
<td>4.08 ± 0.12</td>
<td>2.46 ± 0.07</td>
<td>1.73 ± 0.05</td>
<td>1.39 ± 0.04</td>
<td>1.12 ± 0.03</td>
</tr>
<tr>
<td><strong>Strain AB</strong></td>
<td>9.07 ± 0.26</td>
<td>4.00 ± 0.12</td>
<td>2.23 ± 0.06</td>
<td>1.57 ± 0.05</td>
<td>1.28 ± 0.04</td>
<td>1.08 ± 0.03</td>
</tr>
<tr>
<td><strong>Strain B</strong></td>
<td>8.84 ± 0.26</td>
<td>3.83 ± 0.11</td>
<td>2.30 ± 0.07</td>
<td>1.53 ± 0.04</td>
<td>1.24 ± 0.04</td>
<td>1.07 ± 0.03</td>
</tr>
<tr>
<td><strong>Strain BA</strong></td>
<td>9.45 ± 0.27</td>
<td>4.16 ± 0.12</td>
<td>2.34 ± 0.07</td>
<td>1.78 ± 0.05</td>
<td>1.38 ± 0.04</td>
<td>1.19 ± 0.03</td>
</tr>
<tr>
<td><strong>Female</strong></td>
<td>8.96 ± 0.18</td>
<td>4.21 ± 0.09a</td>
<td>2.36 ± 0.05</td>
<td>1.64 ± 0.03</td>
<td>1.35 ± 0.03</td>
<td>1.11 ± 0.02</td>
</tr>
<tr>
<td><strong>Male</strong></td>
<td>9.25 ± 0.19</td>
<td>3.89 ± 0.08b</td>
<td>2.30 ± 0.05</td>
<td>1.68 ± 0.03</td>
<td>1.28 ± 0.03</td>
<td>1.12 ± 0.02</td>
</tr>
<tr>
<td><strong>Single</strong></td>
<td>9.03 ± 0.16</td>
<td>4.07 ± 0.07</td>
<td>2.30 ± 0.04</td>
<td>1.66 ± 0.07</td>
<td>1.29 ± 0.02</td>
<td>1.10 ± 0.02</td>
</tr>
<tr>
<td><strong>Mixed</strong></td>
<td>9.20 ± 0.23</td>
<td>3.96 ± 0.10</td>
<td>2.36 ± 0.06</td>
<td>1.64 ± 0.04</td>
<td>1.36 ± 0.03</td>
<td>1.13 ± 0.03</td>
</tr>
</tbody>
</table>

Table 4.5: The mean (±SEM) length of the DL (cm) per 100g bodyweight during the production period.

There was a significant strain effect (P < 0.001) and sex x week interaction (P = 0.03) interaction. Within columns for the effect of sex, values with different superscripts are significantly different (P < 0.05).

4.4.10.2. Length of the jejunum (Duodenum to Merkle's Diverticulum: DL-MD)

The effects of strain, sex and pen-sex on the length (cm) of small intestine from the duodenal loop to Merkles Diverticulum (DL-MD) per 100g liveweight are given in table 4.6. Week had a significant effect on DL-MD length (P < 0.001). The largest relative length was at week one and this progressively decreased with time. The effect of strain was significant (P < 0.001). The length of DL-MD segment was greater (P < 0.05) for strains A (6.40 ± 0.06 cm) and B x A (6.59 ± 0.04 cm) than strains B (6.13 ± 0.06 cm) and A x B (6.17 ± 0.06 cm). The effect of sex on the length of the DL-MD segment was significant (P = 0.02) with this being longer (P < 0.05) in females (6.39 ± 0.05 cm) than males (6.25 ± 0.04 cm). Pen-sex also had significant effect (P = 0.04) on the length of the DL-MD segment with this being longer (P < 0.05) for mixed sex pens (6.39 ± 0.06 cm) than for single sex pens (6.25 ± 0.04 cm).
Table 4.6: The mean (± SEM) length in cm of small intestine form DL-MD per 100g liveweight during the production period.

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week</td>
<td>22.8 ± 0.3a</td>
<td>10.1 ± 0.1b</td>
<td>6.0 ± 0.1c</td>
<td>4.4 ± 0.1d</td>
<td>3.5 ± 0.1e</td>
<td>2.9 ± 0.1f</td>
</tr>
<tr>
<td>Strain A</td>
<td>22.5 ± 0.5</td>
<td>10.1 ± 0.2</td>
<td>6.1 ± 0.1</td>
<td>4.5 ± 0.1</td>
<td>3.6 ± 0.1</td>
<td>3.1 ± 0.1</td>
</tr>
<tr>
<td>Strain AB</td>
<td>22.4 ± 0.5</td>
<td>9.9 ± 0.2</td>
<td>5.9 ± 0.1</td>
<td>4.2 ± 0.1</td>
<td>3.4 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Strain B</td>
<td>22.4 ± 0.5</td>
<td>10.1 ± 0.2</td>
<td>6.0 ± 0.1</td>
<td>4.2 ± 0.1</td>
<td>3.4 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Strain BA</td>
<td>24.0 ± 0.5</td>
<td>10.1 ± 0.2</td>
<td>6.0 ± 0.1</td>
<td>4.8 ± 0.1</td>
<td>3.6 ± 0.1</td>
<td>3.1 ± 0.1</td>
</tr>
<tr>
<td>Female</td>
<td>22.7 ± 0.4</td>
<td>10.1 ± 0.2</td>
<td>6.1 ± 0.1</td>
<td>4.5 ± 0.1</td>
<td>3.6 ± 0.1</td>
<td>3.0 ± 0.1</td>
</tr>
<tr>
<td>Male</td>
<td>22.9 ± 0.4</td>
<td>9.9 ± 0.2</td>
<td>5.9 ± 0.1</td>
<td>4.4 ± 0.1</td>
<td>3.4 ± 0.1</td>
<td>3.0 ± 0.1</td>
</tr>
<tr>
<td>Single</td>
<td>23.1 ± 0.5</td>
<td>10.0 ± 0.2</td>
<td>6.1 ± 0.1</td>
<td>4.8 ± 0.1</td>
<td>3.6 ± 0.1</td>
<td>3.0 ± 0.1</td>
</tr>
<tr>
<td>Mixed</td>
<td>22.5 ± 0.3</td>
<td>10.1 ± 0.2</td>
<td>6.0 ± 0.1</td>
<td>4.4 ± 0.1</td>
<td>3.5 ± 0.1</td>
<td>2.9 ± 0.1</td>
</tr>
</tbody>
</table>

Strain (P < 0.001), sex (P = 0.02) and pen-sex (P = 0.04) influenced the length of the DL-MD segment. For week, within the row values with different superscripts are significantly different (P < 0.05).

4.4.10.3. Length of the Ileum (Merkle’s Diverticulum to the ileo-caecal junction (MD-ICJ))

The effects of strain, sex, pen-sex and week on the length (cm) of small intestine from the Merkles Diverticulum to the ileo-caecal junction (MD-ICJ) per 100g liveweight are given in table 4.7. There was significant week effect (P < 0.001). The largest relative length was at week one and this progressively decreased with time. There was no significant sex effect (P = 0.51) on the relative MD-ICJ length.

There was a significant strain x pen-sex interaction (P = 0.03). For strain B birds reared in mixed sex pens (6.21 ± 0.06 cm) had a greater length (P < 0.05), than those reared in single sex pens (5.89 ± 0.06 cm). For all other strains this was not evident. The pen rearing effects for different strain comparisons are more complex. For single sex rearing, strain A (6.48 ± 0.08 cm) and B X A (6.37 ± 0.08 cm) had greater (P < 0.05) segment length than did strain B (5.89 ± 0.06 cm) and strain A X B (5.88 ± 0.08 cm). For mixed sex rearing, again strain A (6.25 ± 0.08 cm) and A X B (6.59 ± 0.12 cm) had greater (P < 0.05) segment length than did strain B (5.92 ± 0.11 cm) and strain B X A (6.21 ± 0.11 cm).
Table 4.7: The mean (± SEM) length in cm of intestine from MD-ICJ per 100g bodyweight during the production period.

There was significant week effect (P < 0.001). There was a significant strain x pen-sex interaction (P = 0.03). For week, within the row, values with different superscripts are significantly different (P < 0.05).

<table>
<thead>
<tr>
<th>Strain/Class</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain A</td>
<td>22.6 ± 0.6</td>
<td>10.2 ± 0.3</td>
<td>6.3 ± 1</td>
<td>4.3 ± 0.1</td>
<td>3.6 ± 0.1</td>
<td>3.0 ± 0.1</td>
</tr>
<tr>
<td>Strain AB</td>
<td>21.6 ± 0.6</td>
<td>9.8 ± 0.3</td>
<td>5.8 ± 0.1</td>
<td>4.0 ± 0.1</td>
<td>3.3 ± 0.1</td>
<td>2.7 ± 0.1</td>
</tr>
<tr>
<td>Strain B</td>
<td>22.0 ± 0.6</td>
<td>10.3 ± 0.3</td>
<td>5.9 ± 0.1</td>
<td>4.0 ± 0.1</td>
<td>3.3 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Strain BA</td>
<td>23.4 ± 0.6</td>
<td>10.3 ± 0.3</td>
<td>6.2 ± 0.1</td>
<td>4.7 ± 0.1</td>
<td>3.5 ± 0.1</td>
<td>3.0 ± 0.1</td>
</tr>
<tr>
<td>Female</td>
<td>22.1 ± 0.4</td>
<td>10.2 ± 0.2</td>
<td>6.2 ± 0.1</td>
<td>4.2 ± 0.1</td>
<td>3.4 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Male</td>
<td>22.7 ± 0.4</td>
<td>10.1 ± 0.2</td>
<td>5.9 ± 0.1</td>
<td>4.3 ± 0.1</td>
<td>3.4 ± 0.1</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Single</td>
<td>22.4 ± 0.4</td>
<td>10.2 ± 0.2</td>
<td>5.9 ± 0.1</td>
<td>4.2 ± 0.1</td>
<td>3.4 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Mixed</td>
<td>22.4 ± 0.5</td>
<td>10.2 ± 0.3</td>
<td>6.2 ± 0.1</td>
<td>4.3 ± 0.1</td>
<td>3.4 ± 0.1</td>
<td>2.9 ± 0.1</td>
</tr>
</tbody>
</table>

4.4.10.4. Total Caecal length (CL)

The effects of strain, sex and pen-sex on the total caecal (CL) length (cm) per 100g liveweight are given in table 4.8. The effect of strain was significant (P = 0.03) with ducks of strain B (2.70 ± 0.04 cm/100g) having shorter relative length (P < 0.05) than ducks of strain A (2.84 ± 0.04cm/100g) and B x A (2.84 ± 0.04cm/100g). Sex had no effect on the total relative CL length (P = 0.30) There was significant pen-sex x week interaction (P = 0.03). The differences were confined to week two where the single sex reared birds had longer length than the mixed sex reared birds (P < 0.05) and week five where the differences in length were reversed with the mixed sex reared birds having the longer CL length (P < 0.05).
<table>
<thead>
<tr>
<th>Strain</th>
<th>Female</th>
<th>Male</th>
<th>Single</th>
<th>Mixed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain A</td>
<td>7.80 ± 0.25</td>
<td>4.33 ± 0.14</td>
<td>2.96 ± 0.09</td>
<td>2.11 ± 0.07</td>
</tr>
<tr>
<td>Strain AB</td>
<td>7.63 ± 0.24</td>
<td>4.27 ± 0.14</td>
<td>2.87 ± 0.09</td>
<td>2.07 ± 0.07</td>
</tr>
<tr>
<td>Strain B</td>
<td>7.77 ± 0.25</td>
<td>4.18 ± 0.14</td>
<td>2.80 ± 0.09</td>
<td>1.98 ± 0.07</td>
</tr>
<tr>
<td>Strain BA</td>
<td>7.95 ± 0.25</td>
<td>4.22 ± 0.14</td>
<td>2.83 ± 0.09</td>
<td>2.25 ± 0.07</td>
</tr>
<tr>
<td>Female</td>
<td>7.66 ± 0.18</td>
<td>4.33 ± 0.10</td>
<td>2.87 ± 0.07</td>
<td>2.09 ± 0.05</td>
</tr>
<tr>
<td>Male</td>
<td>7.92 ± 0.18</td>
<td>4.20 ± 0.10</td>
<td>2.86 ± 0.06</td>
<td>2.11 ± 0.05</td>
</tr>
<tr>
<td>Single</td>
<td>7.81 ± 0.15</td>
<td>4.41 ± 0.08a</td>
<td>2.85 ± 0.05</td>
<td>2.10 ± 0.04</td>
</tr>
<tr>
<td>Mixed</td>
<td>7.76 ± 0.21</td>
<td>4.11 ± 0.11b</td>
<td>2.88 ± 0.08</td>
<td>2.10 ± 0.06</td>
</tr>
</tbody>
</table>

Table 4.8: The mean (± SEM) length in cm of CL per 100g liveweight during the production period.

Strain (P = 0.03) had significant effect and there was a significant pen-sex x week interaction (P = 0.03). For pen-sex rearing, within the columns, values with different superscripts are significantly different (P < 0.05).

4.4.11. Proximate analysis of Carcass Composition

The carcass water, protein, fat and ash content are given in table 4.9 (week three) and table 4.10 (week five). Strain, sex and pen-sex had no effects on carcass composition.

The carcass composition for weeks three and five are given in figure 4.26. There was a highly significant (P < 0.001) effect of week on carcass water, protein and fat %. Ducks three weeks of age (65.8 ± 0.3 %) had a significantly higher (P < 0.05), water content than ducks aged five weeks (61.6 ± 0.5 %). Ducks at five weeks of age had higher (P < 0.05), carcass protein (18.7 ± 0.3 Vs 17.5 ± 0.3) and fat (16.4 ± 0.3 Vs 13.8 ± 0.2) content than did ducks at three weeks of age. There was no significant effect of week on carcass ash % (week three; 2.93 ± 0.03 % and week five; 3.00 ± 0.05 %).
### Table 4.9: The effects of strain, sex and pen-sex on the composition of the carcass for ducks at three weeks of age.

<table>
<thead>
<tr>
<th>Week 3</th>
<th>Water %</th>
<th>Protein %</th>
<th>Fat %</th>
<th>Ash %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain A</td>
<td>64.7 ± 0.5</td>
<td>16.3 ± 0.2</td>
<td>16.1 ± 0.3</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Strain AB</td>
<td>64.2 ± 0.6</td>
<td>16.1 ± 0.2</td>
<td>16.6 ± 0.4</td>
<td>3.1 ± 0.2</td>
</tr>
<tr>
<td>Strain B</td>
<td>64.4 ± 0.7</td>
<td>16.3 ± 0.2</td>
<td>16.6 ± 0.4</td>
<td>2.7 ± 0.2</td>
</tr>
<tr>
<td>Strain BA</td>
<td>65.3 ± 1.0</td>
<td>15.9 ± 0.4</td>
<td>15.9 ± 0.6</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Female</td>
<td>64.7 ± 0.6</td>
<td>16.1 ± 0.2</td>
<td>16.3 ± 0.3</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Male</td>
<td>64.5 ± 0.4</td>
<td>16.2 ± 0.1</td>
<td>16.3 ± 0.3</td>
<td>3.0 ± 0.1</td>
</tr>
<tr>
<td>Single</td>
<td>64.8 ± 0.5</td>
<td>16.1 ± 0.2</td>
<td>16.2 ± 0.3</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Mixed</td>
<td>64.3 ± 0.3</td>
<td>16.3 ± 0.1</td>
<td>16.3 ± 0.3</td>
<td>3.1 ± 0.1</td>
</tr>
</tbody>
</table>

### Table 4.10: The effects of strain, sex and pen-sex on the composition of the carcass for ducks at five weeks of age.

<table>
<thead>
<tr>
<th>Week 5</th>
<th>Water %</th>
<th>Protein %</th>
<th>Fat %</th>
<th>Ash %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain A</td>
<td>61.4 ± 0.7</td>
<td>17.4 ± 0.3</td>
<td>18.1 ± 0.5</td>
<td>3.1 ± 0.1</td>
</tr>
<tr>
<td>Strain AB</td>
<td>59.7 ± 0.9</td>
<td>17.8 ± 0.2</td>
<td>19.1 ± 0.7</td>
<td>3.4 ± 0.2</td>
</tr>
<tr>
<td>Strain B</td>
<td>59.6 ± 0.6</td>
<td>17.8 ± 0.3</td>
<td>19.4 ± 0.5</td>
<td>3.2 ± 0.1</td>
</tr>
<tr>
<td>Strain BA</td>
<td>61.8 ± 0.8</td>
<td>17.2 ± 0.4</td>
<td>17.9 ± 0.6</td>
<td>3.0 ± 0.1</td>
</tr>
<tr>
<td>Female</td>
<td>60.6 ± 0.6</td>
<td>17.4 ± 0.2</td>
<td>18.8 ± 0.4</td>
<td>3.2 ± 0.1</td>
</tr>
<tr>
<td>Male</td>
<td>60.6 ± 0.5</td>
<td>17.7 ± 0.2</td>
<td>18.5 ± 0.4</td>
<td>3.4 ± 0.1</td>
</tr>
<tr>
<td>Single</td>
<td>60.3 ± 0.5</td>
<td>17.7 ± 0.2</td>
<td>18.8 ± 0.4</td>
<td>3.2 ± 0.1</td>
</tr>
<tr>
<td>Mixed</td>
<td>61.3 ± 0.5</td>
<td>17.2 ± 0.3</td>
<td>18.3 ± 0.4</td>
<td>3.2 ± 0.1</td>
</tr>
</tbody>
</table>
Figure 4.26. The effect of week on the carcass % of water, protein, fat and ash.
Water content was higher in week three and protein and fat content higher in week five (* P < 0.05).

4.4.12. Metabolism study

The effects of strain and pen-sex on apparent AME, ileal nitrogen digestibility and nitrogen retention are given in table 4.11. Strain (P = 0.59) and pen-sex (P = 0.97) had no effects on apparent AME. Strain had significant effect on ileal nitrogen digestibility (P = 0.04). Strain A had a higher digestibility (P < 0.05) than strains B and A X B. The effect of pen-sex on ileal nitrogen digestibility was not significant (P = 0.58). Strain (P = 0.047) had a significant effect on nitrogen retention. Strain A had a lower retention rate than did strains B and A X B. Pen-sex (P = 0.88) had no effect on nitrogen retention.

<table>
<thead>
<tr>
<th></th>
<th>AME (MJ/kg)</th>
<th>Ileal nitrogen digestibility (%)</th>
<th>Nitrogen retention (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain A</td>
<td>13.00 ± 0.12</td>
<td>76.2 ± 1.5^a</td>
<td>46.8 ± 1.5^a</td>
</tr>
<tr>
<td>Strain A X B</td>
<td>13.17 ± 0.09</td>
<td>72.1 ± 1.3^b</td>
<td>52.0 ± 0.9^b</td>
</tr>
<tr>
<td>Strain B</td>
<td>13.28 ± 0.08</td>
<td>71.3 ± 0.9^b</td>
<td>52.9 ± 1.2^b</td>
</tr>
<tr>
<td>Strain B X A</td>
<td>13.16 ± 0.21</td>
<td>73.5 ± 1.1^ab</td>
<td>50.8 ± 2.1^ab</td>
</tr>
<tr>
<td>Male Pens</td>
<td>13.13 ± 0.16</td>
<td>74.1 ± 0.9</td>
<td>51.2 ± 1.7</td>
</tr>
<tr>
<td>Female Pens</td>
<td>13.17 ± 0.08</td>
<td>72.6 ± 1.2</td>
<td>50.7 ± 1.1</td>
</tr>
<tr>
<td>Mixed Pens</td>
<td>13.16 ± 0.40</td>
<td>73.1 ± 1.3</td>
<td>50.0 ± 1.3</td>
</tr>
</tbody>
</table>

Table 4.11. The mean (± SEM) apparent metabolisable energy (AME) on an as fed basis, ileal nitrogen digestibility and nitrogen retention for the effect of strain and pen-sex.
4.5. Discussion

Liveweight gain and muscle yield are important factors determining production efficiency. Studies in ducks have shown high correlations between liveweight and muscle content (Kleczek et al., 2006; Bochno et al., 1997). Presently, the Australian market has a specific requirement for a duck with slaughter weight of 2.85 kg. In the present study, predicted liveweight means at 41 days ranged from 2724 g for Strain B X A to 2963 g for Strain B. These are mean values and on average, males were 200 g heavier than females (range 142 g to 272 g for different strains). In practical terms, only three of the sex and strain combinations achieved the desired market weight at 41 days. The liveweights recorded here at six weeks were similar to those recorded in the study of Farrell (2000), where Pekin ducks raised under Australian conditions achieved a mean liveweight of 2834 g at six weeks of age. Overseas, Pekin ducks are capable of achieving mean liveweights of 3280 g at six weeks of age (Applegate et al., 1999). The difference between growth rates of ducks produced under Australian conditions and those produced overseas highlights the necessity for research to be completed under Australian conditions.

Studies reveal that duck genotype has a significant effect on growth rates at an early age (Maruyama et al., 1999; Baeza et al., 1997). In the current study, strain had a significant effect on individual liveweights at 41 of age. Strain B had a significantly higher liveweight than the other strains for both males and females. The high growth rate of this strain indicates that it is capable of achieving market weight at an earlier age than the other strains. The individual liveweights of Strains A and B X A, at 41 days, did not differ significantly and in summer, these strains would require longer than six weeks to achieve the desired market weight. In a commercial situation this would reduce productivity, but increase breast muscle yields. However, studies have shown that over six weeks of age ducks also have increased fat deposition and reduced feed efficiency (Siregar et al., 1982a & b). There were no apparent signs of heterosis for liveweight in either of the crosses in the present study. Wawro et al. (2004) reported that crossbred ducks did not demonstrate heterosis in terms of liveweight, but they did produce higher meat yields. These findings were not substantiated in the present investigation, where the proportion of breast muscle in the reciprocal crosses was inside the range for the parent strains at market age.

While the early growth rates in ducks, exceeds that of other poultry species (Applegate et al., 2005), late breast muscle deposition is a concern. The stringent market specification for a duck of 2.85 kg creates a problem for the Australian industry and this is to do with the poor breast muscle yield during the early weeks of development. Under existing market requirements, it is impossible to produce ducks at the correct weight without compromising breast muscle yield. In the present study, the proportion of breast muscle was low at an early age and reached its peak at a later age than did the development of the leg and thigh muscle. For each subsequent week, the proportion of breast muscle increased significantly. However, the most rapid rate of increase occurred from day 27 to day 41. The predicted mean for the relative proportion of breast muscle at market age ranged from 8.52 to 9.44 % with females having a higher % (9.64) than males (8.50). Wang et al. (2004), reported that Pekin ducks yielded 9.73 % breast muscle. The low yield of breast muscle at market age indicates that it is still maturing with processing occurring prior to maximum rate of breast muscle deposition. Baeza et al. (2002) reported that the most rapid deposition of breast muscle in Muscovy ducks occurred between eight to ten weeks of age. Gille and Salomon (1994), developed an asymptotic growth curve for the m. pectoris (largest muscle of the breast) in Pekin ducks and found that the inflection point did not occur until 50 days of age. Although the proportion of breast muscle could be increased substantially by processing at a later age, the whole duck restaurant market has strict regulations concerning carcass size. Stadelman and Meinert (1977) found that breast muscle contributed 4.8% of the carcass weight at day 28, and at 63 days of age it reached 15.9% of the carcass weight. Maruyama et al. (1999) compared leg muscle and breast muscle development as a proportion of total carcass weight. The increase in percentage breast muscle was proportionate to the decrease in percentage leg muscle. In the present study, maximum leg and thigh muscle development occurs earlier and as proportion of liveweight decreases at a slow rate after week two. In chickens, breast muscle yield is found to be a highly heritable trait. Clayton and Powell (1979) showed that while it is possible to
select for greater breast muscle yield, its strong correlation with increased body weight generally meant that the proportion of breast muscle relative to body weight remained unchanged. The liveweight of domesticated ducks is significantly greater than their wild ancestors but there is no significant difference in the proportion of protein deposition relative to carcass weight (Gille & Salomon 1998). Ducks selected for high breast muscle thickness had higher IGF-I levels than ducks with lower breast muscle thickness and males have higher IGF-1 concentrations than females. Because of the limited research data the importance of this relationship is not known.

A further complication associated with processing at a later age is the distinct decrease in the rate of liveweight gain that occurs after week five of age. The FCR increases significantly from week five to six and this is largely the result of the continued increase in feed intake and decrease in liveweight gain at this time. Strain effects on FCR were limited to week six where it was better for strain B X A than other strains. In the present study, the FCR for the entire production period ranged from 1.90 for to 2.00. The composite FCR was better for strain B X A than for strains B and A x B and for strain A compared to strain A X B. These differences are most likely related to the higher maintenance energy requirements of strain B and A X B which are significantly heavier and have higher feed intakes. These heavier strains produced more total breast meat and it would seem, to be more appropriate, to determine efficiency of production as the feed required to produce a unit of saleable breast meat. This would take into account the higher maintenance requirements of larger birds. The FCR of broilers at six weeks of age has been reported at 1.62 (Havenstein et al., 2003). The loss of energy through increased heat production in ducklings is likely to be a contributing factor to the higher FCR in ducks compared to chickens (Siregar & Farrell, 1980).

In the Australian meat duck industry it is common practice to raise ducks in mixed sex groups. This management style has been adopted because it is widely believed that sexual dimorphism in Pekin ducks grown to six weeks of age (market age) is negligible. Additionally, rearing ducks in mixed sex pens avoids the necessity of vent sexing, which is both an invasive and an expensive procedure. Sexual dimorphism has been detected in most domesticated avian species, including chickens (Barbato & Vasilatos-Youken, 1991), turkeys (Sengul & Kiraz, 2005) and quails (DuPreez & Sales, 1997). However, the degree of dimorphism varies between species and even between breeds within the same species. Sexual dimorphism for liveweights of Pekin ducks is low compared to Muscovy ducks (Oliver et al., 1977; Tai & Rouvier, 1998). There are conflicting opinions as to whether there is sufficient dimorphism to justify single sex rearing in commercial conditions. The number of studies comparing the effect of mixed and single sex rearing in ducks is limited. Farhat and Chavez (2000) reported that ducks reared in single sex pens demonstrated significantly higher liveweights by five weeks than those raised in mixed sex pens. In the current study, males experienced higher growth rates than females and subsequently had a significantly higher liveweight by six weeks of age. The differences between males and females averaged approximately 200 g, with the differences between sexes of the same strain, ranging from 142 g for Strain A to 272 g for Strain A x B. However, a similar difference between sexes was seen whether they were reared as separated sexes or reared together in mixed sex pens. The liveweight and proportion of muscle deposition did not differ significantly between ducks reared as single or mixed sexes. The practical complications of rearing the sexes separately would not seem to warrant the practice. Having said this, there would be an advantage at the point of processing were males reaching the target weight of 2.85 kg could be processed 2-3 days earlier than females. This would ensure there was less variation in processing weight than could be expect if mixed reared batches were processed as a whole group. While it was not investigated here, the nutrient requirements of males and females would be different and single sex rearing could make allowance for the different nutrient requirements of the sexes especially towards the end of production.

On farms, producers often restrict water availability to reduce the problems associated with moist litter. Winn and Godfrey (1967), showed that limiting water consumption in poultry reduces growth rates and increases FCR. In broiler chickens a water to feed ratio of 1.6:1 is considered optimal (Winn & Godfrey, 1967). Previous studies in ducks have reported water to feed ratios of up to 4.2:1 (Scott & Dean, 1991). Siregar and Farrell, (1980) compared the water to feed ratio in ducks and chickens and
found it to be higher in ducks (4.2:1) than chickens (2.3:1). In the same report but a separate experiment, the water to feed ratio for ducks on a low protein diet was 3.3:1 and on a high protein diet was 4.1:1. In the present study, water to feed ratio varied from 2.32 at week three to 3.91 at week six and were significantly affected by both age and strain. The total composite water to feed ratio was around 3.3:1. The high water to feed ratios observed in ducks highlights the necessity to maintain adequate access to water at all times. The water to feed ratios observed in the present study is important from an industry perspective because producers can use them as a benchmark to determine if their ducks are receiving adequate quantities of water. It is important to note that the trial was conducted over summer, which is likely to have had a significant effect on both water and feed intake.

Development of the intestinal tract is a limiting factor in the early growth of birds (Konarzewski et al., 1989). Development of the intestinal tract is required to ensure there is an appropriate uptake of nutrients for growth (King et al., 2000). Physiological development of the digestive tract refers to its ability to digest and absorb nutrients. Anatomical development identifies the physical development of the tract. It has been proposed that it’s the physical development, in terms of size and surface area of the intestinal tract, which most limits early growth in poultry (Sell et al., 1991). The morphological and functional development of the intestinal tract is completed by seven weeks of age in Pekin ducks (Watkins et al., 2004). In Pekin ducks the mass of the intestinal tract increases with age but when the intestinal surface area is represented as a proportion of the liveweight, it undergoes substantial decline with age (King et al., 2000). Existing knowledge on the development of the ducks gastrointestinal tract and its relationship with nutrient utilisation is poor.

Week, sex and pen sex had some significant effects on some of the digestive organs and segments of the small intestine. Strain had minimal effects on the relative weight of digestive organs. There were some sex-pen effects on the proportion of gizzard which varied depending on the strain. There were significant strain effects on most segments of the small intestine. In the main, strains A and B X A had longer relative segment lengths than strains B and A X B. Strains A and B X A were significantly lighter than strains B and A X B. This could suggest that strains A and B x A were less efficient at absorbing nutrients from the intestinal tract. Broilers with a larger intestinal tracts relative to liveweight were found to have superior feed conversion efficiencies (Mahagna & Nir, 1996). In the present study, Strain B X A had the highest proportion of gizzard and also a significantly lower FCR than the other strains. Differences in the relative masses of the intestinal tract, between different genotypes of duck have been reported to be the result of differences in liveweights and any differences in absolute mass of the intestinal tract were small (Watkins et al., 2004). In Pekin ducks the mass of the intestinal tract increases with age but when the intestinal surface area is represented as a proportion of the body weight, it undergoes substantial decline with age (King et al., 2000). The ratio of intestinal surface area (cm²) to liveweight (g) decreased from 1:2 at one week of age to 1:7 at seven weeks of age (King et al., 2000). As a percentage of liveweight the intestinal tract of the Pekin ducks decreased from 14% at two days of age to 4% at maturity, while its wild ancestor, the Mallard, showed a similar decrease from 15% at two days of age to 5% at maturity (Watkins et al., 2004). While selection in broilers has increased the development of the intestinal tract (Jackson & Duke, 1995), this does not appear to be the case in ducks. The high rates of growth in Pekin ducks is most likely related to significantly higher relative intestinal surface area and enzyme activities rather than intestinal mass. So in light of this, the measures of relative length based on liveweight are probably crude and could be of little relevance to metabolic function, well at least, until a relationship between length, mass and function are better documented.

The body composition of animals changes during their growth and development. The allometry of most animals usually follows a similar path. The nervous system develops first, followed by the skeletal development, muscle deposition and finally adipose deposition. These changes are more pronounced in ducks than other poultry species such as chickens (Bochno et al., 2005). In a comprehensive study by Bochno et al., (2005), the tissue components of Pekin ducks were measured and compared as a percentage of carcass weight between 2 to 13 weeks of age. The fat and skin were weighed together and were shown to increase by 1.58%. The mass of bones declined by 7.73% and the lean meat mass increased significantly by 7.9%. The lean meat in different carcass parts was also
analysed and represented a percentage of total lean meat mass. Between 2 to 13 weeks of age the breast muscle increased by 10.99%, while the leg muscle decreased by 11.66%. However, these results only provide an approximation of true carcass composition. To achieve a more accurate measure of carcass composition, carcasses need to be homogenised and analysed using proximate analysis. Carcass composition is economically important. The ideal is for highest protein content and a fat content which meets consumer preferences for cooking and eating quality but is not excessive. Water content was higher at week three of age while the carcass protein and fat contents increased at week five. There were no significant strain effects on carcass composition. Therefore, the crosses provided no advantage in terms of carcass composition. The carcass analysis failed to identify any significant differences in the proportion of carcass components between males and females at week five. However, since most studies recognise five weeks of age as the beginning of sexual dimorphism (Bochno et al., 2005; Farhat & Chavez, 2000) these findings should not be considered unusual.

Rearing ducks as single sexes or as mixed sexes had no influence on carcass composition. Rearing ducks in the different pen-sex groups had no effect on the relative abdominal fat deposition. Larger ducks had more total abdominal fat. While the analysis suggests that there is no effect of sex on the relative abdominal fat weight there is an indication that a difference was starting to emerge in week six. Females mature earlier than males and the pattern in fat deposition seen would be indicative of this difference in maturity.

The experimentally determined AME values ranged from 13.0 to 13.28 MJ/kg with these being 0.2-0.5 MJ/kg higher than the diet formulated value of 12.77 MJ/kg. This was a difference of approximately 1.5 - 4%. Siregar et al., (1982b) reported that the AME determined values using a feed marker procedure were 4-7% higher than calculated values in three experiments with ducks. Strain and pen-sex rearing had no effect on the calculated AME.

A technique for measuring protein digestibility from excreta analysis was originally developed by Kuiken & Lyman (1948). However, due to the contribution of non-protein nitrogen in the urine and microbial nitrogen from the hind gut, the technique actually determines nitrogen retention opposed to protein digestibility. A similar technique developed by Payne et al., (1968) involves sample collection from the ileum, allowing a more accurate determination of protein digestibility. In a study on broiler chickens fed a wheat based diet, the Apparent Protein Digestibility (ADP) calculated from the ileal digesta was 81% and the nitrogen retention calculated from the excreta was 68% (Ravindran et al., 1999). In the same study, broiler chickens fed a canola meal based diet had an ADP of 77% and nitrogen retention of 76%. The large discrepancy between the ADP and the nitrogen retention for the two diets was believed to be the results of differences in microbial populations. In the present study, the apparent ileal nitrogen digestibility ranged from 71.3 to 76.2 % for the different strains and 72.6 to 74.1 % for the different pen-sex groups. The ileal digestibility was lower for strain A than for other strains. The nitrogen retention rate ranged from 50.0 to 51.2 % for the different pen-sex groups and from 46.8 to 52.9 % for the effect of strain, with strain A having a lower nitrogen retention rate than other strains. Ducks of three weeks of age have been reported to have a nitrogen retention rate of 62.6 % (Siregar et al., 1982b). The difference between ileal nitrogen digestibility and nitrogen retention could be a result of microbial protein synthesis. However, it is unlikely that microbial protein could account for such a large differences (McNab, 1990). Another possibility is that a significant proportion of the nitrogen detected in the faeces is non-protein nitrogen from the urine (Robin et al., 1987). Nitrogen in the urine is derived from protein catabolism in the liver. Although some of this protein may be derived from the breakdown of body protein, the majority comes from the breakdown of feed protein. Furthermore, it is unlikely that the majority of the nitrogen in the urine of the ducks in the present study would be derived from the breakdown of body protein because of the significant increase in carcass protein accumulation with age. This would suggest that there was a high rate of tissue protein synthesis and that the excreta nitrogen was more likely derived from breakdown of ingested protein. The theory of high protein catabolism rates is consistent with the differences in ADP and nitrogen retention seen for the strains in the present study. Strain A had the highest level of protein digestion. Due to its higher level of protein absorption, it is likely that strain A would also experience greater rates of dietary protein catabolism. As a consequence of increased protein catabolism more non-protein nitrogen is excreted by the birds, which is reflected in the lower nitrogen
retention rate observed for strain A. These findings are of particular interest to the duck industry. Protein is a necessary feed component for its role in tissue development, but its breakdown and use as energy is inefficient and expensive and much cheaper ingredient sources of energy are available. Furthermore, high rates of nitrogen excretion have negative effects in terms of creating an increase in nitrogenous waste. High ammonia levels in the shed can reduce animal production rates through its adverse affects on health (Kristensen & Wathes, 2000). It is also a health issue for people (Omland, 2002) and has negative effects on the environment (Edwards and Daniel, 1992). Further research is required to establish the theory of high rates of protein catabolism in ducks. The low nitrogen retention rates could indicate that the grower diet may have too high a protein content. Because of its economic implications, this needs to be further investigated.
5. The effects of strain, sex and pen-sex on the performance of commercial ducks under winter conditions

5.1. Introduction

As discussed in chapter four, using imported strains of Pekin duck has created some issues for the local duck industry. The overseas breeding companies have created strains of ducks suitable for their local requirements. The main strains of Pekin ducks used in Australia for commercial production are the Cherry Valley (CV) and Grimaud Frères (GF). Australian market specification required a slaughter weight of 2.85 kg at six weeks processing age. Unlike broilers, maximum breast muscle development in ducks occurs later in development. So for the strains of Pekin presently used in Australia, processing occurs at a time which doesn’t correlate well with maximum breast muscle development.

It is possible, that by crossing the GF and CV strains, heterosis might provide strain crosses that display the favourable attributes of the GF (higher growth rate) and CV (carcass and cooking quality). The desire is to produce a Pekin strain which better meets the very precise Australian market specifications.

In chapter four the effects of strain, sex and pen-sex rearing were evaluated under summer conditions. Season has an influence on growth and carcass composition of ducks and so there is a need to evaluate the GF and CV strains and there crosses under winter conditions.

5.2. Objective

The objective of this study was to assess the effects that strain and sex had on the growth rates of Pekin ducks grown under Australian winter conditions. The effect of single sex rearing is also compared to the normal commercial practice of mixed sex rearing.

5.3. Methods

5.3.1. Duck growth trial

5.3.1.1. Experimental Design

The experimental design was the same as described for the summer study (see section 4.3.1.1.)

5.3.1.2. Treatments

Again the treatments consisted of four strains of Pekin duck reared as single sexes (males or females) or as mixed sex groups, consisting of equal numbers of males and females. The strains used were the Cherry Valley (CV) and Grimaud Freres (GF) and the reciprocal crosses of these two strains. These being the CV male X GF female and the GF male X CV female. As in chapter four, the four strains were produced, by the appropriate matings at a commercial breeding farm owned 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 shed at The University of Sydney, Camden. On arrival ducklings were placed in their allocated pens as single sexes (females or males) or mixed sexes (equal numbers of males and females). The twelve treatments are given in table 5.1.
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Strain</th>
<th>Pen Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cherry Valley</td>
<td>Single (Male)</td>
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<tr>
<td>2</td>
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<tr>
<td>3</td>
<td>Cherry Valley</td>
<td>Mixed</td>
</tr>
<tr>
<td>4</td>
<td>Grimaud Freir</td>
<td>Single (Male)</td>
</tr>
<tr>
<td>5</td>
<td>Grimaud Freir</td>
<td>Single (Female)</td>
</tr>
<tr>
<td>6</td>
<td>Grimaud Freir</td>
<td>Mixed</td>
</tr>
<tr>
<td>7</td>
<td>Cherry Valley cross Grimaud Freir</td>
<td>Single (Male)</td>
</tr>
<tr>
<td>8</td>
<td>Cherry Valley cross Grimaud Freir</td>
<td>Single (Female)</td>
</tr>
<tr>
<td>9</td>
<td>Cherry Valley cross Grimaud Freir</td>
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</tr>
<tr>
<td>10</td>
<td>Grimaud Freir cross Cherry Valley</td>
<td>Single (Male)</td>
</tr>
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<td>11</td>
<td>Grimaud Freir cross Cherry Valley</td>
<td>Single (Female)</td>
</tr>
<tr>
<td>12</td>
<td>Grimaud Freir cross Cherry Valley</td>
<td>Mixed</td>
</tr>
</tbody>
</table>

Table 5.1. The 12 different strain and sex combinations used in the study.

5.3.1.3. Husbandry

The husbandry procedures were the same as for study one (see section 4.3.1.2.).

5.3.1.4. Performance and carcass measurements

Individual liveweights were recorded on days seven (week one), 14 (week two), 21 (week three), 28 (week four), 35 (week five) and 41 (week six). Carcass growth measurements were taken on days six, 13, 20, 27, 34 and 41 from an individual duck selected at random from each pen. The sampling procedure is described in section 3.1.9.

5.3.2. Metabolism study

At day 14 (week two), four ducks were randomly selected and removed from each pen of the growth trial. Equal numbers of males and females were taken for the mixed sex pens. The ducks were placed in 48 metabolism cages and fed *ad libitum* the same commercial grower diet supplied to the ducks in the growth trial, with the addition of an insoluble ash marker, Celite, at a concentration of 10 grams per kilogram of feed. The AME and nitrogen retention were determine using the AIA procedure (see section 3.2.).
5.3.3. 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
log_e transformation, data was transformed.

The fixed model included the effects of sex, pen-sex, strain 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 chi-square 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 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 of means. Microsoft Excel® was used to create graphical
summaries of the backtransformed means. All carcass measurements were analysed as a proportion of
liveweight.

The analysis of the carcass composition and data from the metabolism study was conducted by
ANOVA with significance set at (P < 0.05). Where main effects were detected as significant, pairwise
comparisons were made using LSD procedures (LSD = 2×SED).

5.4. Results

5.4.1. Liveweight

There were highly significant effects of strain (see Figure 5.1), sex (see Figure 5.2) and pen-sex (see
Figure 5.3) on liveweight but these effects changed over time as indicated by the significant strain ×
week, sex × week, and pen-sex x week interactions (all P < 0.001). The standard errors of means have
not been included as they are too small to plot. The extremely large sample size results in these very
small standard errors, hence fairly subtle biological effects are being detected as being statistically
significant. Strain B was heavier (P < 0.05) than the other strains except strain A X B in weeks one
and two. Strain A X B was heavier (P < 0.05) than strains A and B x A and strain B X A heavier (P <
0.05) than strain A in all weeks.

In all weeks except the first, males were heavier than females (P < 0.05). The sex differential existed
for all strains as there was no strain x sex interaction (P = 0.51). While the analysis indicated that the
pen-sex x week interaction was significant, on no week were the differences significant suggesting the
effect is questionable as in the summer trial. There was no detectable sex x pen-sex interaction (P =
0.85) indicating that the effect of single versus mixed pen rearing was the same for males and females
so the arguably small benefit of rearing in single pens was the same for males and females. There was
no strain x pens-sex interaction (P = 0.97) so again the small effect of single or mixed pen rearing was
that same for all strains.

At 41 days the mean (± SEM) liveweights for strain A, A X B, B and B X A were 2847 ± 20 g, 3106 ±
22 g, 3262 ± 23 g, 2951 ± 21 g, respectively. At the same time females had a mean (± SEM)
liveweight of 2942 ± 18 g and males 3137 ± 19 g. For ducks reared in mixed sex pens the mean (±
SEM) liveweight was 3038 ± 21 g and those reared in single sex pens was 3035 ± 18 g.
Figure 5.1. The mean liveweight for the effect of strain over the six week production period. There was significant strain x week interaction (P < 0.001).

Figure 5.2. The mean liveweight for the effect of sex over the six week production period. There was significant sex x week interaction (P < 0.001).
5.4.2. Liveweight gain

The effect of strain on weekly gain is shown in figure 5.4. The effect of strain was significant (P < 0.001) but there was no significant strain x week interaction (P = 0.09). There were significant differences between all strains (P < 0.05). Strain B (505 ± 23) had the highest weekly gain, followed by strain A x B (482 ± 20), then strain B X A (459 ± 20), with strain A (443 ± 20), having the lowest weekly gain. The effect of pen-sex on weekly liveweight gain is shown in figure 5.5. The effect of pen-sex changed with time as indicated by the significant pen-sex x week interaction (P < 0.001). Differences were seen in week two and six. In both weeks, male pens (P < 0.05) had higher weekly gain than female and the mixed pens while the mixed sex pens had higher (P < 0.05) weekly gains than female pens in these same weeks.
5.4.3. Feed Intake

The effect of strain on weekly feed intake (see Figure 5.6) changed over time with the strain x week interaction (P < 0.001) being significant. In all weeks, strains A and B x A had lower (P < 0.05) feed intake than did strains B and A x B. In weeks four and five, the feed intake of strain B x A was higher (P < 0.05) than for strain A. In weeks four to six, the intake of strain B was higher (P < 0.05) than for strain A x B. There was no strain x sex interaction (P = 0.44). Total feed intake for strain A was 5.87 ± 0.07 kg, for strain A X B was 6.46 ± 0.07 kg, for strain B was 6.75 ± 0.07 kg and strain B X A was 6.01 ± 0.06 kg. The effect of strain on total feed intake was significant (P < 0.001) with strain B having a higher (P < 0.05) total feed intake than all other strains. Strain A X B had a total intake higher (P < 0.05) than strains A and B x A while there was no difference between these later two strains.

The mean weekly feed intake for the effect of pen-sex over the six week production period is given in figure 5.7. There was no significant pen-sex effect on weekly feed intake (P = 0.35). Total feed intake for females was 6.23 ± 0.11 kg, for males was 6.30 ± 0.011 kg and mixed pen reared ducks was 6.28 ± 0.09 kg, with there being no differences (P = 0.74).
5.4.4. Feed conversion ratio (FCR)

The effect of strain on weekly FCR is shown in figure 5.8. Strain had no significant effect on the weekly FCR (P = 0.51). The effect of pen-sex on weekly FCR is shown in figure 5.9. There was a significant pen-sex x week interaction (P = 0.002). The main differences were seen in week six were males (P < 0.005) had a lower FCR than female or mixed sex pens. However, females also had a higher FCR (P < 0.05) than males in week two, four and five.
There was no significant strain effect ($P = 0.51$).

There was a significant sex x week interaction ($P = 0.002$).

The total composite FCR for the different strains were, strain A, $2.09 \pm 0.01$; strain A X B, $2.10 \pm 0.01$; strain B, $2.10 \pm 0.01$ and strain B X A, $2.06 \pm 0.01$. There was no significant strain effect ($P = 0.18$). Pen-sex had a significant ($P < 0.01$) effect on total FCR with male pens ($2.03 \pm 0.01$) having a better FCR ($P < 0.05$) than mixed sex pens ($2.10 \pm 0.01$) and female pens ($2.14 \pm 0.01$) with the differences between the later two also being significant ($P < 0.05$).
5.4.5. Water Intake

In every week, the water consumption increased significantly (P < 0.001). The effects of strain and pen-sex on weekly water intake are shown in figures 5.10, and 5.11, respectively. Strain had a significant (P < 0.001) effect on the weekly water intake with the strain x week interaction just marginally non significant (P = 0.054). There was no difference between strains B and A X B but the water intake for both these strains was higher (P < 0.05) than for strains A and B X A. The water consumption of strain B X A was higher (P < 0.05) than Strain A. Pen-sex had no effect on weekly water consumption (P = 0.20).

Total water intake for strain A was 15.83 ± 0.18 L, for strain A X B was 17.79 ± 0.22 L, for strain B was 18.03 ± 0.16 L and strain B X A was 16.25 ± 0.16 L. Strains A and B X A (P < 0.05) had a lower total consumption than strains B and A X B. Pen-sex had no significant effect (P = 0.24) on total water intake with male pens consuming 16.82 ± 0.28 L, female pens consuming 17.19 ± 0.32 L and mixed sex pens consuming 16.92 ± 0.26 L.

Figure 5.10. The mean weekly water intake (mL) for the effect of strain over the production period.

The strain effect was significant (P < 0.001).
Figure 5.11. The mean weekly water intake for the effect of pen-sex over the production period.
Pen-sex had no effect on weekly water consumption (P = 0.20).

5.4.6. Water to feed ratio

The effect of strain on the water to feed ratio changed with time (see Figure 5.12), with the strain x week interaction being significant (P = 0.04). The main differences were seen for strain A X B which had a higher (P < 0.05) ratio than strain A (weeks one and two), strain B (weeks three and four) and strain B x A (week five).

While the sex x week interaction was significant (P = 0.02), the only difference between sexes was seen in week six where female pens had a higher (P < 0.05) water to feed ratio than did the male or mixed pens (see Figure 5.13).

The total composite water to feed ratios for the different strains were, strain A, 2.70 ± 0.05; strain A X B, 2.75 ± 0.05; strain B, 2.68 ± 0.05, and strain B X A, 2.70 ± 0.05. The effect of strain was not significant (P = 0.23). Pen-sex influenced the total water to feed ratio (P = 0.04). The water to feed ratio for female pens (2.76 ± 0.04) was higher (P < 0.05) than for male (2.68 ± 0.04) and mixed sex pens (2.69 ± 0.04).
Figure 5.12. The mean weekly water to feed ratio for the effect of strain over the production period.

There was a significant strain x week interaction (P < 0.001).

Figure 5.13. The mean weekly water to feed ratio for the effect of pen-sex over the production period.

The pen-sex x week interaction was significant (P = 0.02).

5.4.7. Muscle development and yield

The effect of strain, sex and pen-sex on the breast muscle weight to LW ratio expressed as a %, are shown in figures 5.14, 5.15 and 5.16, respectively. There was significant strain x week interaction (P < 0.001). While there are some strain differences in the early weeks there is no consistent pattern to these. The main differences are seen in weeks five and six where strain B had a higher (P < 0.05) breast % than the other strains. In the same period, strain B X A had higher (P < 0.05) breast % than both strains A and A x B and strain A had a higher (P < 0.05) % than strain A X B.
There were significant sex effects but these varied because of the significant interaction between sex and pen-sex ($P = 0.001$). Females reared in single sex pens ($3.36 \pm 0.05 \%$) had a higher ($P < 0.05$) breast % than females reared in mixed sex pens ($3.14 \pm 0.04 \%$) while males reared in single sex pens ($2.92 \pm 0.06 \%$) had a lower ($P < 0.05$) breast % than males reared in mixed sex pens ($3.01 \pm 0.06 \%$).

At 41 days, the mean (± SEM) breast to LW % for strain A, A X B, B and B X A were 8.63 ± 0.34, 8.24 ± 0.33, 9.37 ± 0.33, 8.99 ± 0.38, respectively. At the same time females had a mean (± SEM) breast to LW % of 9.30 ± 0.27 and males 8.31 ± 0.24. For ducks reared in mixed sex pens the mean (± SEM) breast to LW % was 8.67 ± 0.19 and those reared in single sex pens was 8.92 ± 0.14.

Figure 5.14. The mean weekly breast muscle yield expressed as a percentage of liveweight (LW) for the effect of strain over the production period.

There was significant strain x week interaction ($P < 0.001$).

Figure 5.15. The mean weekly breast muscle yield expressed as a percentage of liveweight (LW) for the effect of sex over the production period.

There was a significant sex x pen-sex interaction ($P = 0.001$).
Figure 5.16. The mean weekly breast muscle yield expressed as a percentage of liveweight (LW) for the effect of pen-sex over the production period.

There was a significant sex x pen-sex interaction (P = 0.001).

The effect of strain on the thigh muscle weight to liveweight ratio expressed as a percentage is shown in figure 5.17. The effect of strain was not significant (P = 0.52) and the interaction of strain x week was just marginally not significant (P = 0.063). So while at weeks three and four some effects were found no reliance can be placed on these. There was the tendency for the thigh muscle % to be lower for strain B in week four.

The effects of sex and pen-sex on the % of thigh muscle are shown in figures 5.18 and 5.19, respectively. There was a significant sex x week interaction (P = 0.01) but the differences were limited to week one were the females had a higher % than males (P < 0.05) and week five where this was reversed and males had a higher % than females (P < 0.05). There was significant pen-sex x week interaction (P = 0.03). At week one, ducks reared in mixed pens had higher (P < 0.05) thigh muscle % than ducks reared in single sex pens and this was reversed in week two (P < 0.05). There were no other pen-sex effects.
Figure 5.17. The mean weekly thigh muscle weight expressed as a percentage of liveweight (LW) for the effect of strain over the production period.

The effect of strain was not significant ($P = 0.52$).

Figure 5.18. The mean weekly thigh muscle weight expressed as a percentage of liveweight (LW) for the effect of sex over the production period.

There was a significant sex x week interaction ($P = 0.01$).
Figure 5.19. The mean weekly thigh muscle weight expressed as a percentage of liveweight (LW) for the effect of pen-sex over the production period.

There was significant pen-sex x week interaction ($P = 0.03$).

Day had a significant effect ($P < 0.001$) on the leg muscle (drumstick) weight to liveweight ratio expressed as a %. The % increased from week one to week two and then gradually decreased, each week thereafter. Strain (see Figure 5.20) had no effect ($P = 0.09$) on the leg muscle weight to LW percentage. The effect of sex (see Figure 5.21) was not significant with the sex x strain interaction very marginally non-significant ($P = 0.054$). There was no difference between the sexes for strain A (females: $4.94 \pm 0.07 \%$; males $4.79 \pm 0.07 \%$) and strain B (females: $4.88 \pm 0.07 \%$; males $4.97 \pm 0.07 \%$) but there was trend for females to have a higher % than males for strains A x B (females: $5.10 \pm 0.07 \%$; males $4.97 \pm 0.07 \%$) and B X A (females: $5.12 \pm 0.07 \%$; males $4.87 \pm 0.07 \%$). Females of strain B ($4.88 \pm 0.07 \%$) tended to have a lower % than females of strain A X B ($5.10 \pm 0.07 \%$) and strain B X A ($5.12 \pm 0.07 \%$). Pen-sex (see Figure 5.22) had no effect on leg muscle % ($P = 0.74$).

Figure 5.20. The mean weekly leg (drumstick) muscle weight expressed as a percentage of liveweight (LW) for the effect of strain over the production period.

The effect of strain was not significant ($P = 0.09$).
The effect of sex was significant and the significant sex x strain interaction marginally not significant (P = 0.054).

There was no effect of pen-sex (P = 0.74).

5.4.8. Abdominal fat yield

Week had a significant effect (P < 0.001) on the weight of abdominal fat expressed as % of the liveweight. The fat % increased significantly each week over the production period. The effect of strain (see figure 5.23) was not significant (P = 0.25). The values at week six were, strain A, 1.19 ± 0.07 %; strain A X B, 1.37 ± 0.08 %; strain B ,1.28 ± 0.08 % and strain B x A, 1.32 ± 0.07 %. The effect of sex on the abdominal fat % is shown in figure 5.24. The effect of sex was significant (P =
with females having a higher abdominal fat % than males. At week six the fat % for females was 1.35 ± 0.04 % and males 1.23 ± 0.04 %. The effect of pen-sex on the abdominal fat % is given in figure 5.25. Pen-sex had no effect (P = 0.35) on abdominal fat %.

**Figure 5.23.** The mean weekly abdominal fat weight expressed as a percentage of liveweight (LW) for the effect of strain over the production period.

The effect of strain was not significant (P = 0.25).

**Figure 5.24.** The mean weekly abdominal fat weight expressed as a percentage of liveweight (LW) for the effect of sex over the production period.

The effect of sex was significant (P = 0.01).
Figure 5.25. The mean weekly abdominal fat weight expressed as a percentage of liveweight (LW) for the effect of pen-sex over the production period. The effect of pen-sex was not significant ($P = 0.035$).

5.4.9. Digestive organ weights and gastrointestinal tract measurements

Measurements are given as the ratio of organ weight to liveweight expressed as percentage ($\%$).

5.4.9.1. Liver

The effects of strain, sex and pen-sex on the liver weight to liveweight ratio expressed as $\%$ is given in table 5.2. Strain had no effect ($P = 0.13$) on the liver $\%$. The effect of sex was significant ($P = 0.03$) without there being no sex x week interaction ($P = 0.20$). Females ($1.44 \pm 0.01$) had a lower ($P < 0.05$), $\%$ than males ($1.47 \pm 0.01$). There was a significant interaction between pen-sex and week ($P = 0.048$). The only difference was in week six where the liver $\%$ was lower ($P < 0.05$) for mixed sex pens ($1.03 \pm 0.03$) than for single sex pens ($1.10 \pm 0.02$).
<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain A</td>
<td>5.75 ± 0.18</td>
<td>5.31 ± 0.17</td>
<td>4.66 ± 0.15</td>
<td>3.90 ± 0.12</td>
<td>3.49 ± 0.11</td>
<td>3.00 ± 0.09</td>
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<td>Strain AB</td>
<td>6.03 ± 0.19</td>
<td>5.47 ± 0.17</td>
<td>4.93 ± 0.16</td>
<td>4.05 ± 0.13</td>
<td>3.54 ± 0.11</td>
<td>2.90 ± 0.09</td>
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<tr>
<td>Strain B</td>
<td>6.09 ± 0.19</td>
<td>5.39 ± 0.17</td>
<td>5.52 ± 0.16</td>
<td>3.94 ± 0.13</td>
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<td>Strain BA</td>
<td>5.92 ± 0.09</td>
<td>5.21 ± 0.17</td>
<td>4.87 ± 0.17</td>
<td>4.00 ± 0.12</td>
<td>3.43 ± 0.12</td>
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<tr>
<td>Female</td>
<td>5.92 ± 0.13</td>
<td>5.22 ± 0.11</td>
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<td>2.80 ± 0.08</td>
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<td>4.03 ± 0.08</td>
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<td>3.00 ± 0.06</td>
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</tbody>
</table>

Table 5.2: The effect of strain, sex and pen-sex on the mean (± SEM) liver weight to liveweight ratio expressed as percentage.

The effect of strain (P = 0.13) was not significant. There was a significant sex effect (P = 0.03) and a significant pen-sex x week interaction (P = 0.048). For the effect of pen-sex, values within columns with different superscripts are significant different (P < 0.05).

5.4.9.2. Proventriculus

The effects of week, strain, sex and pen-sex on the proventriculus weight to liveweight ratio expressed as percentage is given in table 5.3. The effects of strain (P = 0.18) and pen-sex (P = 0.41) were not significant. The effect of sex was confounded by an interaction with week as indicated by the significant sex x week interaction (P = 0.007). However, the only difference seen was in week six where females (P < 0.05) had a higher % than males.

5.4.9.3 Gizzard

The effects of strain, sex and pen-sex on the gizzard weight to liveweight ratio expressed as a % is given in table 5.4. Strain (P = 0.07) and pen-sex (P = 0.80) had no effects on the gizzard %. There was a significant sex x week interaction (P = 0.007). The differences were confined to weeks four to six where the males (P < 0.05) had a higher % than did females.
<table>
<thead>
<tr>
<th>Strain</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>0.90 ± 0.03</td>
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<td>0.50 ± 0.02</td>
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<tr>
<td>AB</td>
<td>0.86 ± 0.03</td>
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<td>0.51 ± 0.02</td>
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<tr>
<td>B</td>
<td>0.89 ± 0.03</td>
<td>0.64 ± 0.02</td>
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<thead>
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<th>Strain</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>0.86 ± 0.02</td>
<td>0.65 ± 0.01</td>
<td>0.52 ± 0.01</td>
<td>0.50 ± 0.01</td>
<td>0.47 ± 0.01</td>
<td>0.45 ± 0.01</td>
</tr>
<tr>
<td>Male</td>
<td>0.89 ± 0.02</td>
<td>0.63 ± 0.01</td>
<td>0.52 ± 0.01</td>
<td>0.48 ± 0.01</td>
<td>0.45 ± 0.01</td>
<td>0.41 ± 0.01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strain</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single</td>
<td>0.89 ± 0.01</td>
<td>0.64 ± 0.01</td>
<td>0.52 ± 0.01</td>
<td>0.49 ± 0.01</td>
<td>0.46 ± 0.01</td>
<td>0.44 ± 0.01</td>
</tr>
<tr>
<td>Mixed</td>
<td>0.87 ± 0.02</td>
<td>0.65 ± 0.01</td>
<td>0.53 ± 0.01</td>
<td>0.49 ± 0.01</td>
<td>0.46 ± 0.01</td>
<td>0.42 ± 0.01</td>
</tr>
</tbody>
</table>

Table 5.3: The effect of strain, sex and pen-sex on the mean (± SEM) proventriculus weight to liveweight ratio expressed as percentage.

Strain (P = 0.18) and pen-sex (P = 0.41) had no effects on % proventriculus. There was significant sex x week interaction (P = 0.007). Within columns for the effect of sex, values with different superscripts are significantly different (P < 0.05).
<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain A</td>
<td>5.52 ± 0.18</td>
<td>4.64 ± 0.15</td>
<td>3.51 ± 0.12</td>
<td>3.37 ± 0.11</td>
<td>3.17 ± 0.11</td>
<td>2.97 ± 0.10</td>
</tr>
<tr>
<td>Strain AB</td>
<td>5.58 ± 0.18</td>
<td>4.40 ± 0.15</td>
<td>3.71 ± 0.12</td>
<td>3.50 ± 0.11</td>
<td>3.15 ± 0.10</td>
<td>2.91 ± 0.10</td>
</tr>
<tr>
<td>Strain B</td>
<td>5.20 ± 0.18</td>
<td>4.46 ± 0.15</td>
<td>3.50 ± 0.12</td>
<td>3.32 ± 0.11</td>
<td>3.04 ± 0.10</td>
<td>2.73 ± 0.10</td>
</tr>
<tr>
<td>Strain BA</td>
<td>5.47 ± 0.17</td>
<td>4.46 ± 0.15</td>
<td>3.80 ± 0.12</td>
<td>3.61 ± 0.11</td>
<td>3.15 ± 0.10</td>
<td>2.72 ± 0.09</td>
</tr>
<tr>
<td>Female</td>
<td>5.31 ± 0.13</td>
<td>4.43 ± 0.11</td>
<td>3.56 ± 0.09</td>
<td>3.27 ± 0.08b</td>
<td>2.88 ± 0.07b</td>
<td>2.63 ± 0.06b</td>
</tr>
<tr>
<td>Male</td>
<td>5.57 ± 0.13</td>
<td>4.54 ± 0.11</td>
<td>3.70 ± 0.09</td>
<td>3.63 ± 0.09a</td>
<td>3.39 ± 0.08a</td>
<td>3.05 ± 0.07a</td>
</tr>
<tr>
<td>Single</td>
<td>5.98 ± 0.13</td>
<td>5.48 ± 0.12</td>
<td>5.04 ± 0.12</td>
<td>3.89 ± 0.09</td>
<td>3.61 ± 0.08</td>
<td>2.98 ± 0.07</td>
</tr>
<tr>
<td>Mixed</td>
<td>5.92 ± 0.13</td>
<td>5.23 ± 0.11</td>
<td>4.80 ± 0.11</td>
<td>4.06 ± 0.09</td>
<td>3.47 ± 0.08</td>
<td>2.82 ± 0.06</td>
</tr>
</tbody>
</table>

Table 5.4: The effect of strain, sex and pen-sex on the mean (± SEM) gizzard weight to liveweight ratio expressed as percentage.

Strain (P = 0.07) and pen-sex (P = 0.80) had no effects on gizzard %. There was significant sex x week interaction (P = 0.007). Within columns for the effect of sex, values with different superscripts are significantly different (P < 0.05).

5.4.10. Gastrointestinal tract measurements

Measurements of the GIT are expressed as cm per 100 g of liveweight.

5.4.10.1. Duodenum length (DL)

The effects of strain, sex and pen-sex on the length (cm) of the duodenum (DL) per 100g liveweight is given in table 5.5. The effect of strain varied with week as indicated by the significant diet x week interaction (P = 0.04). In week two and four, strains A and B X A had greater (P < 0.05) DL length than strain B. In week five, the relative DL length was longer for strain A (P < 0.05) than for other strains. The effect of sex changed as indicated by the significant sex x week interaction (P = 0.007). The sex differences are confined to weeks five and six. In week five, males had a longer DL length than females and in week six this is reversed (P < 0.05). There was no effect of pen-sex on DL length (P = 0.28).
Table 5.5: The mean (± SEM) length of the DL (cm) per 100g live weight during the production period.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain A</td>
<td>8.27 ± 0.26</td>
<td>3.88 ± 0.12</td>
<td>2.16 ± 0.07</td>
<td>1.69 ± 0.05</td>
<td>1.40 ± 0.04</td>
<td>1.17 ± 0.04</td>
</tr>
<tr>
<td>Strain AB</td>
<td>8.61 ± 0.27</td>
<td>3.67 ± 0.11</td>
<td>2.17 ± 0.07</td>
<td>1.58 ± 0.05</td>
<td>1.18 ± 0.04</td>
<td>1.09 ± 0.03</td>
</tr>
<tr>
<td>Strain B</td>
<td>8.00 ± 0.27</td>
<td>3.52 ± 0.11</td>
<td>2.20 ± 0.07</td>
<td>1.55 ± 0.05</td>
<td>1.25 ± 0.04</td>
<td>1.09 ± 0.03</td>
</tr>
<tr>
<td>Strain BA</td>
<td>8.14 ± 0.25</td>
<td>3.93 ± 0.11</td>
<td>2.28 ± 0.07</td>
<td>1.71 ± 0.05</td>
<td>1.28 ± 0.04</td>
<td>1.07 ± 0.03</td>
</tr>
</tbody>
</table>

| Female       | 8.27 ± 0.18 | 3.87 ± 0.09 | 2.27 ± 0.05 | 1.62 ± 0.04 | 1.23 ± 0.03 | 1.15 ± 0.03 |
| Male         | 8.23 ± 0.18 | 3.63 ± 0.08 | 2.14 ± 0.05 | 1.64 ± 0.04 | 1.32 ± 0.03 | 1.06 ± 0.02 |

| Single       | 8.14 ± 0.15 | 3.72 ± 0.07 | 2.19 ± 0.04 | 1.61 ± 0.03 | 1.26 ± 0.02 | 1.11 ± 0.02 |
| Mixed        | 8.42 ± 0.23 | 3.77 ± 0.10 | 2.22 ± 0.06 | 1.67 ± 0.05 | 1.29 ± 0.04 | 1.08 ± 0.03 |

Table 5.5: The mean (± SEM) length of the DL (cm) per 100g live weight during the production period.

There are significant strain x week (P = 0.04) and sex x week (P = 0.007) interactions. Pen-sex had no effect (P = 0.28). Within columns for the main treatment effects of strain and sex, values with different superscripts are significantly different (P < 0.05).

5.4.10.2. Length of the jejunum (Duodenum to Merkle’s Diverticulum: DL-MD)

The effects of strain, sex and pen-sex on the length (cm) of small intestine from the duodenal loop to Merkle’s Diverticulum (DL-MD) per 100g liveweight are given in table 5.6. The effect of strain was significant (P < 0.001). The length of DL-MD segment was greater (P < 0.05) for strain B x A (6.14 ± 0.07 cm) than strains B (5.98 ± 0.07 cm) and A x B (6.02 ± 0.07 cm). Strain A (6.19 ± 0.07 cm) had a longer relative DL-CM segment (P < 0.05) than did strain B (5.98 ± 0.07 cm). The effect of sex on the length of the DL-MD segment was significant (P = 0.01) with this being longer (P < 0.05) in females (6.22 ± 0.05 cm) than males (6.06 ± 0.05 cm). Pen-sex had no effect (P = 0.11) on the length of the DL-MD segment.
Table 5.6: The mean (± SEM) length in cm of small intestine from DL-MD per 100g liveweight during the production period.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain A</td>
<td>21.7 ± 0.5</td>
<td>9.8 ± 0.2</td>
<td>5.8 ± 0.1</td>
<td>4.4 ± 0.1</td>
<td>3.5 ± 0.1</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Strain AB</td>
<td>22.8 ± 0.5</td>
<td>9.5 ± 0.2</td>
<td>5.7 ± 0.1</td>
<td>4.2 ± 0.1</td>
<td>3.3 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Strain B</td>
<td>22.0 ± 0.5</td>
<td>9.5 ± 0.2</td>
<td>5.9 ± 0.1</td>
<td>4.0 ± 0.1</td>
<td>3.3 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Strain BA</td>
<td>22.6 ± 0.5</td>
<td>10.3 ± 0.2</td>
<td>6.2 ± 0.1</td>
<td>4.4 ± 0.1</td>
<td>3.7 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Female</td>
<td>22.3 ± 0.4</td>
<td>10.0 ± 0.2</td>
<td>6.0 ± 0.1</td>
<td>4.4 ± 0.1</td>
<td>3.3 ± 0.1</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Male</td>
<td>22.2 ± 0.4</td>
<td>9.6 ± 0.2</td>
<td>5.8 ± 0.1</td>
<td>4.2 ± 0.1</td>
<td>3.5 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Single</td>
<td>22.2 ± 0.3</td>
<td>9.6 ± 0.1</td>
<td>5.8 ± 0.1</td>
<td>4.2 ± 0.1</td>
<td>3.4 ± 0.1</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Mixed</td>
<td>22.1 ± 0.4</td>
<td>10.0 ± 0.2</td>
<td>6.1 ± 0.1</td>
<td>4.3 ± 0.1</td>
<td>3.5 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
</tbody>
</table>

Strain (P < 0.001) and sex (P = 0.01) influenced the length of the DL-MD segment. Pen-sex had no effect (P = 0.11).

5.4.10.3. Length of the Ileum (Merkle’s Diverticulum to the ileo-caecal junction (MD-ICJ))

The effects of strain, diet, sex and week on the length (cm) of small intestine from the Merkle’s Diverticulum to the ileo-caecal junction (MD-ICJ) per 100g liveweight are given in table 5.7. There was significant strain x week interaction (P = 0.02). In week two, strain B had shorter (P < 0.05) MD-ICJ segment than did strain B X A. In weeks four and five strain B had shorter (P < 0.05) MD-ICJ segment than did strains A and B X A. Sex (P = 0.48) and pen-sex (P = 0.51) had no effect on the length of the MD-ICJ segment.
<table>
<thead>
<tr>
<th>Strain</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain A</td>
<td>21.3 ± 0.6</td>
<td>9.9 ± 0.3&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>5.5 ± 0.1</td>
<td>4.3 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.3 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Strain AB</td>
<td>21.7 ± 0.6</td>
<td>9.5 ± 0.3&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>5.7 ± 0.1</td>
<td>4.0 ± 0.1&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>3.1 ± 0.1&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>2.7 ± 0.1</td>
</tr>
<tr>
<td>Strain B</td>
<td>21.6 ± 0.6</td>
<td>9.3 ± 0.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.4 ± 0.1</td>
<td>3.9 ± 0.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.1 ± 0.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.6 ± 0.1</td>
</tr>
<tr>
<td>Strain BA</td>
<td>23.0 ± 0.6</td>
<td>10.4 ± 0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.3 ± 0.1</td>
<td>4.5 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.6 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.7 ± 0.1</td>
</tr>
</tbody>
</table>

| Female   | 21.7 ± 0.4 | 9.8 ± 0.2 | 5.6 ± 0.1 | 4.2 ± 0.1 | 3.1 ± 0.1 | 2.8 ± 0.1 |
| Male     | 22.1 ± 0.4 | 9.7 ± 0.2 | 5.8 ± 0.1 | 4.1 ± 0.1 | 3.4 ± 0.1 | 2.7 ± 0.1 |
| Single   | 21.8 ± 0.4 | 9.7 ± 0.2 | 5.7 ± 0.1 | 4.1 ± 0.1 | 3.3 ± 0.1 | 2.7 ± 0.1 |
| Mixed    | 21.9 ± 0.5 | 9.9 ± 0.3 | 5.8 ± 0.1 | 4.3 ± 0.1 | 3.2 ± 0.1 | 2.7 ± 0.1 |

Table 5.7: The mean (±SEM) length in cm of intestine from MD-ICJ per 100g bodyweight during the production period.

There was significant strain x week interaction (P = 0.02). Sex (P = 0.48) and pen-sex (P = 0.51) had no effects. Within columns for the effect of strain, values with different superscripts are significantly different (P < 0.05).

5.4.10.4. Total Caecal length (CL)

The effects of week, strain, sex and pen-sex on the total caecal (CL) length (cm) per 100g liveweight are given in table 5.8. Week had a significant effect (P < 0.001) with a progressive decrease in the relative CL through the course of the production period with differences between all weeks being significant (P < 0.05). The effect of strain was significant (P = 0.008) with ducks of strain A (2.72 ± 0.04 cm/100g) and B X A (2.70 ± 0.04 cm/100g) having longer relative length (P < 0.05) compared to strain B (2.56 ± 0.03 cm/100g). Sex also had a significant effect on the relative CL length (P = 0.03) with males (2.70 ± 0.03 cm/100g) having a greater relative CL (P < 0.05), than females (2.62 ± 0.03 cm/100g). Pen-sex had no significant effect on the relative CL (P = 0.29).
<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week</td>
<td>7.57 ±</td>
<td>4.11 ±</td>
<td>2.66 ±</td>
<td>1.99 ±</td>
<td>1.60 ±</td>
<td>1.34 ±</td>
</tr>
<tr>
<td></td>
<td>0.13a</td>
<td>0.07b</td>
<td>0.05c</td>
<td>0.03d</td>
<td>0.03e</td>
<td>0.02f</td>
</tr>
<tr>
<td>Strain A</td>
<td>7.52 ±</td>
<td>4.28 ±</td>
<td>2.66 ±</td>
<td>2.03 ±</td>
<td>1.70 ±</td>
<td>1.37 ±</td>
</tr>
<tr>
<td></td>
<td>0.24</td>
<td>0.14</td>
<td>0.09</td>
<td>0.07</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>Strain AB</td>
<td>7.46 ±</td>
<td>4.02 ±</td>
<td>2.72 ±</td>
<td>2.00 ±</td>
<td>1.60 ±</td>
<td>1.35 ±</td>
</tr>
<tr>
<td></td>
<td>0.24</td>
<td>0.14</td>
<td>0.09</td>
<td>0.07</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>Strain B</td>
<td>7.67 ±</td>
<td>3.92 ±</td>
<td>2.50 ±</td>
<td>1.91 ±</td>
<td>1.47 ±</td>
<td>1.34 ±</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>0.13</td>
<td>0.09</td>
<td>0.06</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>Strain BA</td>
<td>7.77 ±</td>
<td>4.10 ±</td>
<td>2.76 ±</td>
<td>1.96 ±</td>
<td>1.66 ±</td>
<td>1.35 ±</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>0.13</td>
<td>0.08</td>
<td>0.06</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Female</td>
<td>7.51 ±</td>
<td>3.97 ±</td>
<td>2.64 ±</td>
<td>1.95 ±</td>
<td>1.54 ±</td>
<td>1.37 ±</td>
</tr>
<tr>
<td></td>
<td>0.20</td>
<td>0.09</td>
<td>0.06</td>
<td>0.04</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Male</td>
<td>7.69 ±</td>
<td>4.19 ±</td>
<td>2.68 ±</td>
<td>2.01 ±</td>
<td>1.67 ±</td>
<td>1.33 ±</td>
</tr>
<tr>
<td></td>
<td>0.17</td>
<td>0.09</td>
<td>0.06</td>
<td>0.05</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>Single</td>
<td>7.61 ±</td>
<td>4.22 ±</td>
<td>2.69 ±</td>
<td>2.03 ±</td>
<td>1.60 ±</td>
<td>1.33 ±</td>
</tr>
<tr>
<td></td>
<td>0.15</td>
<td>0.08</td>
<td>0.05</td>
<td>0.04</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Mixed</td>
<td>7.54 ±</td>
<td>4.22 ±</td>
<td>2.69 ±</td>
<td>2.03 ±</td>
<td>1.60 ±</td>
<td>1.33 ±</td>
</tr>
<tr>
<td></td>
<td>0.21</td>
<td>0.12</td>
<td>0.08</td>
<td>0.06</td>
<td>0.05</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Table 5.8: The mean (± SEM) length in cm of CL per 100g liveweight during the production period.

Week (P < 0.001), strain (P = 0.008) and sex (P = 0.03) all had significant effects. Pen-sex had no significant effect on the relative CL length (P = 0.29). For the effect of week, values within the row with different superscripts are significantly different (P < 0.05).

5.4.11. Proximate analysis of carcass composition

The carcass water, protein, fat and ash contents are given in table 5.9 (week three) and 5.10 (week five). The effect of strain on carcass water content were marginally not significant (P = 0.07) as was the effect of pen-sex (P = 0.07). The effect of pen-sex on carcass protein was significant (P = 0.006) with no interaction between pen-sex and week (P = 0.29) or between pen-sex and sex (P = 0.96). The carcass protein was higher (P < 0.05) for birds in mixed pens (18.8 ± 0.35 %) than birds in single pens (17.7 ± 0.30 %). The effect of sex on carcass fat % was very marginally not significant (P = 0.052). Females (15.5 ± 0.03 %) tended to have a higher fat % than males (14.7 ± 0.03 %) with this tendency seemingly greater in week five.
<table>
<thead>
<tr>
<th>Week 3</th>
<th>Water %</th>
<th>Protein %</th>
<th>Fat %</th>
<th>Ash %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain A</td>
<td>64.8 ± 0.8</td>
<td>18.1 ± 0.7</td>
<td>14.1 ± 0.3</td>
<td>3.0 ± 0.1</td>
</tr>
<tr>
<td>Strain AB</td>
<td>65.2 ± 0.8</td>
<td>17.7 ± 0.5</td>
<td>14.2 ± 0.5</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Strain B</td>
<td>66.3 ± 0.4</td>
<td>16.9 ± 0.4</td>
<td>13.8 ± 0.3</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Strain BA</td>
<td>66.9 ± 0.6</td>
<td>17.1 ± 0.4</td>
<td>13.1 ± 0.4</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Female</td>
<td>65.8 ± 0.3</td>
<td>17.3 ± 0.3</td>
<td>13.9 ± 0.2</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Male</td>
<td>65.8 ± 0.6</td>
<td>17.6 ± 0.5</td>
<td>13.6 ± 0.3</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Single</td>
<td>64.2 ± 0.5</td>
<td>17.2 ± 0.3</td>
<td>13.6 ± 0.3</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Mixed</td>
<td>62.7 ± 0.6</td>
<td>17.9 ± 0.5</td>
<td>14.2 ± 0.3</td>
<td>2.9 ± 0.1</td>
</tr>
</tbody>
</table>

Table 5.9: The effects of strain, sex and pen-sex on the composition of the carcass for ducks at three weeks of age.

<table>
<thead>
<tr>
<th>Week 5</th>
<th>Water %</th>
<th>Protein %</th>
<th>Fat %</th>
<th>Ash %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain A</td>
<td>60.5 ± 1.3</td>
<td>19.3 ± 0.5</td>
<td>16.9 ± 0.9</td>
<td>3.3 ± 0.1</td>
</tr>
<tr>
<td>Strain AB</td>
<td>61.9 ± 0.7</td>
<td>18.5 ± 0.5</td>
<td>16.2 ± 0.4</td>
<td>3.7 ± 0.1</td>
</tr>
<tr>
<td>Strain B</td>
<td>60.7 ± 1.0</td>
<td>19.2 ± 0.5</td>
<td>16.7 ± 0.7</td>
<td>3.3 ± 0.1</td>
</tr>
<tr>
<td>Strain BA</td>
<td>63.2 ± 1.0</td>
<td>17.7 ± 0.7</td>
<td>15.9 ± 0.5</td>
<td>3.2 ± 0.1</td>
</tr>
<tr>
<td>Female</td>
<td>60.9 ± 0.9</td>
<td>18.8 ± 0.4</td>
<td>17.1 ± 0.5</td>
<td>3.2 ± 0.1</td>
</tr>
<tr>
<td>Male</td>
<td>62.2 ± 0.6</td>
<td>18.6 ± 0.4</td>
<td>15.8 ± 0.4</td>
<td>3.4 ± 0.1</td>
</tr>
<tr>
<td>Single</td>
<td>64.2 ± 0.5</td>
<td>18.2 ± 0.4</td>
<td>16.4 ± 0.4</td>
<td>3.3 ± 0.1</td>
</tr>
<tr>
<td>Mixed</td>
<td>62.7 ± 0.6</td>
<td>19.7 ± 0.3</td>
<td>16.6 ± 0.5</td>
<td>3.2 ± 0.1</td>
</tr>
</tbody>
</table>

Table 5.10: The effects of strain, sex and pen-sex on the composition of the carcass for ducks at five weeks of age.

The carcass composition for weeks three and five are given in figure 5.26. There was a highly significant (P < 0.001) effect of week on carcass water, protein and fat %. Ducks three weeks of age (64.2 ± 0.5 %) had a higher (P < 0.05) water content than ducks aged five weeks (62.7 ± 0.6 %). Ducks at five weeks of age had higher (P < 0.05) carcass protein (18.7 ± 0.3 Vs 17.5 ± 0.3) and fat (16.4 ± 0.3 % Vs 13.8 ± 0.2) content than did ducks at three weeks of age. There was no significant effect of week on carcass ash % (week three; 2.93 ± 0.03 % and week five; 3.30 ± 0.05 %).
5.4.12. Metabolism study

The effects of strain and pen-sex on apparent AME, ileal nitrogen digestibility and nitrogen retention are given in table 5.11. Strain \((P = 0.14)\) and pen-sex \((P = 0.73)\) had no effect on apparent AME. Strain had significant effect on ileal nitrogen digestibility \((P = 0.016)\). Strain A X B had a lower ileal nitrogen digestibility \((P < 0.05)\) than the other strains. The effect of pen-sex on ileal nitrogen digestibility was marginally not significant \((P = 0.07)\). Pen-sex \((P = 0.47)\) had no effect on nitrogen retention. While strain had no significant effect on nitrogen retention \((P = 0.16)\). It appears that the nitrogen retention was lower for strain A x B but this was not identified in the analysis. There are large standard errors and so large variation in the determination.
Table 5.11. The mean (± SEM) apparent metabolisable energy (AME), ileal nitrogen digestibility and nitrogen retention for the effect of strain and pen-sex.

For the effect of strain, values within columns with different superscripts are significantly different (P < 0.05).

### 5.5. Discussion

The focus of the discussion will be on the comparison of the results obtained in winter with those of the summer trial. Forty one day processing weight was higher in winter than in summer. The winter and summer values for strain A were 2847 ± 20 g and 2705 ± 33 g; strain A X B were 3106 ± 22 g and 2844 ± 34 g; strain B were 3262 ± 23 g and 2963 ± 39 g; and strain B x A were 2951 ± 21 g and 2724 ± 32 g. In both summer and winter the order for the strains having the higher weight was the same, namely strain B, A X B and then B X A. Of significance to our main objective is the observation that neither cross out performed strain B but the liveweight of these crosses was higher than for strain A. In summer, only strain B achieved the desired market weight (2.85kg) by day 41 while in winter three strains achieved market weight. The lower growth rate in the summer is a considerable problem for the industry. During the hotter months of the year producers need to grow ducks out to 45-46 days of age to achieve market age. This is a major cost to the industry, not just because of the added feed days incurred but also the significant drop in feed efficiency that occurs with age.

As in summer, in winter males (3137 ± 19 g) were heavier than females (2942 ± 18 g). The differential was 195g which was similar to the difference of 202 g seen in summer. This difference causes the industry problems as it creates variation in slaughter weight that needs to be accommodated on the production line. It has been one issue prompting interest in single sex rearing. While there may be processing advantages with single sex rearing the data generated in the present study clearly supports the conclusion that single sex rearing provides no growth advantage to either sex. This was the same conclusion as reached in the summer trial (chapter 4).

While in general, the pattern of liveweight gain was similar in summer and winter, the decrease from maximum gain to end of production was different. In both summer and winter maximum liveweight gain was achieved in weeks three and four (85.3 to 89 g/d). In summer there was significant decrease in gain in week five (74 g/d) and increase in week six (84 g/d). In winter, there was minimal decrease in liveweight gain in week five (86 g/d) but a significant decrease occurred in week six (71 g/d).
While its only speculation, the more rapid decrease in gain in week five, in summer is possibly related to the higher shed temperature. There is a real need for the industry to find strategies to combat the problems of summer heat stress in conventional duck sheds.

The FCR was lower in summer than winter with the difference being 5-8%. Feed intake and liveweight were greater in winter and the difference in FCR could be related to the higher maintenance requirements of larger birds and the increased energy required for thermoregulation. This is supported by the difference in week six FCR for winter (3.38 ± 0.13) compared to summer (2.87 ± 0.13). It could simply be that the ducks reach a mature weight earlier in winter than summer. In winter the average slaughter weight of ducks at 41 days for some strains was well above market weight. Whatever, it does indicate that feed efficiency decreases rapidly above market weight of 2.85 kg. If the industry envisages developing the cut up market, the poor feed efficiency at an older age could be a limitation with the current strains being used under Australian conditions.

As to be expected, water intake was higher in summer being approximately 2L more per bird or 50 ml/day. With the average feed intake higher and water intake lower in winter the water to feed ratio was lower in winter than summer. In summer it was around 3.3 and winter 2.7. These ratios are much lower than the 4.2 reported by others (Siregar & Farrell, 1980; Scott & Dean, 1991).

Unlike in summer were no effects of strain on breast weight as a percentage of LW were observed, strain effects were significant in winter. The major differences in winter occurred in weeks five and six where there was a definite pattern to the strain effects. The breast % was highest in strain B then strain B x A, followed by strain A and lastly strain A X B. A point of importance is that the crosses did not out perform strain B although was some advantage for strain B X A over strain A which was not detected in summer. The effects of pen-sex on breast % were complicated by the significant sex x pen-sex interaction. Females reared as single sexes had a higher breast % than females reared in mixed sex pens. However, this effect was the reverse in males. This interaction was not seen in summer. Females had a higher breast % than males just as was seen in summer. It is generally accepted that the females mature earlier than males and so maximum rate of muscle development will occur earlier. As commented on in chapter four, the late development of breast muscle in ducks is an issue for the industry. As described for the summer trial, the rate of breast muscle development increases rapidly after week four. The same pattern is seen in the winter trial. So again ducks are being slaughtered before the time of maximum breast muscle development.

Between summer and winter there was slight difference in the % of leg muscle in week one of the production period. In summer the thigh muscle % was lower in week one than week two but in winter it was as high in week one as week two. The average thigh muscle % was similar in summer and winter. In summer, there were no strain, sex or pen-sex effects and while the analysis indicated that there were some sex and pen-sex effects in winter, these were very minimal and inconsistent. The pattern of leg muscle development was similar in summer and winter. There were no significant strain, sex or pen-sex effects on leg muscle % in either winter or summer. In winter the sex x strain interaction was marginally non significant so there were some trends reported on in the results section.

Abdominal fat % increased each week after week one in both summer and winter. At 41 days the % tended to be higher in summer than winter. In summer, there was no strain, sex or pen-sex effects on fat % and in winter similarly there were no strain or pen-sex effects. In winter females had a higher fat % than males. Females mature earlier than males and so they will had an increased propensity to lay down abdominal fat earlier in production. While there were no significant sex effects in summer there were indications that in week five and six, fat % was increasing at a faster rate in females. The lack of a significant difference in summer could be related to the lower liveweight of both sexes at week six, in summer compared to winter.

The summer and winter differences in liver, proventriculus and gizzard weights expressed as % of LW were minimal. The pattern for the relative weight to be high in week one and then decrease each week, was the same in both seasons. In summer, there were some strain effects complicated by the
interaction with pens-sex. However, because of the analysis being employed very small differences are pick up as being significant.

There were some significant effects of strain, sex and pen-sex on the relative segments of the small intestine with the patterns in winter being similar to those seen in the summer trial. As a general observation strains A and B x A had longer relative lengths than did strains B and A X B in both winter and summer, but there were some discrepancies. There is a question over how physiologically relevant the measure used (length/100g LW) really is. Strains A and B x A were the lightest strains in both summer and winter. So is the strain effects seen just a reflection of the differences in weight. If the differences in relative length are related to metabolic efficiency then the measure is important but there is really no evidence that this is the case. In general, females had shorter relative segments lengths than males but again females were lighter than males in both summer and winter. Again as general comment, pen-sex had no effect on relative small intestine segment lengths.

There were similarities in carcass composition for summer and winter. In both seasons no effects of strain were recorded. In winter, there were pen-sex effects that were not seen in summer. Carcass protein content was higher for birds reared in mixed sex pens than in single sex pens. Also in winter, females tended to be fatter than males but this was not detected in summer. This could be related to the higher liveweight of females in winter. Females mature earlier than males and in winter they achieved a higher liveweight which might allow the propensity for increased fat deposition to be realised. In both seasons, the changes in carcass composition with age are similar. In week three, ducks have a higher carcass water % and in week five, higher carcass protein and fat %.

The calculated AME, ileal nitrogen digestibility and nitrogen retention were similar to the values determined for the summer study (Chapter four). There should have been no seasonal effects on the values for the AME as the birds were maintained in a temperature controlled room so the temperature regime would have been the same for both metabolism studies. The strains were the same and they were reared as single or mixed sex pens. The only difference would be that the diets were prepared at different times. So the small differences in the calculated values are probably related to diet preparation. Again the nitrogen retention rates are low as they were in the summer study. In both seasons, strain and pen sex had no effects on AME. The low nitrogen retention in both summer and winter suggest that the protein content of the grower diet could be too high as was discussed previously in chapter 4.
6. The effect of feeding diets differing in protein and sorghum content on the performance of commercial duck strains under summer conditions

6.1. Introduction

Results from studies one and two (reported in Chapters 4 and 5) indicate that the protein concentrations of the commercial grower diet fed to ducks was too high. This was supported by the low nitrogen retention rates observed in the metabolism studies. The results suggest that it might be possible to reduce protein content of commercial duck diet and yet achieve similar performance to the present commercial diet formulations.

Presently, commercial duck diets rely heavily on wheat as the main grain as an energy source. With competition for wheat being high, especially with the increasing demand for human consumption, intensive animal industries are going to have to rely on alternative grain sources in the near future. An alternative being evaluated in the broiler industry is sorghum. There is a need to evaluate the suitability of sorghum as an alternative for duck diets.

6.2. Objectives

The objectives of the present study was to investigate the performance of commercial ducks fed diets with lower protein concentrations than is presently being used and replacing part of the wheat component of the diet with sorghum.

6.3. Methods

6.3.1. Duck growth trial

6.3.1.1. Experimental Procedures

There were 48 pens allocated to the study (see section 2.1). The study used a completely randomised design with blocking. Each treatment was randomly allocated to one pen in each block in the shed. Initially there were 36 ducks in each pen, but this number was reduced over time.

6.3.1.2. Treatments

There were 12 different treatments consisting of four strains and three separate diets. The strains were the Grimaud Freir (GF) and Cherry Valley (CV) and their reciprocal crosses, Cherry Valley (male) X Grimaud Freir (female) and the Grimaud Freir (male) X Cherry Valley (female), all reared as mix sexes.

The dietary treatments used were:

Control Diet: this was the commercial diet fed as starter on days 1-14 (formulated to contain 21.7% protein and 12.5 MJ/kg ME) and grower diet fed on days 15-41 (formulated to contain 18.1% protein and 12.8 MJ/kg ME). For this treatment the grain component of the starter was, wheat 50% and sorghum 15.5% and for the grower diet was 50% wheat and 24% sorghum.
Low protein diet: this was fed as starter on days 1-14 (formulated to contain 19.1% protein and 12.5 MJ/kg ME) and grower on days 15-41 (formulated to contain 15.7% protein and 12.8 MJ/kg ME). For this treatment the grain component of the starter was, wheat 50% and sorghum 20% and grower diet was 49.9% wheat and 27.5% sorghum.

High Sorghum diet: this was similar to the commercial diet fed as starter on days 1-14 (formulated to contain 21.7% protein and 12.5 MJ/kg ME) and grower on days 15-41 (formulated to contain 17.8% protein and 12.8 MJ/kg ME). For this treatment the grain component of the starter was, wheat 31% and sorghum 31% and grower diet was 36% wheat and 36% sorghum.

Diets were formulated and supplied by Inghams Pty Ltd (Berrima, NSW, Australia).

6.3.1.3. Husbandry

The husbandry procedures are as described in sections 3.1.1 to 3.1.7.

6.3.1.4. Performance and carcass measurements

Briefly, on days seven (week one), 14 (week two), 21 (week three), 28 (week four), 35 (week five) and 41 (week six) all ducks were individually weighed. On days six, 13, 20, 27, 34 and 41 growth measurements were taken from an individual duck selected at random from each pen. Carcass and GIT measurements were made as described in section 3.1.9. At the end of the production period all remaining ducks were processed by PEPE’S Ducks Pty Ltd. On days 20 (week three) and 34 (week five) the carcasses and all body parts used for growth measurements were retained. The carcasses were autoclaved, homogenised and after freeze-drying the crude fat, protein and ash were determined as described in section 3.1.10.

6.3.2. Metabolism study

At day 14 (week two), four ducks were randomly selected and removed from each pen of the growth trial. Equal numbers of males and females were taken. The ducks were placed in 48 metabolism cages and fed ad libitum the same commercial grower diet supplied to the ducks in the growth trial, with the addition of an insoluble ash marker, Celite, at a concentration of 10 grams per kilogram of feed. Sampling was the same as described in section 3.2.

6.3.3. Statistical analysis

The mixed model REML procedure in GenStat Release 10 (www.vsni.co.uk) was used for the analysis of data. Data were loge transformed where necessary. The fixed model included the effects of strain, diet, sex and week and the random model included the effects of block, pen and bird identification.

For example the following mixed model was fitted to the duck liveweight data:

\[
\log_e \text{Weight} = \text{Constant} + \text{Diet} + \text{Sex} + \text{Strain} + \text{Week} + \text{Diet.Sex} + \text{Diet.Strain} + \text{Diet.Week} + \\
\text{Sex.Strain} + \text{Sex.Week} + \text{Strain.Week} + \\
\text{Block} + \text{Pen} + \text{Tag} + \epsilon
\]

All significance testing of fixed effects was conducted using Wald chi-square tests with a significance threshold of \( P < 0.05 \). Non-significant interactions were removed from the model. Pairwise comparison of means was conducted using LSD-type procedures (LSD = 2×SED).
For the proximate carcass analysis and the metabolism study, differences between treatments were determined using ANOVA (SAS: Statview, version 5). When differences were significant individual comparisons were made using the least significant difference (LSD) procedure.

6.4. Results

For reasons of ‘commercial in confidence’ the strains have been designated as Strain A, Strain B, and the crosses as A x B and B x A with no specific order designated.

6.4.1. Liveweight

There were highly significant effects of strain (see Figure 6.1), diet (see Figure 6.2) and sex (see Figure 6.3) on liveweight but these effects changed over time, as indicated by the significant strain × week, sex × week, and diet × week interactions (all \( P < 0.001 \)). There were no significant strain × diet (\( P = 0.44 \)), strain × sex (\( P = 0.91 \)) and diet × sex (\( P = 0.72 \)) interactions. The standard errors of means have not been included as they are too small to plot. The extremely large sample size results in these very small standard errors, hence fairly subtle biological effects are being detected as being statistically significant.

At every week there were significant differences in mean liveweight, with strain B being heavier the other strains (\( P < 0.05 \)), followed by strain A X B which was heavier than strains A and B x A (\( P < 0.05 \)). In the first three weeks, strain A and B X A had similar weights but thereafter strain B x A was heavier (\( P < 0.05 \)). At the end of the production period the final liveweight for strains A, A X B, B and B X A were 2793 ± 25 g, 2999 ± 27 g, 3204 ± 29 g and 2878 ± 26 g, respectively.

In all weeks, ducks on the low protein diet were lighter than ducks on the control or sorghum diets (\( P < 0.05 \)) but there was no difference between birds fed the control and sorghum diets. At the end of the production period the final liveweight for birds fed the control, low protein and high sorghum diets were 2996 ± 24 g, 2916 ± 23 g and 2984 ± 24, respectively.

In all weeks, the males were heavier than the females (\( P < 0.05 \)). At the end of the production period the final liveweight for females was 2861 ± 20 g and for males was 3075 ± 22 g.

![Figure 6.1. The mean liveweight for the effect of strain over the six week production period.](image)

There was a significant strain × week interaction (\( P < 0.001 \)).
6.4.2. Liveweight gain (LW)

Liveweight gain increased in weeks one to three, reached a plateau in weeks four and five and then decreased in week six. The effect of strain on weekly gain is shown in figure 6.4. The effect of strain was significant ($P < 0.001$) with there being no strain x week interaction ($P = 0.09$). Strain B had the greatest gain followed by strain A x B, then B X A and strain A having the lowest gain ($P < 0.05$).

The effect of diet on weekly gain is shown in figure 6.5. The diet effect changed over time with there being a significant diet x week interaction ($P < 0.001$). In weeks one to four, birds on the low protein diet had lower weekly gain than those on the other two diets ($P < 0.05$). In week five, the gain was similar for all diets and in week six birds on the low protein diet had a higher gain than those on the
other diets ($P < 0.05$) with the sorghum diet being higher than the control diet ($P < 0.05$). There was no strain x diet interaction ($P = 0.65$).

**Figure 6.4. The mean weekly gain for the effect of strain over the production period.**
There was a significant strain effect ($P < 0.001$) but no strain x week interaction ($P = 0.09$).

**Figure 6.5. The mean weekly gain for the effect of diet over the production period.**
There was a significant strain x week interaction ($P < 0.001$).
6.4.3. Feed Intake

The effect of strain on feed weekly intake is shown in figure 6.6. Strain had significant effect on feed intake (P < 0.001) but there was no strain x week interaction (P = 0.19). Feed intake of strain B was higher than for other strains (P < 0.05) and the intake for strain A X B was greater than strains A and B x A (P < 0.05). The intakes for strain A and B X A were similar.

The effect of diet changed over the production period as indicated by the significant diet x week interaction (P < 0.001). The main differences were seen in weeks one and two (see Figure 6.7) where birds fed the low protein diet had lower intake than birds on the other diets (P < 0.05). In week three, birds on the low protein diet had a higher intake than those on the sorghum diet but not the control diet (P < 0.05). There were no differences in feed intake after week three.

The composite feed intake for the entire production period for strains A, A x B, B and B x A were 5.95 ± 0.08 kg, 6.33 ± 0.06 kg, 6.77 ± 0.08 kg and 5.98 ± 0.74 kg, respectively. The total intake was higher for strain B than all other strains (P < 0.05), and strain A X B had an intake higher (P < 0.05) than strains A and B X A which were similar. The composite feed intake for the entire production period for the control, low protein and sorghum diets were 6.29 ± 0.10 kg, 6.28 ± 0.10 kg and 6.21 ± 0.11 kg, respectively. There were no differences due to diet.

![Figure 6.6](image_url)

**Figure 6.6. The mean weekly feed intake for the effect of strain over the production period.**

Strain had significant effect on feed intake (P < 0.001) but there was no strain x week interaction (P = 0.19).
6.4.4. Food Conversion Ratio (FCR)

The effect of strain on weekly FCR was significant (P < 0.01) with no significant interaction with week (P = 0.84). The weekly FCR was lower for strain B X A than for other strains (P < 0.05) with there being no other differences between strains (see Figure 6.8).

The effect of diet on weekly FCR is given in figure 6.9. The effect of diet changed with time as indicated by the significant diet x week interaction (P < 0.001). The differences were mostly seen in weeks three, four and six. In week three, the FCR for birds on the low protein diet was higher than for birds on the other diets (P < 0.05). In week four, the only significant difference was where the FCR was lower for the control diet than for the low protein diet (P < 0.05). In week six, the FCR was different for all dietary treatments with the birds on the low protein diet having a better FCR than birds on other diets (P < 0.05) and those fed sorghum having lower FCR than those on the control diet (P < 0.05).

The total composite FCR for the production period for the different strains were strain A, 2.16 ± 0.03; strain A X B, 2.14 ± 0.01; strain B, 2.14 ± 0.02 and strain B X A, 2.10 ± 0.03. There was no effect of strain on total FCR (P = 0.12). There was a significant effect of diet on the composite FCR (P < 0.001). The composite FCR for birds fed control diet was 2.13 ± 0.02, for the low protein diet was 2.18 ± 0.02 and for the sorghum diet it was 2.10 ± 0.02 with the value for the low protein diet being higher than for the other diets (P < 0.05).
Figure 6.8. The mean weekly feed conversion ratio (FCR) for the effect of strain over the production period.

The effect of strain was significant (P < 0.01) with no significant interaction with week (P = 0.84).

Figure 6.9. The mean weekly feed conversion ratio (FCR) for the effect of diet over the production period.

There was a significant diet x week interaction (P < 0.001).

6.4.5. Water Intake

The effects of strain and diet on weekly water intake are shown in figures 6.10 and 6.11, respectively. Both the strain x week and diet x week interactions were significant (P < 0.001). In all weeks the water intakes of strains A and B X A were lower than for strains B and A x B (P < 0.05). For weeks one to four the water intake of strain A X B was similar to strain B but in weeks five and six it was lower (P < 0.05). The water intakes of strains A and B x A were similar. The total composite water intake for strain A was 16.99 ± 0.33 L, strain A X B was 18.44 ± 0.38 L, strain B was 19.14 ± 0.37 L.
and strain B X A was 16.84 ± 0.31 L. Strain had a significant effect on total water intake (P < 0.001). The water intake for strains B and A X B were higher than those for strains A and B x A (P < 0.05).

After week one, the water intake for birds on the low protein diet was lower than for the other diets (P < 0.05). Diet had significant effect on total water intake (P < 0.001). The total water intake for birds on the low protein diet (16.66 ± 0.29 L) was less (P < 0.05) than it was for the birds on either the control (18.53 ± 0.36 L) or sorghum diets (18.35 ± 0.33 L).

**Figure 6.10.** The mean weekly water intake (mL) for the effect of strain over the production period.

The strain x week interaction was significant (P < 0.001).

**Figure 6.11.** The mean weekly water intake for the effect of diet over the production period.

The interaction diet x week was significant (P < 0.001).
6.4.6. Water to feed ratio

Strain had no significant effect (P = 0.12) on the water to feed ratio (see Figure 6.12). The interaction between diet and week was significant (P < 0.001). From week three the water to feed ratio was lower (P < 0.05) for the birds on the low protein diet than the other two diets (see Figure 6.13).

The total composite water to feed ratios for the different strains were, strain A, 2.86 ± 0.06; strain A X B; 2.91 ± 0.06; strain B, 2.83 ± 0.06 and strain B X A, 2.86 ± 0.06. Strain had no effect on total water to feed ratio (P = 0.24). The total water to feed ratio for birds on the control diet was 2.97 ± 0.06, the low protein diet was 2.65 ± 0.03 and sorghum diet was 2.94 ± 0.03. Diet had a significant effect on total water to feed ratio (P < 0.001) with the value for birds fed on the low protein diet being lower than for birds fed the other diets (P < 0.05).

![Figure 6.12. The mean weekly water to feed ratio for the effect of strain over the production period.](image)

Strain had no significant effect on the water to feed ratio (P = 0.12).
Figure 6.13.  The mean weekly water to feed intake ratio for the effect of diet over the production period.

There was a significant diet x week interaction (P < 0.001).

6.4.7. Muscle development and yield

Muscle yield is determined as the muscle weight to liveweight ratio expressed as a percentage (%). The effect of strain, diet and sex on the breast muscle weight to LW %, are shown in figures 6.14, 6.15 and 6.16, respectively. Week, strain, diet and sex all had significant effects on the % breast muscle (all P < 0.001). The breast muscle weight to LW % increased at each week the birds aged with differences between all weeks being significant (P < 0.05). Ducks of strains B and B X A had significantly more breast % than did strains A and A X B (P < 0.05). At week six, the final breast to LW % were strain A, 8.24 ± 0.21 %; strain A X B, 8.36 ± 0.22%; strain B, 8.92 ± 0.23 % and strain B X A, 8.97 ± 0.24 %.

Ducks on the low protein diet had a lower breast % than did ducks on the control and sorghum diets. At week six, the final breast to LW % for birds on the control diet was 9.11 ± 0.23, low protein diet was 7.94 ± 0.20 and for the sorghum diet was 8.84 ± 0.22.

Females had a higher breast % than did the males (P < 0.05). At week six the final breast % for females was 8.98 ± 0.21 and males was 8.28 ± 0.19.
Figure 6.14. The mean weekly breast muscle yield expressed as a percentage of liveweight (LW) for the effect of strain over the production period.

The effect of strain was significant (P < 0.001).

Figure 6.15. The mean weekly breast muscle yield expressed as a percentage of liveweight (LW) for the effect of diet over the production period.

The effect of diet was significant (P < 0.001).
Figure 6.16. The mean weekly breast muscle yield expressed as a percentage of liveweight (LW) for the effect of sex over the production period. The effect of sex was significant ($P < 0.001$).

The effect of strain and diet on the thigh muscle weight to liveweight expressed as a percentage, are shown in figures 6.17 and 6.18, respectively. The effect of week on the thigh muscle weight to LW % was significant ($P < 0.001$). In the first two weeks, there was no change in thigh muscle %, but in the third week it was significantly lower ($P<0.05$). It then increased significantly in the fourth week ($P<0.05$), only to decrease again in the fifth and sixth weeks.

Diet had a significant effect on thigh muscle % ($P = 0.007$). Ducks on the low protein diet had lower thigh muscle % ($P < 0.05$) than did ducks on the control and sorghum diets. Both strain ($P = 0.46$) and sex ($P = 0.11$) had no significant effects on the thigh muscle %.

Figure 6.17. The mean weekly thigh muscle yield expressed as a percentage of liveweight (LW) for the effect of strain over the production period. The effect of strain was not significant ($P=0.46$).
Figure 6.18. The mean weekly thigh muscle yield expressed as a percentage of liveweight (LW) for the effect of diet over the production period.

The effect of diet was significant (P = 0.007).

There was a highly significant effect of week (P < 0.001) on the leg (drumstick) muscle weight to liveweight %. The leg muscle % significantly increased (P < 0.05) from week one to two, and then to its peak at week three. It then significantly decreased (P < 0.05) every week after week three. The effects of strain and diet on the leg muscle % are given in figures 6.19 and 6.20, respectively. Strain (P = 0.13), diet (P = 0.14) and sex (P = 0.07) all had no significant effects on the leg muscle %.

Figure 6.19. The mean weekly leg muscle yield expressed as a percentage of liveweight (LW) for the effect of strain over the production period.

The effect of strain was not significant (P = 0.13).
6.4.8. Abdominal fat yield

The effect of strain, diet and sex on the abdominal fat weight to liveweight expressed as a percentage, are shown in figures 6.21, 6.22 and 6.23, respectively. The effect of strain was marginally not significant (P = 0.08).

The effect of sex was influenced by both diet and week as indicated by the significant sex x diet interaction (P = 0.007) and sex x week interaction (P = 0.02). Over time, the difference in abdominal fat % was significant only in the final week, where female (1.57 ± 0.04%) ducks had a higher (P < 0.05) % than did male ducks (1.38 ± 0.04%). It was also found that the female ducks on the control diet (0.89 ± 0.08 %) had an abdominal fat % which was significantly lower (P < 0.05) than females on the low protein diet (0.94 ± 0.08 %). When considering male ducks, those on the low protein diet (1.17 ± 0.07 %) had significantly higher (P < 0.05) abdominal % than those ducks on the sorghum diet (0.93 ± 0.07 %) and they in turn had significantly higher (P < 0.05) % than the males on the control diet (0.81 ± 0.08 %).
Figure 6.21. The mean weekly abdominal fat weight expressed as a percentage of liveweight (LW) for the effect of strain over the production period.

The effect of strain was not significant (P=0.08).

Figure 6.22. The mean weekly abdominal fat weight expressed as a percentage of liveweight (LW) for the effect of diet over the production period.

There was a significant diet x sex interaction (P = 0.007).
6.4.9. Digestive organ weights and gastrointestinal tract measurements

Measurements are given as the ratio of organ weight to liveweight expressed as percentage (%).

6.4.9.1. Liver

Strain (P = 0.87) and sex (P = 0.68) had no effect on the liver weight to liveweight ratio expressed as a percentage (see Table 6.1). There were significant week (P < 0.001) and diet (P < 0.001) effects. After each week of age ducks had a lower liver % (P < 0.05). Ducks on the low protein diet (4.67 ± 0.02) had significantly higher (P < 0.05) liver % than ducks on control diet (4.31 ± 0.02) or sorghum diet (4.28 ± 0.02).
<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week</td>
<td>6.86 ± 0.09\textsuperscript{a}</td>
<td>5.95 ± 0.09\textsuperscript{b}</td>
<td>5.18 ± 0.08\textsuperscript{c}</td>
<td>4.05 ± 0.07\textsuperscript{d}</td>
<td>3.40 ± 0.06\textsuperscript{e}</td>
<td>2.66 ± 0.06\textsuperscript{f}</td>
</tr>
<tr>
<td>Control</td>
<td>6.77 ± 0.16</td>
<td>5.85 ± 0.19</td>
<td>4.98 ± 0.10</td>
<td>3.73 ± 0.15</td>
<td>3.48 ± 0.10</td>
<td>2.60 ± 0.11</td>
</tr>
<tr>
<td>Low Protein</td>
<td>7.01 ± 0.12</td>
<td>6.30 ± 0.11</td>
<td>5.64 ± 0.13</td>
<td>4.39 ± 0.10</td>
<td>3.45 ± 0.09</td>
<td>2.86 ± 0.11</td>
</tr>
<tr>
<td>Sorghum</td>
<td>6.81 ± 0.15</td>
<td>5.70 ± 0.11</td>
<td>4.93 ± 0.12</td>
<td>3.99 ± 0.09</td>
<td>3.29 ± 0.10</td>
<td>2.53 ± 0.09</td>
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<tr>
<td>Strain A</td>
<td>6.48 ± 0.18</td>
<td>5.80 ± 0.17</td>
<td>5.09 ± 0.17</td>
<td>4.07 ± 0.13</td>
<td>3.35 ± 0.13</td>
<td>2.77 ± 0.13</td>
</tr>
<tr>
<td>Strain AB</td>
<td>6.97 ± 0.19</td>
<td>6.15 ± 0.22</td>
<td>5.12 ± 0.19</td>
<td>5.01 ± 0.12</td>
<td>3.44 ± 0.10</td>
<td>2.57 ± 0.11</td>
</tr>
<tr>
<td>Strain B</td>
<td>7.09 ± 0.13</td>
<td>5.91 ± 0.12</td>
<td>5.22 ± 0.17</td>
<td>3.94 ± 0.21</td>
<td>3.48 ± 0.10</td>
<td>2.66 ± 0.14</td>
</tr>
<tr>
<td>Strain BA</td>
<td>6.92 ± 0.13</td>
<td>5.95 ± 0.19</td>
<td>5.28 ± 0.15</td>
<td>4.17 ± 0.12</td>
<td>3.34 ± 0.12</td>
<td>2.65 ± 0.12</td>
</tr>
<tr>
<td>Female</td>
<td>6.86 ± 0.12</td>
<td>5.98 ± 0.14</td>
<td>5.19 ± 0.10</td>
<td>4.01 ± 0.10</td>
<td>3.35 ± 0.07</td>
<td>2.62 ± 0.09</td>
</tr>
<tr>
<td>Male</td>
<td>6.86 ± 0.12</td>
<td>5.92 ± 0.10</td>
<td>5.17 ± 0.14</td>
<td>4.08 ± 0.11</td>
<td>3.45 ± 0.09</td>
<td>2.69 ± 0.09</td>
</tr>
</tbody>
</table>

Table 6.1. The effect of week, diet, strain and sex on the mean (± SEM) liver weight to liveweight ratio expressed as percentage.

For week, the values within the row with different superscripts are significantly different (P < 0.05).

6.4.9.2. Proventriculus

The effects of week, strain, diet and sex on the proventriculus weight to liveweight ratio expressed as percentage are given in table 6.2. Week had significant effect (P < 0.001), with a progressive decrease in the percentage as age increased (P < 0.05). The effect of strain (P = 0.32) was not significant. The effect of diet was confounded by an interaction with sex as indicated by the significant diet x sex interaction (P = 0.02). Females on the sorghum diet (0.47 ± 0.01 %) had a lower proventriculus % (P < 0.05) than females on the low protein diet (0.50 ± 0.01 %) while males on the low protein diet (0.48 ± 0.01 %) had a higher percentage (P < 0.05) than males on either the control (0.43 ± 0.01 %) or sorghum diets (0.45 ± 0.01 %).
<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week</td>
<td>0.83 ± 0.02</td>
<td>0.60 ± 0.01</td>
<td>0.45 ± 0.01</td>
<td>0.40 ± 0.01</td>
<td>0.36 ± 0.01</td>
<td>0.35 ± 0.01</td>
</tr>
<tr>
<td>Control</td>
<td>0.81 ± 0.02</td>
<td>0.60 ± 0.01</td>
<td>0.46 ± 0.01</td>
<td>0.38 ± 0.01</td>
<td>0.35 ± 0.01</td>
<td>0.34 ± 0.01</td>
</tr>
<tr>
<td>Low Protein</td>
<td>0.87 ± 0.05</td>
<td>0.62 ± 0.02</td>
<td>0.46 ± 0.01</td>
<td>0.41 ± 0.01</td>
<td>0.39 ± 0.01</td>
<td>0.38 ± 0.01</td>
</tr>
<tr>
<td>Sorghum</td>
<td>0.81 ± 0.02</td>
<td>0.58 ± 0.02</td>
<td>0.44 ± 0.01</td>
<td>0.39 ± 0.01</td>
<td>0.35 ± 0.01</td>
<td>0.35 ± 0.01</td>
</tr>
<tr>
<td>Strain A</td>
<td>0.86 ± 0.03</td>
<td>0.60 ± 0.01</td>
<td>0.46 ± 0.02</td>
<td>0.40 ± 0.01</td>
<td>0.36 ± 0.01</td>
<td>0.35 ± 0.01</td>
</tr>
<tr>
<td>Strain A X B</td>
<td>0.76 ± 0.06</td>
<td>0.58 ± 0.02</td>
<td>0.45 ± 0.01</td>
<td>0.39 ± 0.01</td>
<td>0.37 ± 0.02</td>
<td>0.36 ± 0.02</td>
</tr>
<tr>
<td>Strain B</td>
<td>0.83 ± 0.03</td>
<td>0.62 ± 0.02</td>
<td>0.45 ± 0.01</td>
<td>0.40 ± 0.01</td>
<td>0.36 ± 0.01</td>
<td>0.34 ± 0.06</td>
</tr>
<tr>
<td>Strain B X A</td>
<td>0.87 ± 0.02</td>
<td>0.60 ± 0.02</td>
<td>0.46 ± 0.01</td>
<td>0.40 ± 0.01</td>
<td>0.34 ± 0.01</td>
<td>0.36 ± 0.02</td>
</tr>
<tr>
<td>Female</td>
<td>0.85 ± 0.03</td>
<td>0.60 ± 0.01</td>
<td>0.47 ± 0.01</td>
<td>0.41 ± 0.01</td>
<td>0.37 ± 0.01</td>
<td>0.38 ± 0.01</td>
</tr>
<tr>
<td>Male</td>
<td>0.81 ± 0.03</td>
<td>0.59 ± 0.01</td>
<td>0.44 ± 0.01</td>
<td>0.38 ± 0.01</td>
<td>0.35 ± 0.01</td>
<td>0.34 ± 0.01</td>
</tr>
</tbody>
</table>

**Table 6.2.** The mean (± SEM) proventriculus weight to liveweight ratio expressed as a percentage.

Week had significant effect (P < 0.001) while strain did not (P = 0.32). There was significant diet x sex interaction (P = 0.02). For week, the values within the row with different superscripts are significantly different (P < 0.05).

### 6.4.9.3 Gizzard

The effects of week, strain, diet and sex on the gizzard weight to liveweight ratio expressed as percentage is given in table 6.3. Week had significant effect (P < 0.001) on the percentage of gizzard weight to liveweight and after each week of age the % decreased (P < 0.05). The effects of diet (P = 0.89) and strain (P = 0.48) were not significant. Sex had significant influence on the gizzard % (P < 0.001) with the females (3.42 ± 0.03) having a lower % (P < 0.05), than the males (3.71 ± 0.04).
Table 6.3: The mean (±SEM) gizzard weight to liveweight ratio expressed as percentage.

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week</td>
<td>5.11 ± 0.07a</td>
<td>4.40 ± 0.06b</td>
<td>3.57 ± 0.06c</td>
<td>3.17 ± 0.05d</td>
<td>2.93 ± 0.07e</td>
<td>2.87 ± 0.08f</td>
</tr>
<tr>
<td>Control</td>
<td>5.08 ± 0.14</td>
<td>4.48 ± 0.15</td>
<td>3.73 ± 0.12</td>
<td>3.11 ± 0.08</td>
<td>2.77 ± 0.13</td>
<td>2.96 ± 0.13</td>
</tr>
<tr>
<td>Low Protein</td>
<td>4.97 ± 0.11</td>
<td>4.35 ± 0.06</td>
<td>3.45 ± 0.09</td>
<td>3.24 ± 0.10</td>
<td>3.07 ± 0.11</td>
<td>2.95 ± 0.15</td>
</tr>
<tr>
<td>Sorghum</td>
<td>5.27 ± 0.10</td>
<td>4.38 ± 0.11</td>
<td>3.53 ± 0.08</td>
<td>3.17 ± 0.06</td>
<td>2.94 ± 0.10</td>
<td>2.72 ± 0.11</td>
</tr>
<tr>
<td>Strain A</td>
<td>5.27 ± 0.14</td>
<td>4.33 ± 0.16</td>
<td>3.53 ± 0.13</td>
<td>3.25 ± 0.10</td>
<td>3.07 ± 0.13</td>
<td>2.95 ± 0.12</td>
</tr>
<tr>
<td>Strain AB</td>
<td>4.98 ± 0.08</td>
<td>4.22 ± 0.10</td>
<td>3.51 ± 0.08</td>
<td>3.07 ± 0.07</td>
<td>2.85 ± 0.12</td>
<td>2.95 ± 0.18</td>
</tr>
<tr>
<td>Strain B</td>
<td>5.11 ± 0.13</td>
<td>4.66 ± 0.11</td>
<td>3.53 ± 0.08</td>
<td>3.26 ± 0.10</td>
<td>2.75 ± 0.14</td>
<td>2.78 ± 0.20</td>
</tr>
<tr>
<td>Strain BA</td>
<td>5.08 ± 0.18</td>
<td>4.39 ± 0.10</td>
<td>3.70 ± 0.15</td>
<td>3.12 ± 0.10</td>
<td>3.05 ± 0.14</td>
<td>2.82 ± 0.10</td>
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<tr>
<td>Female</td>
<td>4.96 ± 0.09</td>
<td>4.23 ± 0.07</td>
<td>3.52 ± 0.08</td>
<td>3.03 ± 0.07</td>
<td>2.73 ± 0.10</td>
<td>2.66 ± 0.10</td>
</tr>
<tr>
<td>Male</td>
<td>5.26 ± 0.09</td>
<td>4.59 ± 0.10</td>
<td>3.61 ± 0.07</td>
<td>3.28 ± 0.05</td>
<td>3.12 ± 0.08</td>
<td>3.03 ± 0.10</td>
</tr>
</tbody>
</table>

Week and sex had significant effects (both P < 0.001) while the effects of diet (P = 0.89) and strain (P = 0.48) were not significant. For week, the values within the row with different superscripts are significantly different (P < 0.05).

6.4.10. Gastrointestinal tract measurements

Measurements of the GIT are expressed as cm per 100 g of liveweight.

6.4.10.1. Duodenum length (DL)

The effects of strain and sex on the length (cm) of the duodenum (DL) per 100g liveweight is given in table 6.4, while the effect of diet is shown in figure 6.24. The effect of diet varied with time as indicated by the significant diet x week interaction (P = 0.003). In the first week, ducks on the low protein diet had significantly greater (P < 0.05) relative length than ducks on the control diet. By the end of the second week, ducks on the low protein diet had significantly higher (P < 0.05) relative length than ducks on the sorghum diet. The third and fourth week showed no significant differences between any diets, but in the week five, ducks on the low protein diet had significantly greater (P<0.05) relative lengths than ducks on the other diets. In week six, the relative length was lowest (P<0.05) for birds on the sorghum diet. Strain (P = 0.14) and sex (P = 0.27) had no significant effects on the length (cm) of the DL per 100g liveweight.
The effect of diet on the length of the DL (cm) per 100g bodyweight during the production period.

The effect of diet varied with week as indicated by the significant diet x week interaction ($P = 0.003$).

**Table 6.4:** The mean (±SEM) length of the DL (cm) per 100g liveweight during the production period.

Strain ($P = 0.14$) and sex ($P = 0.27$) had no significant effects.

6.4.10.2. Length of the jejunum (Duodenum to Merkle's Diverticulum: DL-MD)

Week had significant effect ($P < 0.001$) on the length (cm) of small intestine from the dueodenal loop to Merkle’s Diverticulum (DL-MD) per 100g liveweight (See table 6.5). There was a progressive decrease in the relative length of the DL-MD with increasing age with differences between all weeks being significant ($P < 0.05$).
Both diet \((P = 0.004)\) and strain \((P = 0.037)\) had significant effects on the relative length of the DL-MD segment. Ducks fed on the low protein diet \((6.3 \pm 0.1 \text{ cm/100g})\) had greater relative length \((P < 0.05)\), than ducks fed the control \((6.0 \pm 0.1 \text{ cm/100g})\) and sorghum diets \((5.9 \pm 0.1 \text{ cm/100g})\). Ducks of strain A \((6.3 \pm 0.1 \text{ cm/100g})\) and B X A \((6.2 \pm 0.1 \text{ cm/100g})\) had longer relative length \((P < 0.05)\), compared to ducks of strains B \((5.9 \pm 0.1 \text{ cm/100g})\) and A X B \((6.0 \pm 0.1 \text{ cm/100g})\). Sex had no significant effect \((P = 0.21)\) on the relative length of the DL-MD segment (see table 6.5).

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>21.4 ± 0.4</td>
<td>9.7 ± 0.1</td>
<td>5.9 ± 0.2</td>
<td>4.1 ± 0.1</td>
<td>3.3 ± 0.1</td>
<td>2.7 ± 0.1</td>
</tr>
<tr>
<td>Low Protein</td>
<td>23.2 ± 0.6</td>
<td>10.0 ± 0.2</td>
<td>6.1 ± 0.1</td>
<td>4.4 ± 0.1</td>
<td>3.6 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Sorghum</td>
<td>21.4 ± 0.5</td>
<td>9.3 ± 0.3</td>
<td>5.8 ± 0.2</td>
<td>4.3 ± 0.1</td>
<td>3.3 ± 0.1</td>
<td>2.7 ± 0.1</td>
</tr>
<tr>
<td>Strain A</td>
<td>22.1 ± 0.5</td>
<td>9.5 ± 0.2</td>
<td>6.2 ± 0.2</td>
<td>4.6 ± 0.1</td>
<td>3.5 ± 0.1</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Strain AB</td>
<td>21.3 ± 0.7</td>
<td>9.6 ± 0.3</td>
<td>5.5 ± 0.2</td>
<td>4.2 ± 0.1</td>
<td>3.3 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Strain B</td>
<td>21.7 ± 0.6</td>
<td>9.9 ± 0.3</td>
<td>5.9 ± 0.1</td>
<td>4.1 ± 0.1</td>
<td>3.3 ± 0.1</td>
<td>2.6 ± 0.1</td>
</tr>
<tr>
<td>Strain BA</td>
<td>22.8 ± 0.6</td>
<td>9.7 ± 0.3</td>
<td>5.9 ± 0.2</td>
<td>4.3 ± 0.1</td>
<td>3.6 ± 0.1</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Female</td>
<td>22.0 ± 0.5</td>
<td>9.9 ± 0.2</td>
<td>6.0 ± 0.1</td>
<td>4.3 ± 0.1</td>
<td>3.4 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Male</td>
<td>21.9 ± 0.4</td>
<td>9.5 ± 0.2</td>
<td>5.7 ± 0.1</td>
<td>4.2 ± 0.1</td>
<td>3.4 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
</tbody>
</table>

Table 6.5. The mean (±SEM) length in cm of small intestine from DL-MD per 100g liveweight during the production period.

Week \((P < 0.001)\), diet \((P = 0.004)\) and strain \((P = 0.037)\) all had significant effects. For week, the values within the row with different superscripts are significantly different \((P < 0.05)\).

6.4.10.3. Length of the Ileum (Merkle’s Diverticulum to the ileo-caecal junction (MD-ICJ))

The effects of strain, diet, sex and week on the length (cm) of small intestine from the Merkle’s Diverticulum to the ileo-caecal junction (MD-ICJ) per 100g liveweight are given in table 6.6. There was significant reduction each week in the relative length of the MD-ICJ segment \((P < 0.001)\). Diet had significant effect \((P = 0.002)\) with ducks on the low protein diet \((6.2 \pm 0.1 \text{ cm/100g})\) having greater relative length \((P < 0.05)\) than ducks fed the control \((5.9 \pm 0.1 \text{ cm/100g})\) or sorghum diets \((5.8 \pm 0.1 \text{ cm/100g})\). The strain effect was also significant \((P = 0.002)\). Ducks of strain A \((6.2 \pm 0.1 \text{ cm/100g})\) and B X A \((6.0 \pm 0.1 \text{ cm/100g})\) had longer relative length \((P < 0.05)\), compared to strains B \((5.8 \pm 0.1 \text{ cm/100g})\) and A X B \((5.8 \pm 0.1 \text{ cm/100g})\). Sex had no significant effects on the relative lengths \((P = 0.98)\).
<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week</td>
<td>21.6 ± 0.3a</td>
<td>9.5 ± 0.1b</td>
<td>5.8 ± 0.1c</td>
<td>4.1 ± 0.1d</td>
<td>3.3 ± 0.1e</td>
<td>2.8 ± 0.1f</td>
</tr>
<tr>
<td>Control</td>
<td>20.9 ± 0.4</td>
<td>9.5 ± 0.2</td>
<td>5.7 ± 0.1</td>
<td>4.2 ± 0.1</td>
<td>3.3 ± 0.1</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Low Protein</td>
<td>22.7 ± 0.7</td>
<td>9.9 ± 0.2</td>
<td>5.8 ± 0.1</td>
<td>4.3 ± 0.1</td>
<td>3.2 ± 0.1</td>
<td>2.6 ± 0.1</td>
</tr>
<tr>
<td>Sorghum</td>
<td>21.0 ± 0.5</td>
<td>9.0 ± 0.2</td>
<td>6.0 ± 0.2</td>
<td>4.0 ± 0.1</td>
<td>3.3 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Strain A</td>
<td>21.7 ± 0.6</td>
<td>9.8 ± 0.3</td>
<td>5.8 ± 0.1</td>
<td>4.1 ± 0.1</td>
<td>3.3 ± 0.1</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Strain AB</td>
<td>20.9 ± 0.5</td>
<td>9.4 ± 0.1</td>
<td>6.1 ± 0.2</td>
<td>4.3 ± 0.1</td>
<td>3.2 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Strain B</td>
<td>21.3 ± 0.9</td>
<td>9.3 ± 0.3</td>
<td>5.7 ± 0.2</td>
<td>3.9 ± 0.1</td>
<td>3.4 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Strain BA</td>
<td>22.2 ± 0.7</td>
<td>9.2 ± 0.3</td>
<td>5.8 ± 0.3</td>
<td>4.2 ± 0.1</td>
<td>3.2 ± 0.1</td>
<td>2.6 ± 0.1</td>
</tr>
<tr>
<td>Female</td>
<td>21.2 ± 0.5</td>
<td>9.3 ± 0.2</td>
<td>5.7 ± 0.1</td>
<td>4.2 ± 0.1</td>
<td>3.3 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Male</td>
<td>21.9 ± 0.4</td>
<td>9.6 ± 0.2</td>
<td>5.7 ± 0.1</td>
<td>4.2 ± 0.1</td>
<td>3.3 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
</tbody>
</table>

Table 6.6: The mean (± SEM) length in cm of small intestine from MD-ICJ per 100g liveweight during the production period.

Week (P < 0.001), diet (P = 0.002) and strain (P = 0.002) all had significant effects on the relative length of the MD-ICJ segment. For week, the values within the row with different superscripts are significantly different (P < 0.05).

6.4.10.4. Total Caecal length (CL)

The effects of week, diet, strain and sex on the CL length (cm) per 100g liveweight are given in table 6.7. Week had a significant effect (P < 0.001), with a progressive decrease in the CL length through the course of the study with differences between all weeks being significant (P < 0.05). Diet had a significant effect on relative CL length (P < 0.001). Ducks on the low protein diet (2.71 ± 0.03 cm/100g) having greater relative length (P < 0.05) compared to ducks fed the control (2.59 ± 0.03 cm/100g) or sorghum diets (2.52 ± 0.03 cm/100g). The effect of strain was significant (P < 0.001) with ducks of strain A (2.71 ± 0.04 cm/100g) and B X A (2.69 ± 0.04 cm/100g) having longer relative length (P < 0.05), compared to strains B (2.52 ± 0.03 cm/100g) and A X B (2.52 ± 0.03 cm/100g). Sex had no significant effects on the relative lengths (P = 0.28).
Week, diet and strain (all P < 0.001), had significant effects on the relative length of the CL. For week, the values within the row with different superscripts are significantly different (P < 0.05).

6.4.11. Proximate analysis of carcass composition

The carcass water, protein, fat and ash content are given in table 6.8 (week three) and 6.9 (week five). Diet had significant effect on carcass water % (P = 0.003) with ducks on the low protein diet (61.1 ± 0.5) having a lower % (P < 0.05) than ducks on the control (63.0 ± 0.6) or high sorghum (63.2 ± 0.5) diets. With no significant week x diet interaction (P = 0.63). Strain had no significant effect on carcass water % (P = 0.88). Also the effect of sex was marginally not significant (P = 0.08).

Strain had a significant (P= 0.02) effect on carcass protein %. Strain A X B (18.0 ± 0.5) had lower carcass protein % (P < 0.05), than ducks of strains A (19.2 ± 0.2) and B X A (19.3 ± 0.4) but not strain B (18.5 ± 0.3). The strain x week interaction was not significant (P = 0.90). Neither diet (P = 0.22) or sex (P = 0.59) had a significant effect on carcass protein %.

Strain had no significant effect on the carcass fat % (P = 0.38). The effect of diet on carcass fat % was marginally not significance (P = 0.07). There was a tendency for ducks on the control diet (14.9 ± 0.4) to have lower carcass fat content than the ducks on the low protein (16.1 ± 0.4) and sorghum diets (15.6 ± 0.4). Carcass fat % was not affected by sex (P= 0.30).

Strain had no significant effect on the carcass ash % (P = 0.83). The effect of diet on carcass ash % was significant (P = 0.005) and the diet x week interaction almost significant (P= 0.06). Birds on the low protein diet (3.26 ± 0.11) had higher carcass ash % (P < 0.05), than those birds fed the sorghum
diet (2.89 ± 0.05) but most of the effect can be attributed to the differences in week five. Sex had no significant effect on the carcass ash % (P= 0.35).

<table>
<thead>
<tr>
<th>Week 3</th>
<th>Water %</th>
<th>Protein %</th>
<th>Fat %</th>
<th>Ash %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>64.5 ± 0.7</td>
<td>18.2 ± 0.4</td>
<td>14.2 ± 0.4</td>
<td>3.0 ± 0.1</td>
</tr>
<tr>
<td>Diet</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Protein</td>
<td>62.1 ± 0.5</td>
<td>19.3 ± 0.3</td>
<td>15.5 ± 0.4</td>
<td>3.0 ± 0.1</td>
</tr>
<tr>
<td>Diet</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorghum</td>
<td>64.5 ± 0.5</td>
<td>17.9 ± 0.3</td>
<td>14.7 ± 0.5</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Diet</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strain A</td>
<td>62.8 ± 0.8</td>
<td>18.9 ± 0.4</td>
<td>15.1 ± 0.7</td>
<td>3.1 ± 0.1</td>
</tr>
<tr>
<td>Strain AB</td>
<td>63.9 ± 0.3</td>
<td>17.8 ± 0.3</td>
<td>15.4 ± 0.4</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Strain B</td>
<td>64.2 ± 0.8</td>
<td>18.3 ± 0.6</td>
<td>14.4 ± 0.4</td>
<td>3.0 ± 0.1</td>
</tr>
<tr>
<td>Strain BA</td>
<td>63.9 ± 0.7</td>
<td>18.8 ± 0.4</td>
<td>14.3 ± 0.5</td>
<td>2.9 ± 0.1</td>
</tr>
<tr>
<td>Strain B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>64.1 ± 0.5</td>
<td>18.2 ± 0.3</td>
<td>14.6 ± 0.4</td>
<td>3.0 ± 0.1</td>
</tr>
<tr>
<td>Male</td>
<td>63.2 ± 0.5</td>
<td>18.7 ± 0.3</td>
<td>15.0 ± 0.4</td>
<td>3.0 ± 0.1</td>
</tr>
</tbody>
</table>

Table 6.8: The effects of diet, strain and sex on the carcass composition of ducks at three weeks of age.

For the effects of diet, strain and sex values within the same column having different superscripts are significantly different (P < 0.05).

The carcass composition for weeks three and five are given in figure 6.25. There was a highly significant (P < 0.001) effect of week on carcass water %, whereby ducks aged three weeks (63.7 ± 0.3 %) had a significantly higher (P < 0.05) water content than ducks aged five weeks (61.2 ± 0.4 %). There was no significant effect (P = 0.12) of week on carcass protein % (week three, 18.5 ± 0.2 % and week five, 19.1 ± 0.3%). Week had significant effect on carcass fat (P = 0.003) with the carcass fat % higher (P < 0.05) in week five (16.3 ± 0.4 %) than in week three (14.8 ± 0.3 %). There was a no significant effect (P = 0.17) of week on carcass ash % (week three: 3.0 ± 0.1 % and week five: 3.1 ± 0.1 %).
## Table 6.9: The effects of diet, strain and sex on the carcass composition of ducks at five weeks of age.

<table>
<thead>
<tr>
<th></th>
<th>Week 3</th>
<th>Week 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diet</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control Diet</td>
<td>61.5 ± 0.8</td>
<td>19.7 ± 0.4</td>
</tr>
<tr>
<td>Low Protein Diet</td>
<td>60.1 ± 0.7</td>
<td>18.9 ± 0.7</td>
</tr>
<tr>
<td>Sorghum Diet</td>
<td>62.0 ± 0.6</td>
<td>18.7 ± 0.2</td>
</tr>
<tr>
<td><strong>Strain</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strain A</td>
<td>62.2 ± 0.8</td>
<td>19.5 ± 0.4</td>
</tr>
<tr>
<td>Strain AB</td>
<td>60.8 ± 0.9</td>
<td>18.3 ± 0.9</td>
</tr>
<tr>
<td>Strain B</td>
<td>61.3 ± 0.8</td>
<td>18.7 ± 0.3</td>
</tr>
<tr>
<td>Strain BA</td>
<td>60.4 ± 0.9</td>
<td>19.9 ± 0.6</td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>61.9 ± 0.5</td>
<td>19.1 ± 0.3</td>
</tr>
<tr>
<td>Male</td>
<td>60.5 ± 0.</td>
<td>19.1 ± 0.5</td>
</tr>
</tbody>
</table>

*Figure 6.25. The effect of week on the carcass % of water, protein, fat and ash.*

Water content was higher in week three and fat content high in week five (*P < 0.05).
6.4.12. Metabolism study

The grower diet AME was calculated by two methods, the total faecal collection and the insoluble ash marker procedures. The AME and AMEn values are given in table 6.10. The values for AME are similar using both procedures while the AMEn using the total collection procedure were consistently lower than the values using the insoluble ash marker procedure.

For the AME and AMEn values determined by the total collection method, no effect of diet (P = 0.50) or strain (P = 0.95) was detected. Using the insoluble ash marker procedure, strain had an effect on AME (P = 0.01) but not diet (P = 0.15). The AME for strain A was lower than for strain B x A (P < 0.05). The effect of strain on the AMEn determination using the insoluble ash marker procedure (P = 0.04) was significant. Strain A X B had a lower AMEn than strains B and B x A (P < 0.05) and strain A had a lower AMEn than strain B (P < 0.05). There was a tendency (P = 0.06) for the AMEn as determined by the insoluble marker procedure to be lower for the ducks fed the control diet.

<table>
<thead>
<tr>
<th></th>
<th>AME Total Excreta Method (MJ/kg)</th>
<th>AME Insoluble Marker Method (MJ/kg)</th>
<th>AMEn Total Excreta Method (MJ/kg)</th>
<th>AMEn Insoluble Marker Method (MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>14.36 ± 0.05</td>
<td>14.38 ± 0.06</td>
<td>12.77 ± 0.07</td>
<td>12.96 ± 0.03</td>
</tr>
<tr>
<td>Low protein</td>
<td>14.26 ± 0.06</td>
<td>14.60 ± 0.12</td>
<td>12.71 ± 0.06</td>
<td>13.17 ± 0.09</td>
</tr>
<tr>
<td>Sorghum</td>
<td>14.37 ± 0.08</td>
<td>14.48 ± 0.08</td>
<td>12.73 ± 0.07</td>
<td>13.00 ± 0.07</td>
</tr>
<tr>
<td>Strain A</td>
<td>14.31 ± 0.06</td>
<td>14.27 ± 0.07</td>
<td>12.77 ± 0.06</td>
<td>12.94 ± 0.06&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>Strain A X B</td>
<td>14.33 ± 0.08</td>
<td>14.46 ± 0.11&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>12.64 ± 0.09</td>
<td>12.92 ± 0.08&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Strain B</td>
<td>14.37 ± 0.08</td>
<td>14.52 ± 0.07&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>12.86 ± 0.07</td>
<td>13.16 ± 0.06&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Strain B X A</td>
<td>14.32 ± 0.09</td>
<td>14.71 ± 0.12&lt;sup&gt;c&lt;/sup&gt;</td>
<td>12.66 ± 0.09</td>
<td>13.14 ± 0.10&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

| Probability   | 0.50                             | 0.15                               | 0.85                             | 0.06                                |
| Probability   | 0.95                             | 0.01                               | 0.23                             | 0.04                                |
| Probability   | 0.90                             | 0.13                               | 0.75                             | 0.43                                |

Table 6.10. The mean (± SEM) apparent metabolisable energy (AME) and nitrogen corrected apparent metabolisable energy (AMEn) for four strains of ducks fed three different grower diets using the total excreta collection and insoluble marker methods.

For strain, within columns, the values with different superscripts are significantly different (P<0.05).
The total nitrogen retention calculated using the two methods are shown in table 6.11. When using the insoluble marker method, strain (P = 0.002) was found to have a significant effect on the total nitrogen retention. Birds of strain A retained less nitrogen than the other strains (P < 0.05). This was not evident using the total excreta method (P = 0.64).

Diet had a significant effect on the ileal nitrogen digestibility (P = 0.04). Ducks on the sorghum diet had a lower (P < 0.050) ileal nitrogen digestibility than ducks on the control diet. Strain (P = 0.53) had no effect on ileal nitrogen digestibility.

<table>
<thead>
<tr>
<th></th>
<th>Nitrogen retention (%)</th>
<th>Nitrogen Retention Marker Method (%)</th>
<th>Ileal nitrogen digestibility Marker Method (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control</strong></td>
<td>82.9 ± 0.6</td>
<td>73.9 ± 1.0</td>
<td>84.1 ± 0.9ª</td>
</tr>
<tr>
<td><strong>Low protein</strong></td>
<td>81.5 ± 0.6</td>
<td>75.3 ± 1.5</td>
<td>83.1 ± 0.7ªab</td>
</tr>
<tr>
<td><strong>Sorghum</strong></td>
<td>80.8 ± 1.0</td>
<td>72.6 ± 1.3</td>
<td>80.7 ± 1.0ªb</td>
</tr>
<tr>
<td><strong>Strain A</strong></td>
<td>81.1 ± 1.1</td>
<td>69.7 ± 1.1ªb</td>
<td>83.9 ± 1.1</td>
</tr>
<tr>
<td><strong>Strain A X B</strong></td>
<td>81.2 ± 1.1</td>
<td>74.1 ± 1.7ªa</td>
<td>81.8 ± 1.2</td>
</tr>
<tr>
<td><strong>Strain B</strong></td>
<td>82.6 ± 0.8</td>
<td>74.1 ± 0.9ªa</td>
<td>82.2 ± 1.0</td>
</tr>
<tr>
<td><strong>Strain B X A</strong></td>
<td>82.0 ± 0.8</td>
<td>77.8 ± 1.4ªa</td>
<td>82.6 ± 1.0</td>
</tr>
<tr>
<td><strong>Probability</strong></td>
<td></td>
<td></td>
<td>0.04</td>
</tr>
<tr>
<td><strong>Diet</strong></td>
<td>0.19</td>
<td>0.29</td>
<td></td>
</tr>
<tr>
<td><strong>Strain</strong></td>
<td>0.64</td>
<td>0.002</td>
<td>0.53</td>
</tr>
<tr>
<td><strong>Diet X Strain</strong></td>
<td>0.79</td>
<td>0.93</td>
<td>0.72</td>
</tr>
</tbody>
</table>

Table 6.11. The mean (± SEM) nitrogen retention (%) for four strains of ducks fed three different grower diets using the total excreta collection and insoluble marker methods and the ileal nitrogen digestibility (%) using the insoluble marker method.

6.5. Discussion

Strain A and B are the parent strains presently being used in commercial practice. Strain B was consistently heavier throughout the production period. The crosses were intermediate in terms of the growth rate seen in the parent lines with strain A X B being superior to B X A. These observations are in line with the results reported in chapters four and five. The differences in liveweight during production were also seen in weekly gain with the heavier strains having the greatest weekly liveweight gain throughout the study. The differences in liveweight were also mirrored by the feed intake, with the heavier strains having the highest consumption. The pattern of differences in liveweight gain and feed intake resulted in the composite FCR for the production period being similar for all strains (2.10 to 2.16). The differences in the pattern of water intake were similar to the feed
intake with it being higher for strains B and A X B than for strains A and B X A. The differences in feed and water intake resulted in there being no difference in the water to feed ratio (2.8-2.9) when the strains are compared.

Right from week one of the study, ducks on the low protein diet were lighter and at the end of the production period the difference amounted to around 70-80 g when compared to birds fed the control and high sorghum diets. This was approximately, a 2.5% reduction in final liveweight. The difference was much greater in week two (approximately 6%) and week four (approximately 5%). This suggests that there was some degree of compensatory growth with the effect of the low dietary protein being most detrimental during the earlier stages of the production period. This is supported by the pattern of weekly liveweight gain. At weeks one to four, ducks on the low protein diet had significantly lower weekly liveweight gain. However, in week five there were no differences in gain and then in week six, the gain for ducks on the low protein diet was significantly greater than for ducks on the control or high sorghum diets. The larger difference in liveweight during the earlier part of the production period (weeks one to three) for ducks on the low protein diet was associated with lower feed intake. After week three the feed intakes were similar for all diets. For the entire production period the total feed consumption of ducks was similar for all diets. The poorer growth earlier and similar total feed intakes resulted in a significantly higher FCR for ducks fed the low protein diet. The differences in feed and water intakes resulted in the water to fee ratio being less when ducks were fed the low protein diet (2.65 Vs 2.9).

Males were persistently heavier than females for all strains and when fed the different diets. At the end of the production period the average difference between the sexes was 214 g. This difference was similar to the noted in chapters four and five.

The breast weight as % of LW ranged from 8.24% for strain A to 8.97 % for strain B x A. As a general observation, the male line seemed to have an influence on the breast % because it was similar between strains A and A x B and between strains B and B x A. Using the breast % and final LW weight, the yield of breast weight for A was 230g and B was 286 g for the crosses A X B was 251 g and B X A was 258 g. The low protein diet resulted in a lower breast to LW %. When the differences in final liveweight are taken in to account, the average breast weight yield for the low protein diet was 232 g compared to 274 g for the control diet and 265 g for the high sorghum diet. While the females had a higher breast weight to LW % than the males, when the differences in final liveweight are taken into account, the average breast weight was similar for females (257 g) and males (254 g). Strain, sex and diet had no effect on the leg weight to liveweight %. Only diet had any effect on the thigh weight to liveweight %. It was lower for the ducks on the low protein diet.

In the final week of the production period, females had a higher abdominal fat % than males. Females mature earlier than males and this probably accounts for the increased rate of fat deposition in week six.

There were some differences in the ratio of organ weights and GIT lengths to liveweight. The most frequent differences related to diet, with the low protein diet being different to the other diets. The relevance of these differences is difficult to interpret. If they influence performance then it would be expected that the relative % would be smaller for ducks fed the low protein diet. However in most cases the differences seen were higher for the ducks on the low protein diet and this could simply be due to the differences in liveweight.

Carcass water content was higher in week three than in week five while fat content was higher in week five. There was no difference in carcass protein or ash content between weeks three and five. The low protein diet resulted in lower carcass water content and this was associated with a tendency for higher fat content compared to the control diet. No other effects of diet were noted. The strain effects on carcass composition were minimal. Strain A x B had a lower protein content compared to strains A and B X A.
Following the low nitrogen retention rates reported in chapter four and five using the AIA procedure it was considered relevant to evaluate both the AIA and total collection procedures for determining AME and nitrogen retention in the current study. There were some differences in the AME and AMEn values determined using the two procedures. The AME and AMEn were in general, higher using the AIA procedure. For AME, the difference ranged from 0.02 to 0.34 MJ/kg for diet and -0.03 to 0.39 MJ/kg for strain. For AMEn, the difference ranged from 0.19 to 0.48 MJ/kg for the different diets and 0.17 to 0.48 MJ/kg for the different strains. The determined values were higher than the formulated values. There were no effects of diet or strain on AME calculated using the total collection method. When the AIA procedure was used to calculate AME, strain was found to have an effect but not diet. Strain A had a lower AME than did the other strains. When the total collection procedure was used to determine AMEn there was no strain or diet effects. As for AME when the AIA procedure was used to determine AMEn, strain was found to have an effect. Strain A X B had a lower AMEn than did strains B and B X A while strain A had lower value than strain B.

Ileal nitrogen retention for strain effects ranged from 81.8 to 83.9% and for diet ranged from 80.7 to 84.1%. The diet effect was significant with the ileal nitrogen digestibility being lower for the sorghum diet compared to the control diet with low protein diet being intermediate. Using the AIA procedure the nitrogen retention rate ranged from 72.6 to 75.3% for the different diets and 69.1 to 77.8% for the different strains. Strain A had a lower retention rate compared to the other strains. Using the total collection procedure the nitrogen retention rate ranged from 80.8 to 82.9% for the different diets and 81.8 to 82.6% for the different strains. Neither diet nor strain had a significant effect. The nitrogen retention rate using the total collection procedure is high being similar to values determined for ileal nitrogen digestibility. This is not feasible and suggests that there is a problem with the total collection method for determining nitrogen retention. In the total collection method, the faeces are dried in an oven. The faeces contain a combination of protein and non-protein nitrogen. Much of the non-protein nitrogen would be in the form of uric acid and volatile ammonia. Heating of the faeces would release the volatile nitrogen components. With ducks the volatile nitrogen components could be considerable. With the AIA procedure the faeces sample taken is freeze dried and so there is much less opportunity for the loss of the volatile nitrogen from the sample. The average faecal nitrogen content of the freeze dried samples was 4.62 ± 0.09% compared to 3.26 ± 0.07% for the bulk faecal samples oven dried. If the freeze dried faecal nitrogen values for individual pens are used in the calculation of nitrogen retention using the total faecal dry matter as determined by the oven drying method, the average nitrogen retention is close to 72% and this in the range of values calculated using the AIA method. There is a problem with the total collection method when the faeces are oven dried.

Published data have identified the protein requirements for ducks under different environmental conditions (Leclercq & Carville, 1976; Oluyemi & Fetuga, 1978; Yunyan, et al., 1989; Mazanowski, et al., 1991; He, et al., 1994; Chen et al., 2000; Zhou, et al., 2001; Xu, et al., 2002). The protein content of duck diets have not been adequately investigated under Australian conditions. It is important to provide the correct amount of protein, as too little will limit muscle development, and too much will increased feed costs and the amount of nitrogen excreted as waste. In the present study, diets with approximately 3% less dietary protein in both the starter and grower diets to those found in the current commercial diets were fed to ducks. This reduction appears to be excessive considering that the ducks on the reduced protein diet had poor growth performance compared to ducks on the current commercial diet. Lower feed and water consumption, weight gain, breast and thigh muscle weights and the higher FCR support this conclusion. It would appear that the major effects of the low protein diet occurred during the first four weeks but especially during the starter period. There appeared to be some compensatory growth in weeks five and six where the weekly liveweight gain was either similar or superior for the ducks fed the low protein diet. These observations suggest that the starter diet needs to contain 21-22% protein. However, the protein content of the grower diet could be lower or a three phase feeding program could be introduced where a finisher diet is fed in weeks five and six and that this diet could have lower protein content. Protein levels similar to those of the low protein diets were fed by Siregar et al. (1982a) who found that dietary protein levels of 19% in the starter and 16% in the grower; maintained proper growth in ducks. The differences in the results
could be related to differences in the genetic strains used in the two studies, whereby the modern duck strains may have a higher protein requirement especially in the starter period.

Wheat and sorghum are the most common grains used by the Australian poultry industry (Black et al., 2005), with wheat making up 50% of the raw materials of commercial meat-duck diets and with sorghum accounting for the rest of the grain component. At the time of the present study, wheat price was excessively high and this had generated increased interest in replacing wheat with sorghum in duck diets. There is strong speculation that the demand on wheat for human use will increase and that the poultry industry will need to decrease its reliance on wheat as a feed grain. While sorghum is a good source of CP, the protein may not be completely available to the animal (Okoh et al., 1989, Selle et al., 2010)). The lower digestibility of sorghum protein is believed to be due to anti-nutritional factors which limits its potential as a feed ingredient for poultry (Jacob et al., 1997; Selle et al., 2010). There does not appear to be any studies comparing Australian grown sorghum to Australian grown wheat as a grain source in duck diets. Alternatively, literature exploring the use of sorghum within broiler diets is readily available (Okoh et al., 1989; Kumar, 1996; Jacob et al., 1997; Black et al., 2005; Ebadi et al., 2005; Reddy et al., 2005). A study by Black et al. (2005) offered broilers both a sorghum based diet and a wheat based diet. Despite a similar daily intake of dietary AME, broilers offered wheat based diets grew 20% faster and used 17% less feed than those offered sorghum based diets. A study by Elkin and Rogler (1991) assessed the differential response of ducks and chicks to dietary sorghum tannins. The study observed depressed growth rates and feed efficiency following the feeding of ducklings a high tannin sorghum diet compared to a low tannin sorghum diet, this was similar in broilers. However, the negative effects of dietary sorghum tannins on weight gain and FCR are less severe in ducks than in chicks (Elkin & Rogler, 1991). In the present study, part of the wheat component of the diet was replaced with sorghum. This alteration in the grain component did not affect performance, as ducks on the higher sorghum diet performed just as well as those fed the commercial control diet. The calculated AME and AMEn values were similar for all diets. Replacing wheat with sorghum had no effect on energy metabolism. There was a decrease in ileal nitrogen digestion when the sorghum content was increased and a tendency for the nitrogen retention to be slightly lower but these differences had no effect on performance. From these results, it appears that ducklings can cope with increased sorghum grain in the diet, and still perform at a consistent level.

In consultation, with the industry partners it was decided that the cross A X B really had no potential in the commercial production. The growth rate was inferior to the strain B and the yield of breast was poorer than the parent strains. Stain B x A had better performance than strain A, with higher growth rate, better breast yield and better FCR. It was decided that it deserved further evaluation at this stage.
7. The effect of feeding diets with differing protein, energy and whole wheat content on the performance of commercial duck strains under winter conditions

7.1. Introduction

In study three (chapter 6) ducks fed the low protein diets were seen to have lower growth rates in the first four weeks but similar or better growth rates in weeks five and six of production compared to ducks fed the standard commercial diets. This suggested that the protein content of the diet fed in weeks five and six could be reduced and warranted the introduction of finisher diet to the feeding program of commercial ducks. It is now common practice to replace some of the ground wheat in broiler diets with whole wheat. This is a practice which could be employed in the preparation of duck diets and so reduce milling costs and potentially improving gut function and feed efficiency. The energy content of commercial ducks diets is set at around 12.3-12.5 MJ/kg ME. There is a need to evaluate whether a higher energy density might improve growth performance.

7.2. Objective

The objectives of the present study were to evaluate the performance of commercial Peking ducks strain fed diets differing in protein, energy and the form of the wheat fed. Pekin ducks were fed the standard starter and finisher diets and their performance compared to ducks fed a low protein diet during weeks five and six, a high energy diet fed in the starter and grower phases and a diet where part of the grain component of the diet was fed as whole wheat.

7.3. Methods

7.3.1. Duck growth trial

The study was conducted in winter (June and July).

7.3.1. 1. Experimental design

There were 48 pens allocated to the study. The experiment was conducted using a completely randomised design with blocking. Each treatment was randomly allocated a pen in each block of the shed. Initially 18 males and 18 females were placed in each pen, but this number was reduced over time as birds were removed for the metabolism study and tissue collections.

7.3.1.2. Treatments

There were 12 different treatments consisting of three strains and four diets. The strains used were Grimaud Freres and Cherry Valley and the cross between the Grimaud Feres (male) and Cherry Valley (female), all reared as mixed sexes.

The dietary formulations used were:

Control Diet: this was the commercial diet fed as a starter on days 1-14 (21.6% protein and 12.3 MJ/kg ME) and grower fed on days 15-41 (17.8% protein and 12.5 MJ/kg ME). For this treatment the
grain component of the starter was ground wheat 44% and sorghum 20% and grower diet was 43.5% ground wheat and 30% sorghum.

Low protein diet: was fed as starter on days 1-14 (21.6% protein and 12.3 MJ/kg DE) and grower diet fed on days 15-28 (17.8% protein and 12.5 MJ/kg DE) and a finisher diet fed from days 29-41 (17.0% protein and 12.8 MJ/kg DE). For this treatment the grain component of the starter was, ground wheat 50% and sorghum 20% and the grower diet it was 49.9% ground wheat and 27.5% sorghum and the finisher diet it was 48.5 % ground wheat and 30.0% sorghum.

High energy diet: fed as starter diet on days 1-14 (22.3% protein and 12.8 MJ/kg DE) and grower diet fed days 15-41 (18.6% protein and 13.0 MJ/kg DE). For this treatment the grain component of the starter was, ground wheat 49% and sorghum 20% and grower diet was 48% ground wheat and 30% sorghum.

Whole wheat diet: fed as starter on days 1-14 (21.6% protein and 12.3 MJ/kg DE) and grower fed on days 15-41 (17.8% protein and 12.6 MJ/kg DE). For this treatment the grain component of the starter was, ground wheat 29.0%, whole wheat 15% and sorghum 20.0% and the grower diet was 28.5% ground wheat, 15% whole wheat and 30% sorghum.

7.3.1.3. Husbandry

The husbandry procedures are as described in the sections 3.1.1 to 3.1.7.

7.3.1.4. Performance and carcass measurements

Briefly, on days seven (week one), 14 (week two), 21 (week three), 28 (week four), 35 (week five) and 41 (week six) all ducks were individually weighed. On days six, 13, 20, 27, 34 and 41 growth measurements were taken from an individual duck selected at random from each pen. Carcass and GIT measurements were made as described in section 3.1.9. At the end of the production period all remaining ducks were processed by PEPE’S Ducks Pty Ltd. On days 20 (week three) and 34 (week five) the carcasses and all body parts used for growth measurements were retained. The carcasses were autoclaved, homogenised and after freeze-drying the crude fat, protein and ash were determined as described in section 3.1.10.

7.3.2. Metabolism study

At day 14 (week two), four ducks were randomly selected and removed from each pen of the growth trial. Equal numbers of males and females were taken. The ducks were placed in 48 metabolism cages and fed ad libitum the same commercial grower diets supplied to the ducks in the growth trial, with the addition of an insoluble ash marker, Celite, at a concentration of 10 grams per kilogram of feed. Sampling was the same as described in section 3.2.

7.3.3. Statistical analysis

Data were analysed using the REML linear mixed model function of Genstat® 11th edition. Data was loge transformed where necessary. The fixed model included the effects of strain, diet, sex and week and all first level combinations, and the random model included the effects of block, pen and bird identification. Significance testing of fixed effects was conducted using Wald chi-square tests with a significance threshold of P < 0.05. Any non-significant interactions were removed from the model and for significant effects the least significant difference (LSD) procedure was used to make pair-wise comparisons of means.

For the proximate carcass analysis and the metabolism study differences between treatments were determined using ANOVA (SAS: Statview, version 5). When differences were significant individual comparisons were made using the least significant difference (LSD) procedure.
7.4. Result

For reasons of ‘commercial in confidence’ the parent strains and the cross between them have been designated as Strain A, Strain B, and C, with no particular order designated.

7.4.1. Liveweight

There were highly significant effects of strain (see Figure 7.1), sex (see Figure 7.2) and diet (see Figure 7.3) on liveweight but these effects changed over time, as indicated by the significant strain × week, sex × week, and diet × week interactions (all $P < 0.001$). There were no significant strain × diet ($P = 0.15$) and strain × sex ($P = 0.62$) interactions. The standard errors of means have not been included as they are too small to plot. The extremely large sample size results in these very small standard errors, hence fairly subtle biological effects are being detected as being statistically significant.

At every week, there were significant differences in mean strain liveweight, with strain B being heavier than the other strains ($P < 0.05$). In all weeks, strain C was heavier than strain A ($P < 0.05$). At six weeks, the final mean (± SEM) liveweights were 2887 ± 14 g, 3328 ± 17 g and 3081 ± 15 g for strains A, B and C, respectively.

Male ducks were significantly heavier ($P < 0.05$) than female ducks at all times except week one, and the differential increased as the birds aged. There was also a significant sex × diet interaction ($P = 0.013$) (see Figure 7.4). No obvious pattern was evident, but the significant pairwise comparisons for females was for those fed the high energy diet to be significantly heavier than those fed the low protein diet ($P < 0.05$), and for males those fed the control diet to be significantly heavier than those fed the whole wheat diet ($P < 0.05$).

Although the diet × week interaction was significant ($P < 0.001$), no particular pattern was evident as the diets that resulted in significantly higher or lower liveweight varied considerably from week to week. However, there was never any significant difference between the control and the high energy diets. An important observation was that at the end of the production period (week six) there were no significant differences in the liveweight between the different dietary treatments. At six weeks, the final mean (± SEM) liveweights were 3100 ± 15 g, 3072 ± 15 g, 3112 ± 16 g and 3091 ± 16 g for the control, low protein, high energy and whole wheat diets, respectively.

![Figure 7.1. The mean liveweight for the effect of strain over the six week production period.](image)

There was a significant strain x week interaction ($P < 0.001$).
Figure 7.2. The mean liveweight for the effect of sex over the production period.
There was a significant sex x week ($P < 0.001$) interaction.

Figure 7.3. The mean liveweight (g) for the effect of diet over the production period.
The diet $\times$ week interaction was significant ($P < 0.001$).
Figure 7.4. The mean (± SEM) average liveweight for the separate sexes feed the treatment diets during the production period.

The sex × diet interaction was significant (P = 0.013).

7.4.2. Liveweight gain

There was a significant effect of strain which changed over the period of the study (see Figure 7.5) as indicated by the significant strain x week interaction (P < 0.001). The rate of weekly gain increased until week four and then declined in weeks five and six. The rate of gain for strain B was consistently higher than the other strains in all weeks except week six where it is similar to strain C. The rate of gain for strain A was significantly lower than the other strains except in week one where it is similar. There is a very rapid decline in weekly gain for strain B from week five to week six.

The effect of diet on the average weekly gain is shown in figure 7.6. There was a significant diet x week interaction (P < 0.001). The weekly gain in week five was significantly lower for the low protein diet compared to the control diet (P < 0.05) and in week six it was significantly higher (P < 0.05) than for the control and high energy diets. The only other significant difference was in week six where the weekly gain for the high energy diet was lower than for the control diet (P < 0.05). The combined gain in weeks five and six were similar for the treatments, being 1078 ± 8 g, 1060 ± 7 g, 1061 ± 7 g and 1063 ± 7 g for the control, low protein, high energy and whole wheat diets, respectively.
7.4.3. Feed Intake

The effect of strain on weekly feed intake is shown in figure 7.7. The strain effect changed over time as indicated by the significant strain x week interaction (P < 0.001). The feed intake for Strain B was significantly higher (P < 0.05) than for the other strains while the intake of strain C was significantly higher than that of strain A (P < 0.05). The largest difference between strains occurred in week five. While this pattern remained in week six the differences were not as great. There is the appearance that feed intake decreased in week six but it needs to be remembered that the intake in week six is for six
days and not seven day as the final measurements are made on day 41 of the study. The strain x diet interaction was not significant (P = 0.07).

The effect of diet on weekly feed intake is shown in figure 7.8. There was no significant effects due to diet (P = 0.07). There may be some effect with the high energy diet having lower feed intake in week six but this was not proven in the analysis.

Diet had no significant effect (P = 0.22) on total composite feed intake. The effect of strain was highly significant (P < 0.001) with strain B having a higher total intake than the other strains (P < 0.05) and strain C having a higher intake than strain A (P < 0.05). The composite feed intake for the entire production period for strains A, B and C were 5.97 ± 0.03 kg, 6.85 ± 0.04 kg and 6.23 ± 0.03 kg, respectively. The composite feed intake for the entire production period for the control, low protein, high energy and whole wheat diets were 6.36 ± 0.11 kg, 6.34 ± 0.10 kg, 6.31 ± 0.11 kg and 6.40 ± 0.13 kg, respectively.

![Figure 7.7. The mean weekly feed intakes (g) for the effect of strain over the production period.](image)

There was significant strain x week interaction (P < 0.001).

![Figure 7.8. The mean weekly feed intakes (g) for the effect of diet over the production period.](image)

Diet had no significant effect on mean feed intake (P = 0.073).
7.4.4. Food Conversion Ratio (FCR)

The dietary effects on weekly FCR are given in figure 7.9 and those of strain are shown in figure 7.10. There was a significant diet x week interaction (P < 0.001). The FCR increased steadily during the production period. The main dietary effects were seen in weeks five and six. In week five, the FCR for the low protein diet was higher, and in week six, lower than the other diets (P < 0.05). In week six, the FCR for the high energy diet was higher than for the control diet (P < 0.05).

There was significant strain x week interaction (P = 0.002) but no strain x diet interaction (P = 0.55). The main strain effects are seen in week six where strain B had a higher FCR than the other two strains (P < 0.05).

There was significant strain effect (P = 0.005) but no dietary effect (P = 0.36) or strain x diet interaction (P = 0.45) on the composite FCR. Strain C had a significantly (P < 0.05) lower FCR (2.03 ± 0.01) than did either strain A (2.08 ± 0.01) or strain B (2.08 ± 0.01). The composite FCR for the control, low protein, high energy and whole wheat diets were 2.07 ± 0.01, 2.06 ± 0.01, 2.05 ± 0.01 and 2.07 ± 0.01, respectively.

Figure 7.9. The mean weekly feed conversion ratio (FCR) for the effect of diet over the production period.

There was a significant interaction between diet x week (P < 0.001).
There was a significant interaction between strain and week (P=0.002).

7.4.5. Water Intake

The effect of diet on mean weekly water intake is shown in figure 7.11. The effect of diet changed over time as indicated by the significant diet x week interaction (P < 0.001). There were no significant differences among diets except at weeks five and six where birds on the low protein diet had a lower water intake than those on the control and high energy diets (P < 0.05). In week six, birds on the whole wheat diet consumed significantly less water than the control birds (P<0.05) but not to the same extent, as birds on the low protein diet.

The effect of strain on mean weekly water intake is seen in figure 7.12. The significant interaction strain x week (P < 0.001) identifies that the strain differences changed over time. Strain B consumed more water than strain A in all weeks (P < 0.05) and more than strain C in all weeks except week one (P < 0.05). Strain C consumed more water than strain A in all weeks (P < 0.05) except week three. There was no significant strain x diet interaction (P = 0.39).

Strain had a significant effect (P < 0.001) on composite water intake but there was no significant dietary effect (P = 0.21) or strain x diet interaction (P = 0.54). Strain B (17.43 ± .015 L) consumed more water than both strain A (14.86 ± .016 L) and strain C (15.81 ± 0.16 L) (P < 0.05). The differences between strains A and C were also significant (P < 0.05). The total water consumption for the control, low protein, high energy and whole wheat diets were 6.16 ± 0.40 L, 15.69 ± 0.28 L, 16.14 ± 0.33 L, 16.10 ± 0.41 L, respectively.
Figure 7.11. The mean weekly water intake (mL) for the effect of diet over the production period.

There was a significant interaction between diet and week (P < 0.001).

Figure 7.12. The mean weekly water intake for the effect of strain over the production period.

The interaction of strain x week was significant (P<0.001).

7.4.6. Water to feed ratio

The water to feed ratio is calculated as the volume of water in mL consumed for each gram of feed consumed. The effect of strain changed with time (see Figure 7.13) as indicated by the significant strain x week interaction (P < 0.001). There were minimal differences between strains except in week one where strain C had a water to feed ratio higher than other strains (P < 0.05) and in week six where the ratio was lower for strain A than the other strains (P < 0.05). The effect of diet on the water to feed ratio is provided in figure 3.14. There was a significant diet x week interaction (P = 0.002). Again there were minimal differences. In week six, birds on the low protein diet had a lower ratio than
birds on the control and high energy diets (P < 0.05). Also in week five, the ratio for the low protein diet was lower than for the high energy diet (P < 0.05).

Neither strain (P = 0.19) or diet (P = 0.10) had significant effects on the composite water to feed. The composite water to feed ratios were 2.49 ± 0.02, 2.54 ± 0.02 and 2.53 ± 0.02 for strains A, B and C, respectively. For the control, low protein, high energy and whole wheat diets the values were 2.54 ± 0.03, 2.47 ± 0.02, 2.56 ± 0.03 and 2.51 ± 0.02, respectively.

**Figure 7.13.** The mean weekly water to feed ratio for the effect of strain over the production period.

The effect of strain changed with time as indicated by the significant strain x week interaction (P < 0.001).

**Figure 7.14.** The mean weekly water to feed intake ratio for the effect of diet over the production period.

There was a significant diet x week interaction (P = 0.002).
7.4.7. Muscle development and yield

Values for breast, thigh and leg (drumstick) muscle yield are expressed as percentage of the liveweight at the time of sampling. There was a significant effect of week (P < 0.001) with the percentage of breast muscle increasing throughout the production period. The increase was more rapid after week four with the percentage more than doubling in the next two weeks. The effect of diet on percentage of breast muscle weight to bodyweight is given in figure 7.15, the dietary effects were not significant (P = 0.83). At the last sampling day (day 41) the mean (± SEM) breast percentages were 9.52 ± 0.28, 9.40 ± 0.28, 9.52 ± 0.28 and 9.81 ± 0.28 for the control, low protein, high energy and whole wheat diets, respectively.

The effect of strain on the percentage of breast muscle is shown in figure 7.16. The effect of strain was significant (P < 0.001), but the interactions of strain with sex (P = 0.95) and week (P = 0.24) were not. Both strain B and strain C had higher breast percentages than did strain A (P < 0.05). At the last sampling day (day 41) the mean (± SEM) breast percentages were 8.85 ± 0.35, 10.02 ± 0.40 and 9.85 ± 0.39 for strains A, B and C.

There were significant effect of sex (P < 0.001), on the breast percentage with it being higher in the females than in the males (see Figure 7.17). This was consistent throughout the production period with there being no strain x week interaction (P = 0.96). On the final sampling day (day 41) the mean (± SEM) percentage was 9.92 ± 0.35 for females and 9.22 ± 0.27 for males. There was no sex x week interaction (P = 0.24).

![Figure 7.15. The mean weekly breast muscle weight to LW ratio expressed as a % for the effect of diet over the production period.](image)

The effect of diet was not significant (P = 0.83).
Figure 7.16. The mean weekly breast muscle weight to LW ratio expressed as a % for the effect of strain over the production period.

The effect of strain was significant (P < 0.001).

Figure 7.17. The mean weekly breast muscle weight to LW ratio expressed as a % for the effect of sex over the production period.

The effect of sex was significant (P < 0.001).

There was a significant effect of week (P < 0.001) on the mean (± SEM) % thigh muscle. The values being, week one, 4.70 ± 0.07%; week two, 5.06 ± 0.06%; week three, 5.11 ± 0.08%; week four, 4.59 ± 0.10; week five, 4.62 ± 0.05% and week six, 4.29 ± 0.05%. The effect of diet on thigh muscle % is given in figure 7.18. There were no significant differences due to diet (P = 0.31). The effect of strain was marginally not significant (P = 0.07) with the values given in figure 7.19. The effect of sex was marginally not significant (P = 0.09) and the weekly values are given in figure 7.20.
Figure 7.18. The mean weekly thigh muscle weight to LW ratio expressed as a % for the effect of diet over the production period.

The effect of diet was not significant (P = 0.07).

Figure 7.19. The mean weekly thigh muscle weight to LW ratio expressed as a % for the effect of strain over the production period.

The effect of strain was marginally not significant (P = 0.07).
Figure 7.20. The mean weekly thigh muscle weight to LW ratio expressed as a % for the effect of sex over the production period.

The effect of sex was not significant (P = 0.09).

The effects of diet, strain and sex on leg muscle (drumstick) weight as a percentage of LW are given in figure 7.21, 7.22 and 7.23, respectively. There was significant effect of week (P < 0.001) on the leg muscle % with the mean (± SEM) % for week one being 5.04 ± 0.06; week two, 5.78 ± 0.07; week three, 5.45 ± 0.06; week four, 5.06 ± 0.07; week five, 4.74 ± 0.06 and week six, 4.21 ± 0.05. Comparisons between all weeks were significant (P < 0.05), except for that between weeks one and four. There were no significant effects due to diet (P = 0.10) or strain (P = 0.69). There was a significant interaction between sex x week (P = 0.04). The only difference between males and females was in week one, where females had a higher leg muscle to LW percentage than males (P < 0.05).

Figure 7.21. The mean weekly leg (drumstick) muscle weight to LW ratio expressed as a % for the effect of diet over the production period.

The effect of diet was not significant (P = 0.10).
Figure 7.22. The mean weekly leg (drumstick) muscle weight to LW ratio expressed as a % for the effect of strain over the production period.

The effect of strain was not significant (P = 0.69).

Figure 7.23. The mean weekly leg (drumstick) muscle weight to LW ratio expressed as a % for the effect of sex over the production period.

There was a significant sex x week interaction (P = 0.004).

7.4.8. Abdominal fat yield

The effects of week, diet and sex on the ratio of abdominal fat weight to liveweight expressed as a percentage are given in table 7.1. The amount of abdominal fat is minimal in ducks before seven days of age and so no values are available for week one. Week had significant effect (P < 0.001), on the fat percentage. There was a progressive increase in the percentage through the course of the study with differences between all weeks, except weeks four and five, being significant (P < 0.05). The effects of diet (P = 0.57) and sex (P = 0.13) were not significant. The effect of strain is shown in figure 7.24. The
effect of strain was significant ($P = 0.006$) but the strain x week interaction was not ($P = 0.41$). Strain A ($0.77 \pm 0.03$) had lower fat % ($P < 0.05$), than did Strain B ($0.89 \pm 0.03$) but not strain C ($0.84 \pm 0.03$).

### Table 7.1. The mean (± SEM) ratio of abdominal fat weight to liveweight expressed as percentage for the effects of week, diet and sex.

<table>
<thead>
<tr>
<th></th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week</td>
<td>$0.43 \pm 0.04^a$</td>
<td>$0.77 \pm 0.03^b$</td>
<td>$0.96 \pm 0.05^c$</td>
<td>$0.98 \pm 0.06^d$</td>
<td>$1.23 \pm 0.09^d$</td>
</tr>
<tr>
<td>Control</td>
<td>$0.43 \pm 0.04$</td>
<td>$0.77 \pm 0.03$</td>
<td>$0.96 \pm 0.05$</td>
<td>$0.98 \pm 0.06$</td>
<td>$1.23 \pm 0.09$</td>
</tr>
<tr>
<td>Low Protein</td>
<td>$0.50 \pm 0.07$</td>
<td>$0.85 \pm 0.06$</td>
<td>$1.09 \pm 0.05$</td>
<td>$1.18 \pm 0.08$</td>
<td>$1.31 \pm 0.07$</td>
</tr>
<tr>
<td>High Energy</td>
<td>$0.46 \pm 0.04$</td>
<td>$0.75 \pm 0.05$</td>
<td>$0.96 \pm 0.06$</td>
<td>$1.04 \pm 0.03$</td>
<td>$1.34 \pm 0.10$</td>
</tr>
<tr>
<td>Whole Wheat</td>
<td>$0.41 \pm 0.05$</td>
<td>$0.77 \pm 0.06$</td>
<td>$0.98 \pm 0.06$</td>
<td>$1.05 \pm 0.05$</td>
<td>$1.25 \pm 0.10$</td>
</tr>
<tr>
<td>Female</td>
<td>$0.46 \pm 0.04$</td>
<td>$0.78 \pm 0.03$</td>
<td>$1.06 \pm 0.03$</td>
<td>$1.05 \pm 0.04$</td>
<td>$1.37 \pm 0.07$</td>
</tr>
<tr>
<td>Male</td>
<td>$0.43 \pm 0.03$</td>
<td>$0.78 \pm 0.03$</td>
<td>$0.94 \pm 0.04$</td>
<td>$1.07 \pm 0.04$</td>
<td>$1.20 \pm 0.05$</td>
</tr>
</tbody>
</table>

Week had significant ($P < 0.001$) effect on the fat % but there were no diet ($P = 0.57$) and sex ($P = 0.13$) differences. For week, values within the row with different superscripts are significantly different ($p < 0.001$).

**Figure 7.24.** The effect of strain on the mean weekly abdominal fat weight to liveweight ratio expressed as percentage over the production period.

The effect of strain ($P = 0.006$) was significant.
7.4.9. Digestive organ weights and gastrointestinal tract measurements

Measurements are given as the ratio of organ weight to liveweight expressed as a percentage (%).

7.4.9.1. Liver

Diet ($P = 0.14$) and sex ($P = 0.16$) had no effects on the liver weight to liveweight ratio expressed as a percentage (see Table 7.2). There was a significant strain x week interaction ($P = 0.05$). However, the differences were limited to week three where the percentage was higher for strain B than strain C ($P < 0.05$), and in week six where the % for strain C was higher than strain A and B ($P < 0.05$).

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>5.95 ± 0.20</td>
<td>5.37 ± 0.10</td>
<td>5.03 ± 0.13</td>
<td>4.21 ± 0.16</td>
<td>3.47 ± 0.09</td>
<td>3.39 ± 0.09</td>
</tr>
<tr>
<td>Low Protein</td>
<td>6.02 ± 0.18</td>
<td>5.79 ± 0.17</td>
<td>4.68 ± 0.11</td>
<td>4.18 ± 0.08</td>
<td>3.56 ± 0.15</td>
<td>3.48 ± 0.20</td>
</tr>
<tr>
<td>High Energy</td>
<td>5.88 ± 0.15</td>
<td>5.45 ± 0.09</td>
<td>5.09 ± 0.26</td>
<td>4.01 ± 0.14</td>
<td>3.39 ± 0.10</td>
<td>3.21 ± 0.08</td>
</tr>
<tr>
<td>Whole Wheat</td>
<td>5.99 ± 0.23</td>
<td>5.86 ± 0.17</td>
<td>4.93 ± 0.10</td>
<td>4.17 ± 0.10</td>
<td>3.75 ± 0.11</td>
<td>3.38 ± 0.10</td>
</tr>
<tr>
<td>Strain A</td>
<td>6.13 ± 0.14</td>
<td>5.60 ± 0.07</td>
<td>4.99 ± 0.14&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.17 ± 0.13</td>
<td>3.61 ± 0.12</td>
<td>3.30 ± 0.08&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Strain B</td>
<td>5.95 ± 0.19</td>
<td>5.65 ± 0.12</td>
<td>5.16 ± 0.19&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.09 ± 0.11</td>
<td>3.57 ± 0.06</td>
<td>3.20 ± 0.07&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Strain C</td>
<td>5.80 ± 0.16</td>
<td>5.57 ± 0.17</td>
<td>4.69 ± 0.09&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.18 ± 0.08</td>
<td>3.46 ± 0.11</td>
<td>3.59 ± 0.13&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Female</td>
<td>6.07 ± 0.13</td>
<td>5.52 ± 0.09</td>
<td>4.92 ± 0.14</td>
<td>4.20 ± 0.09</td>
<td>3.61 ± 0.09</td>
<td>3.46 ± 0.11</td>
</tr>
<tr>
<td>Male</td>
<td>5.85 ± 0.14</td>
<td>5.69 ± 0.11</td>
<td>4.96 ± 0.11</td>
<td>4.10 ± 0.08</td>
<td>3.47 ± 0.07</td>
<td>3.28 ± 0.07</td>
</tr>
</tbody>
</table>

Table 7.2. The effect of diet, strain and sex on the mean (± SEM) ratio of liver weight to liveweight expressed as percentage.

The effect of diet ($P = 0.14$) and sex ($P = 0.16$) were not significant but there was significant strain x week interaction ($P = 0.006$). For strain, values within columns with different superscripts are significantly different ($p < 0.001$).

7.4.9.2. Proventriculus

The effects of week, strain, diet and sex on the ratio of proventriculus weight to liveweight expressed as percentage is given in table 7.3. Week had significant effect ($P < 0.001$) with a progressive decrease in the percentage through the course of the study with differences between all weeks except weeks five and six being significant ($P < 0.05$). The effects of diet ($P = 0.86$), strain ($P = 0.96$) and sex ($P = 0.08$) were not significant.
<table>
<thead>
<tr>
<th>Week</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
</table>
| Week | 0.82 ±  
0.01<sup>a</sup> | 0.57 ±  
0.01<sup>b</sup> | 0.48 ±  
0.01<sup>c</sup> | 0.39 ±  
0.01<sup>d</sup> | 0.33 ±  
0.01<sup>e</sup> | 0.33 ±  
0.01<sup>e</sup> |
| Control | 0.84 ±  
0.02 | 0.53 ±  
0.02 | 0.48 ±  
0.01 | 0.38 ±  
0.01 | 0.33 ±  
0.01 | 0.33 ±  
0.01 |
| Low Protein | 0.79 ±  
0.04 | 0.59 ±  
0.01 | 0.47 ±  
0.02 | 0.39 ±  
0.01 | 0.33 ±  
0.01 | 0.32 ±  
0.01 |
| High Energy | 0.81 ±  
0.02 | 0.58 ±  
0.02 | 0.47 ±  
0.01 | 0.39 ±  
0.01 | 0.33 ±  
0.01 | 0.34 ±  
0.01 |
| Whole Wheat | 0.82 ±  
0.02 | 0.60 ±  
0.02 | 0.49 ±  
0.01 | 0.39 ±  
0.01 | 0.32 ±  
0.01 | 0.32 ±  
0.01 |
| Strain A | 0.83 ±  
0.02 | 0.58 ±  
0.02 | 0.48 ±  
0.01 | 0.38 ±  
0.08 | 0.32 ±  
0.01 | 0.33 ±  
0.01 |
| Strain B | 0.80 ±  
0.03 | 0.58 ±  
0.01 | 0.48 ±  
0.01 | 0.40 ±  
0.01 | 0.34 ±  
0.01 | 0.32 ±  
0.06 |
| Strain C | 0.82 ±  
0.03 | 0.56 ±  
0.01 | 0.47 ±  
0.01 | 0.37 ±  
0.06 | 0.33 ±  
0.01 | 0.34 ±  
0.01 |
| Female | 0.82 ±  
0.01 | 0.57 ±  
0.02 | 0.49 ±  
0.01 | 0.39 ±  
0.01 | 0.33 ±  
0.01 | 0.34 ±  
0.01 |
| Male | 0.81 ±  
0.02 | 0.57 ±  
0.01 | 0.47 ±  
0.01 | 0.38 ±  
0.01 | 0.33 ±  
0.01 | 0.33 ±  
0.01 |

Table 7.3. The mean (± SEM) ratio of proventriculus weight to liveweight expressed as percentage.

Week had significant effect (P < 0.001) while the effects of diet (P = 0.86), strain (P = 0.96) and sex (P = 0.08) were not significant. For week, values within the row with different superscripts are significantly different (P < 0.05).

### 7.4.9.3 Gizzard

The effects of week and diet on the ratio of gizzard weight to liveweight expressed as percentage is given in table 7.4. Week had significant effect (P < 0.001), on the percentage of gizzard weight to liveweight with a progressive decrease in the ratio through the course of the study with differences between all weeks except week four and five being significant (P < 0.05). The effect of diet was not significant (P = 0.79). The effect of strain (see Figure 7.25) was significant (P < 0.001), but there was no strain x week interaction (P = 0.14). The gizzard percentage for strain A (3.72 ± 0.06) was greater (P < 0.05) than that for strain B (3.53 ± 0.05) but not strain C (3.68 ± 0.06). Sex (see Figure 7.26) had a significant effect (P < 0.001), on gizzard % but there was no sex x week interaction (P = 0.54). The gizzard % was greater (P < 0.05) in males (3.80 ± 0.05) than females (3.49 ± 0.05).
Table 7.4: The mean (±SEM) ratio of gizzard weight to liveweight expressed as percentage.

Week and strain had significant effects (both P < 0.00) while the effect of diet was not significant (P = 0.79). For week, values within the row with different superscripts are significantly different (P < 0.05).

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week</td>
<td>5.16 ± 0.08&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.35 ± 0.07&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.57 ± 0.05&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.32 ± 0.06&lt;sup&gt;d&lt;/sup&gt;</td>
<td>3.15 ± 0.06&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.92 ± 0.05&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Control</td>
<td>5.10 ± 0.20</td>
<td>4.29 ± 0.12</td>
<td>3.53 ± 0.09</td>
<td>3.13 ± 0.11</td>
<td>3.28 ± 0.12</td>
<td>2.97 ± 0.07</td>
</tr>
<tr>
<td>Low Protein</td>
<td>5.18 ± 0.13</td>
<td>4.23 ± 0.11</td>
<td>3.36 ± 0.13</td>
<td>3.43 ± 0.11</td>
<td>3.19 ± 0.12</td>
<td>2.95 ± 0.12</td>
</tr>
<tr>
<td>High Energy</td>
<td>4.99 ± 0.13</td>
<td>4.41 ± 0.15</td>
<td>3.60 ± 0.11</td>
<td>3.39 ± 0.11</td>
<td>3.14 ± 0.11</td>
<td>2.92 ± 0.12</td>
</tr>
<tr>
<td>Whole Wheat</td>
<td>5.38 ± 0.18</td>
<td>4.47 ± 0.15</td>
<td>3.73 ± 0.06</td>
<td>3.36 ± 0.12</td>
<td>2.99 ± 0.08</td>
<td>2.83 ± 0.10</td>
</tr>
</tbody>
</table>

Figure 7.25: The effect of strain on the ratio of gizzard weight to liveweight expressed as a percentage during the production period.

The effect of strain was significant (P < 0.001).
7.4.10. Gastrointestinal tract measurements

Measurements of the GIT are expressed as cm per 100 g of liveweight.

7.4.10.1. Duodenum length (DL)

The effects of week, diet and sex on the length (cm) of the duodenum (DL) per 100g liveweight are given in table 7.5. Week had significant (P < 0.001) effect on the relative DL length. There was a progressive decrease in the relative length through the course of the study with differences between all weeks being significant (P < 0.05). There were no diet (P = 0.68) or sex (P = 0.64) effects. The effect of strain on DL length is shown in figure 7.27. The effect of strain was significant (P < 0.001) but there was no strain x week interaction (P = 0.82). Strain A (2.31 ± 0.03) had a greater DL length (P < 0.05) than strain B (2.05 ± 0.03) but not strain C (2.20 ± 0.03).
### Table 7.5: The mean (± SEM) length of the DL (cm) per 100g liveweight weight during the production period.

Week had a significant effect (P < 0.001), but diet (P = 0.68) and sex (P = 0.64) did not. For week, values within the row with different superscripts are significantly different (P < 0.05).

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Week</strong></td>
<td>8.27 ±</td>
<td>3.60 ±</td>
<td>1.99 ±</td>
<td>1.49 ±</td>
<td>1.21 ±</td>
<td>1.03 ±</td>
</tr>
<tr>
<td></td>
<td>0.12a</td>
<td>0.06b</td>
<td>0.04c</td>
<td>0.04d</td>
<td>0.02e</td>
<td>0.01f</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>8.20 ±</td>
<td>3.50 ±</td>
<td>2.01 ±</td>
<td>1.51 ±</td>
<td>1.29 ±</td>
<td>0.98 ±</td>
</tr>
<tr>
<td></td>
<td>0.26</td>
<td>0.06</td>
<td>0.08</td>
<td>0.05</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td><strong>Low Protein</strong></td>
<td>8.36 ±</td>
<td>3.54 ±</td>
<td>1.85 ±</td>
<td>1.40 ±</td>
<td>1.19 ±</td>
<td>1.07 ±</td>
</tr>
<tr>
<td></td>
<td>0.30</td>
<td>0.12</td>
<td>0.08</td>
<td>0.13</td>
<td>0.05</td>
<td>0.03</td>
</tr>
<tr>
<td><strong>High Energy</strong></td>
<td>8.29 ±</td>
<td>3.77 ±</td>
<td>2.01 ±</td>
<td>1.59 ±</td>
<td>1.19 ±</td>
<td>1.02 ±</td>
</tr>
<tr>
<td></td>
<td>0.27</td>
<td>0.12</td>
<td>0.07</td>
<td>0.05</td>
<td>0.06</td>
<td>0.02</td>
</tr>
<tr>
<td><strong>Whole Wheat</strong></td>
<td>8.24 ±</td>
<td>3.58 ±</td>
<td>2.08 ±</td>
<td>1.48 ±</td>
<td>1.18 ±</td>
<td>1.04 ±</td>
</tr>
<tr>
<td></td>
<td>0.15</td>
<td>0.15</td>
<td>0.12</td>
<td>0.06</td>
<td>0.05</td>
<td>0.02</td>
</tr>
<tr>
<td><strong>Female</strong></td>
<td>8.06 ±</td>
<td>3.62 ±</td>
<td>2.00 ±</td>
<td>1.45 ±</td>
<td>1.20 ±</td>
<td>1.04 ±</td>
</tr>
<tr>
<td></td>
<td>0.19</td>
<td>0.08</td>
<td>0.07</td>
<td>0.07</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td><strong>Male</strong></td>
<td>8.48 ±</td>
<td>3.57 ±</td>
<td>1.98 ±</td>
<td>1.53 ±</td>
<td>1.23 ±</td>
<td>1.02 ±</td>
</tr>
<tr>
<td></td>
<td>0.14</td>
<td>0.09</td>
<td>0.05</td>
<td>0.04</td>
<td>0.03</td>
<td>0.02</td>
</tr>
</tbody>
</table>

**Figure 7.27.** The effect of strain on the length of the DL (cm) per 100g liveweight during the production period.

The strain effect was significant (P < 0.001).
7.4.10.2. Length of the jejunum (Duodenum to Merkle’s Diverticulum: DL-MD)

Week had significant effect (P < 0.001) on the length (cm) of small intestine from the duodenal loop to Merkles Diverticulum (DL-MD) per 100g liveweight (see Table 7.6). There was a progressive decrease in the relative length throughout the course of the study with differences between all weeks being significant (P < 0.05). Diet had no effect on the DL-MD length (P = 0.88) and neither did sex (P = 0.09). Strain (see Figure 7.28) had an effect (P < 0.001), but there was no strain x week interaction (P = 0.81). Strain B (5.93 ± 0.06) had a significantly shorter (P < 0.05), relative length compared to strain A (6.28 ± 0.06) or strain C (6.22 ± 0.06).

![Figure 7.28](image)

Figure 7.28. The effect of strain on the length of the small intestine from the DL to MD (cm) per 100g liveweight during the production period.

The strain effect was significant (P < 0.001).

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>21.69 ± 0.37</td>
<td>10.12 ± 0.22</td>
<td>5.82 ± 0.12</td>
<td>4.22 ± 0.12</td>
<td>3.59 ± 0.07</td>
<td>2.93 ± 0.07</td>
</tr>
<tr>
<td>Low Protein</td>
<td>21.49 ± 0.76</td>
<td>9.97 ± 0.20</td>
<td>5.89 ± 0.19</td>
<td>3.96 ± 0.37</td>
<td>3.42 ± 0.08</td>
<td>2.91 ± 0.06</td>
</tr>
<tr>
<td>High Energy</td>
<td>21.28 ± 0.42</td>
<td>10.25 ± 0.21</td>
<td>6.09 ± 0.22</td>
<td>4.27 ± 0.10</td>
<td>3.42 ± 0.11</td>
<td>2.94 ± 0.06</td>
</tr>
<tr>
<td>Whole Wheat</td>
<td>21.98 ± 0.63</td>
<td>9.59 ± 0.48</td>
<td>6.14 ± 0.21</td>
<td>4.29 ± 0.11</td>
<td>3.30 ± 0.13</td>
<td>2.91 ± 0.08</td>
</tr>
<tr>
<td>Female</td>
<td>21.5 ± 0.4</td>
<td>10.18 ± 0.18</td>
<td>6.10 ± 0.14</td>
<td>4.16 ± 0.20</td>
<td>3.44 ± 0.07</td>
<td>2.97 ± 0.05</td>
</tr>
<tr>
<td>Male</td>
<td>21.7 ± 0.32</td>
<td>9.81 ± 0.24</td>
<td>5.88 ± 0.12</td>
<td>4.21 ± 0.07</td>
<td>3.43 ± 0.07</td>
<td>2.89 ± 0.04</td>
</tr>
</tbody>
</table>

Table 7.6: The mean (± SEM) length in cm of the small intestine, from the DL to MD per 100g liveweight during the production period.

Week had a significant (P < 0.001) effect while the diet (P = 0.88) and sex (P = 0.09) effects were not significant. For week, values within the row with different superscripts are significantly different (P < 0.05).
7.4.10.3. Length of the Ileum (Merkle’s Diverticulum to the ileo-caecal junction (MD-ICJ))

The effects of week, diet and sex on the length (cm) of the small intestine from the MD to CJ per 100g liveweight is given in table 7.7. The strain effects are shown in figure 7.29. The week effect was significant (P < 0.001) with a progressive decrease in the MD-CJ length through the course of the study with differences between all weeks being significant (P < 0.05). There were no diet (P = 0.96) or sex (P= 0.45) effects. Strain had a significant effect (P < 0.001) with strain B (5.74 ± 0.06) having a significantly shorter (P < 0.05), relative length than strain A (6.33± 0.07) or strain C (6.12 ± 0.07).

<table>
<thead>
<tr>
<th>Week</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week</td>
<td>21.73 ± 0.34&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.94 ± 0.11&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.73 ± 0.10&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.13 ± 0.10&lt;sup&gt;d&lt;/sup&gt;</td>
<td>3.37 ± 0.05&lt;sup&gt;e&lt;/sup&gt;</td>
<td>2.80 ± 0.03&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
<tr>
<td>Control</td>
<td>22.02 ± 0.67</td>
<td>9.99 ± 0.16</td>
<td>5.64 ± 0.13</td>
<td>4.17 ± 0.10</td>
<td>3.47 ± 0.08</td>
<td>2.81 ± 0.07</td>
</tr>
<tr>
<td>Low Protein</td>
<td>21.29 ± 0.22</td>
<td>9.76 ± 0.22</td>
<td>5.74 ± 0.22</td>
<td>3.87 ± 0.37</td>
<td>3.36 ± 0.11</td>
<td>2.83 ± 0.06</td>
</tr>
<tr>
<td>High Energy</td>
<td>21.18 ± 0.56</td>
<td>10.32 ± 0.24</td>
<td>5.73 ± 0.26</td>
<td>4.18 ± 0.12</td>
<td>3.30 ± 0.10</td>
<td>2.82 ± 0.05</td>
</tr>
<tr>
<td>Whole Wheat</td>
<td>22.30 ± 0.70</td>
<td>9.68 ± 0.28</td>
<td>5.82 ± 0.15</td>
<td>4.29 ± 0.09</td>
<td>3.33 ± 0.09</td>
<td>2.74 ± 0.04</td>
</tr>
<tr>
<td>Female</td>
<td>20.84 ± 0.44</td>
<td>9.98 ± 0.17</td>
<td>5.81 ± 0.13</td>
<td>4.05 ± 0.20</td>
<td>3.35 ± 0.06</td>
<td>2.81 ± 0.05</td>
</tr>
<tr>
<td>Male</td>
<td>22.62 ± 0.47</td>
<td>9.90 ± 0.15</td>
<td>5.66 ± 0.14</td>
<td>4.20 ± 0.07</td>
<td>3.38 ± 0.07</td>
<td>2.79 ± 0.03</td>
</tr>
</tbody>
</table>

Table 7.7: The mean (± SEM) length in cm of the small intestine from DL-CJ per 100g liveweight during the production period.

Week effects were significant (P < 0.001) while those of diet (P = 0.96) and sex (P = 0.45) were not. For week, values within the row with different superscripts are significantly different (P < 0.05).

Figure 7.29. The effect of strain on the length of the small intestine from MD to ICJ (cm) per 100g liveweight during the production period.

The strain effect was significant (P < 0.001).
7.4.10.4. Total Caecal length (CL)

The effects of week and diet on the combined length of CL (cm) per 100g liveweight are given in table 7.8. Week had a significant effect (P < 0.001) with a progressive decrease in the CL length through the course of the study with differences between all weeks being significant (P < 0.05). Diet had no effect (P = 0.40). The effect of strain on CL length is shown in figure 3.30. There was a significant strain x sex interaction (P = 0.03). For females, strain A (0.99 ± 0.02) had a greater length (P < 0.05), than did females of strains B (0.89 ± 0.02) and C (0.93 ± 0.02), while for males, strain B (0.92 ± 0.02) had a shorter length (P < 0.05), than strain C (0.97 ± 0.02) but not strain A (0.96 ± 0.02).

<table>
<thead>
<tr>
<th>Week</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7.81 ±</td>
<td>3.80 ±</td>
<td>2.44 ±</td>
<td>1.87 ±</td>
<td>1.61 ±</td>
<td>1.33 ±</td>
</tr>
<tr>
<td></td>
<td>0.11²</td>
<td>0.06²</td>
<td>0.04²</td>
<td>0.05²</td>
<td>0.03³</td>
<td>0.02³</td>
</tr>
<tr>
<td>Control</td>
<td>7.73 ±</td>
<td>4.00 ±</td>
<td>2.39 ±</td>
<td>1.90 ±</td>
<td>1.63 ±</td>
<td>1.33 ±</td>
</tr>
<tr>
<td></td>
<td>0.23</td>
<td>0.13</td>
<td>0.09</td>
<td>0.06</td>
<td>0.05</td>
<td>0.03</td>
</tr>
<tr>
<td>Low Protein</td>
<td>7.91 ±</td>
<td>3.66 ±</td>
<td>2.38 ±</td>
<td>1.77 ±</td>
<td>1.56 ±</td>
<td>1.35 ±</td>
</tr>
<tr>
<td></td>
<td>0.19</td>
<td>0.11</td>
<td>0.06</td>
<td>0.17</td>
<td>0.06</td>
<td>0.05</td>
</tr>
<tr>
<td>High Energy</td>
<td>7.92 ±</td>
<td>3.79 ±</td>
<td>2.60 ±</td>
<td>1.92 ±</td>
<td>1.64 ±</td>
<td>1.32 ±</td>
</tr>
<tr>
<td></td>
<td>0.21</td>
<td>0.09</td>
<td>0.07</td>
<td>0.05</td>
<td>0.06</td>
<td>0.04</td>
</tr>
<tr>
<td>Whole Wheat</td>
<td>7.71 ±</td>
<td>3.73 ±</td>
<td>2.35 ±</td>
<td>1.90 ±</td>
<td>1.60 ±</td>
<td>1.32 ±</td>
</tr>
<tr>
<td></td>
<td>0.27</td>
<td>0.11</td>
<td>0.06</td>
<td>0.05</td>
<td>0.05</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Table 7.8: The mean (± SEM) length (cm) of CL per 100g liveweight during the production period.

Week effects were significant (P < 0.001) while those of diet (P = 0.40) were not. For week, values within the row with different superscripts are significantly different (P < 0.05).
7.4.11. Proximate analysis of Carcass Composition

The carcass water, protein, fat and ash content are given in table 7.9 (week three) and 7.10 (week five). There were no significant effects of strain, diet or sex on the composition of the carcass at week three or week five.

<table>
<thead>
<tr>
<th>Week 3</th>
<th>Water %</th>
<th>Protein %</th>
<th>Fat %</th>
<th>Ash %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Diet</td>
<td>65.9 ± 0.6</td>
<td>17.9 ± 0.3</td>
<td>13.0 ± 0.5</td>
<td>3.3 ± 0.1</td>
</tr>
<tr>
<td>Low Protein Diet</td>
<td>64.6 ± 0.8</td>
<td>18.4 ± 0.6</td>
<td>13.2 ± 0.4</td>
<td>3.7 ± 0.3</td>
</tr>
<tr>
<td>High Energy</td>
<td>64.9 ± 0.6</td>
<td>18.7 ± 0.4</td>
<td>12.9 ± 0.3</td>
<td>3.4 ± 0.1</td>
</tr>
<tr>
<td>Whole Wheat</td>
<td>65.1 ± 1.2</td>
<td>18.4 ± 0.7</td>
<td>13.0 ± 0.5</td>
<td>3.5 ± 0.2</td>
</tr>
<tr>
<td>Strain A</td>
<td>64.6 ± 0.8</td>
<td>18.9 ± 0.6</td>
<td>12.9 ± 0.2</td>
<td>3.5 ± 0.1</td>
</tr>
<tr>
<td>Strain B</td>
<td>65.4 ± 0.6</td>
<td>18.0 ± 0.4</td>
<td>13.3 ± 0.4</td>
<td>3.3 ± 0.1</td>
</tr>
<tr>
<td>Strain C</td>
<td>65.3 ± 0.7</td>
<td>18.1 ± 0.3</td>
<td>12.9 ± 0.4</td>
<td>3.7 ± 0.2</td>
</tr>
<tr>
<td>Female</td>
<td>65.2 ± 0.6</td>
<td>18.4 ± 0.4</td>
<td>13.0 ± 0.2</td>
<td>3.5 ± 0.2</td>
</tr>
<tr>
<td>Male</td>
<td>65.1 ± 0.6</td>
<td>18.3 ± 0.4</td>
<td>13.1 ± 0.3</td>
<td>3.5 ± 0.1</td>
</tr>
</tbody>
</table>

Table 7.9: The effects of diet, strain and sex on the composition of the carcass for ducks at three weeks of age.

The carcass composition for weeks three and five are given in figure 7.31. The effect of week on carcass composition was significant (P < 0.001). The average water content was greater (P < 0.05) in week three (65.1 ± 0.4%) than in week five (63.7 ± 0.3%). In both weeks, the percentage protein and ash were similar but the fat percentage was higher (P < 0.05) in week five (14.6 ± 0.3%) than in week three (13.1 ± 0.2%).
<table>
<thead>
<tr>
<th>Week 5</th>
<th>Water %</th>
<th>Protein %</th>
<th>Fat %</th>
<th>Ash %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Diet</td>
<td>63.8 ± 0.4</td>
<td>18.9 ± 0.3</td>
<td>13.9 ± 0.4</td>
<td>3.5 ± 0.1</td>
</tr>
<tr>
<td>Low Protein Diet</td>
<td>63.4 ± 0.9</td>
<td>18.7 ± 0.4</td>
<td>14.5 ± 0.7</td>
<td>3.5 ± 0.1</td>
</tr>
<tr>
<td>High Energy</td>
<td>63.6 ± 0.4</td>
<td>18.2 ± 0.4</td>
<td>14.8 ± 0.5</td>
<td>3.4 ± 0.1</td>
</tr>
<tr>
<td>Whole Wheat</td>
<td>64.2 ± 0.5</td>
<td>17.6 ± 0.4</td>
<td>14.9 ± 0.8</td>
<td>3.2 ± 0.1</td>
</tr>
<tr>
<td>Strain A</td>
<td>63.6 ± 0.5</td>
<td>18.4 ± 0.3</td>
<td>14.6 ± 0.5</td>
<td>3.4 ± 0.1</td>
</tr>
<tr>
<td>Strain B</td>
<td>63.1 ± 0.1</td>
<td>18.8 ± 0.4</td>
<td>14.6 ± 0.6</td>
<td>3.1 ± 0.1</td>
</tr>
<tr>
<td>Strain C</td>
<td>64.4 ± 0.4</td>
<td>17.7 ± 0.3</td>
<td>14.3 ± 0.5</td>
<td>3.3 ± 0.1</td>
</tr>
<tr>
<td>Female</td>
<td>63.3 ± 0.4</td>
<td>18.5 ± 0.3</td>
<td>14.7 ± 0.3</td>
<td>3.4 ± 0.1</td>
</tr>
<tr>
<td>Male</td>
<td>64.1 ± 0.4</td>
<td>18.1 ± 0.3</td>
<td>14.3 ± 0.5</td>
<td>3.4 ± 0.1</td>
</tr>
</tbody>
</table>

Table 7.10: The effects of diet, strain and sex on the composition of the carcass for ducks at five weeks of age.

Figure 7.31. The effect of week on the carcass % of water, protein, fat and ash.

Week had a significant effect on carcass composition (P < 0.001). Water content was higher in week three and fat content high in week five (* P < 0.05).
7.4.12 Metabolism study

Both the total faecal collection and insoluble marker methods were used to determine the dietary AME and percentage nitrogen retention. The strain and diet effects on the AME are given in table 7.11 and the percentage nitrogen retention and ileal nitrogen digestibility are given in table 7.12. The AME and AMEn values are slightly higher using the insoluble marker method. Using this method, no significant effects of diet or strain were recorded. Using the total excreta collection method there were no strain effects on AME and AMEn but there were significant diet effects. For AME, the high energy diet gave a higher value than did the whole wheat diet (P < 0.05). When the adjustment was made to zero nitrogen retention (AMEn), the high energy diet had a value higher than both the control and whole wheat diets (P < 0.05). Neither, diet or strain had any effects on nitrogen retention using either the excreta collection or marker methods. The total excreta method gave nitrogen retention rates slightly higher (2-3%) than the insoluble marker method. There were no differences in ileal nitrogen digestibility.

<table>
<thead>
<tr>
<th></th>
<th>AME Total Excreta Method (MJ/kg)</th>
<th>AME Insoluble Marker Method (MJ/kg)</th>
<th>AMEn Total Excreta Method (MJ/kg)</th>
<th>AMEn Insoluble Marker Method (MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>13.79 ± 0.05 \textsuperscript{ab}</td>
<td>13.98 ± 0.13</td>
<td>12.18 ± 0.05 \textsuperscript{b}</td>
<td>12.39 ± 0.11</td>
</tr>
<tr>
<td>High Energy</td>
<td>13.91 ± 0.08 \textsuperscript{a}</td>
<td>14.10 ± 0.09</td>
<td>12.44 ± 0.06 \textsuperscript{a}</td>
<td>12.67 ± 0.09</td>
</tr>
<tr>
<td>Whole Wheat</td>
<td>13.65 ± 0.06 \textsuperscript{b}</td>
<td>13.71 ± 0.07</td>
<td>12.20 ± 0.03 \textsuperscript{b}</td>
<td>12.30 ± 0.07</td>
</tr>
<tr>
<td>Strain A</td>
<td>13.79 ± 0.06</td>
<td>13.78 ± 0.11</td>
<td>12.34 ± 0.04</td>
<td>12.39 ± 0.10</td>
</tr>
<tr>
<td>Strain B</td>
<td>13.80 ± 0.06</td>
<td>14.20 ± 0.16</td>
<td>12.14 ± 0.06</td>
<td>12.54 ± 0.15</td>
</tr>
<tr>
<td>Strain C</td>
<td>13.89 ± 0.09</td>
<td>13.84 ± 0.09</td>
<td>12.20 ± 0.07</td>
<td>12.37 ± 0.9</td>
</tr>
<tr>
<td>Probability</td>
<td></td>
<td></td>
<td>0.001</td>
<td>0.11</td>
</tr>
<tr>
<td>Diet</td>
<td>0.05</td>
<td>0.13</td>
<td>0.16</td>
<td>0.66</td>
</tr>
<tr>
<td>Strain X Diet</td>
<td>0.40</td>
<td>0.38</td>
<td>0.13</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Table 7.11. The mean (± SEM) apparent metabolisable energy (AME) and nitrogen corrected apparent metabolisable energy (AMEn) for three strains of ducks fed three different grower diets using the total excreta collection and insoluble marker procedures.

For diet, within columns values with different superscripts are significantly different (P < 0.05).
<table>
<thead>
<tr>
<th></th>
<th>Nitrogen retention (%)</th>
<th>Nitrogen Retention Marker Method (%)</th>
<th>Ileal nitrogen digestibility Marker Method (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>71.7 ± 1.0</td>
<td>70.6 ± 0.7</td>
<td>83.0 ± 0.5</td>
</tr>
<tr>
<td>High Energy</td>
<td>70.7 ± 2.2</td>
<td>69.1 ± 1.1</td>
<td>83.1 ± 0.6</td>
</tr>
<tr>
<td>Whole Wheat</td>
<td>69.7 ± 1.6</td>
<td>68.1 ± 0.8</td>
<td>83.0 ± 0.8</td>
</tr>
<tr>
<td>Strain A</td>
<td>71.0 ± 1.2</td>
<td>68.8 ± 0.8</td>
<td>83.5 ± 0.5</td>
</tr>
<tr>
<td>Strain B</td>
<td>70.9 ± 1.7</td>
<td>71.2 ± 0.8</td>
<td>83.0 ± 0.7</td>
</tr>
<tr>
<td>Strain C</td>
<td>70.9 ± 1.5</td>
<td>68.3 ± 0.9</td>
<td>82.6 ± 0.7</td>
</tr>
<tr>
<td>Probability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diet</td>
<td>0.66</td>
<td>0.07</td>
<td>0.99</td>
</tr>
<tr>
<td>Strain</td>
<td>0.96</td>
<td>0.07</td>
<td>0.69</td>
</tr>
<tr>
<td>Diet X Strain</td>
<td>0.91</td>
<td>0.27</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Table 7.12. The mean (± SEM) nitrogen retention rates (%) for three strains of ducks fed three different grower diets using the total excreta collection and insoluble marker methods and the ileal nitrogen digestibility (%) using the insoluble marker method.

7.5. Discussion

Strain B had superior day 41 processing weight and this is the same strain as performed best in the earlier studies. Strain C (the cross) was heavier than strain A in all weeks. All strains achieved at least market weight (2.85 kg) by 41 days and this was the same as the previous winter study were the same strains were used (chapter 5). The average difference between males and females was 204 g and this was similar to the difference observed in the previous studies. While there were some dietary effects, there was no discernible pattern. A very relevant finding was that on day 41, there were no differences in processing weight between different dietary treatments. Feeding the low protein diet on days 29-41 produced similar results to feeding the higher protein control diet.

Females fed the high energy diet were heavier than those fed the low protein diet but not those on the control diet. Males on the high energy diet were never heavier than the control birds. There was a tendency for birds fed the high energy diet to have a lower feed intake in week six but they had a higher FCR in week six than the birds on the control diet. The results suggest that there is no performance advantage to feeding more than 12.5 MJ/kg ME to any of the three strains used in this study.
The pattern of liveweight gain was influenced by strain with the differences showing the same pattern as seen for absolute liveweight. Transfer of ducks from the control grower diet to the low protein finisher diet resulted in a significant decrease in liveweight gain in week five. However, this rebounded in week six and the ducks on the low protein diet recorded a significantly higher liveweight gain in week six. The total liveweight gain in weeks five and six were similar for all diets.

For the effect of strain, the differences in feed intake showed the same pattern as the differences in liveweight gain. The total intake of feed was similar for ducks on the different diets. The dietary effect on liveweight gain in weeks five and six resulted in higher FCR in week five and lower FCR in week six for ducks fed the low protein diet in the finisher phase. Over the 41 days there was no effect of diet on total FCR. The FCR ranged from 2.06-2.08 and this was similar to the values achieved in the previous winter study (Chapter five).

While there were some minor effects on weekly water to feed ratio the composite values were not influenced by diet or strain. The water to feed ratio was around 2.5 and this was similar to the 2.7 obtained in the earlier winter study detailed in chapter five.

Diet had no effect on the breast to liveweight % with it being around 9.5%. Strain A had a lower % than the other strains. The differences in breast % and liveweight resulted in strain A having 45-78 g less total breast meat at day 41 than strain B and C. This is substantial when the number of birds being processed is large and again identifies a continuing issue the duck industry faces, that is, the low breast yield at current processing weights. As has already been established in earlier studies, the females mature earlier and have a higher breast % than males. Sex, strain and diet had no influence on thigh muscle to liveweight %. While there were no effects of diet or sex on leg to liveweight %, there were minimal strain effects in some weeks but not at week six. Sex and diet had no effect on abdominal fat to liveweight %. Strain A had a lower fat % than did strain B. This is probably related to the differences in absolute liveweight between these two strains.

There were no effects of diet on the digestive organ (liver, proventriculus and gizzard) weight to liveweight %. This was little surprising as one reported consequence of feeding whole grain is enhancement of gizzard development (Hetland et al., 2002; Gabriel et al., 2003). The starter and grower pellet size of duck feed is greater than used to feed broilers and so it’s possible the larger pellets are sufficient to promote gizzard function. There were minimal sex effects on the organ weights to liveweight % and strain effects were limited to strain A having a higher % than strain B. This could be simply related to the differences in absolute liveweight.

There were minimal differences in the relative length of the small intestinal segments. There were no diet and sex effects on the relative length of the duodenum, jejunum and ileum. There was an interaction between strain and sex affecting the relative caecal length. Females of strain A had greater caecal length than females of strain B and C while males of B had shorter length than did males of strain C. There were some strain effects on the relative lengths of the small intestine segments. Strain A had greater duodenal length than strain B while strain A and C had longer relative jejunum and ileal lengths then strain B. These strains differences could be related simply to the differences in liveweight and there remains the question of what the relationship is between this measure and function.

There were no significant effects of strain, sex or diet on carcass composition. As seen in the earlier studies carcass water content in higher in younger ducks and carcass fat % increases with age.

As identified in chapter six, the values determined for AME and AMEn are slightly higher when using the AIA method than the total collection method. This might be associated with the loss of some volatile components (VFA’s) during the oven drying process. There were no diet or strain effects on AME or AMEn, ileal nitrogen digestibility or nitrogen retention using the AIA procedure. Using the total collection method, strain had no effect on AME but the high energy diet had a higher value than the whole wheat diet. When adjusted for zero nitrogen retention, the AMEn for the high energy was higher than for the control and whole wheat diets. There were no diet or strain effects on ileal nitrogen digestibility. There were no diet or strain effects on nitrogen retention using either determination.
procedure. Unlike the large differences in nitrogen retention seen for the two procedures reported in chapter six, the difference in the present study was only 2-3%. In the present study, the ileal nitrogen digestibility was similar to values reported in chapter six. However, there are large differences in nitrogen retention between the two studies using the total excreta method. In the present study, the average faecal nitrogen content for the total collection was 4.56 ± 0.10 % and for the freeze dried samples collected using the AIA method was 4.84 ± 0.06 %. This compares with values of 3.62 ± 0.07 % and 4.62 ± 0.09 % for the total collection and AIA procedures reported in chapter six. So for the two studies, the values for the AIA (freeze drying) are similar but there is a big discrepancy for the total collection (oven drying) method. This places serious reservations on using the oven dried samples in the total collection method for determination of faecal nitrogen. Really for the total collection method a faecal sample should be freeze dried and used for determination of nitrogen.

Reasons advanced for including whole grain in the diet include, decreased processing costs, increase performance, improved gut function and associate better health (Cummings, 1994). Improved performance following the feeding of broilers has been reported (Preston, et al., 2000; Wu et al., 2004). There are contradictory reports of there being no benefit in performance (Bennett et al., 2002; Celick, et al., 2008). A suggested reason for any improvement in performance is an increase in gizzard size and the possible improvement this gives to digestion (Hetland et al., 2002; Gabriel et al., 2003). Svilhus et al., (2002) suggested that the gizzard has a major influence on the rate of digesta flow through the GIT of broilers. Feed needs to be broken down to a fairly homogenous size for it to enter the duodenum (Svilhus et al., 2002). In their study these researchers found that whole grain feeding failed to decrease digesta flow rate, although gizzard volume was increased and so retention time in the gizzard could actually be greater. Ravindran et al., (2006) found the whole wheat feeding in broilers increased gizzard size but feed intake and performance were decreased and FCR was improved. These workers thought that the decreased weight gain could have been a consequence of young chicks not consuming the whole grain easily and that this depressed early growth persisted to a later age.

There do not seem to be equivalent studies in ducks using whole grain feeding. In the present study using 15% whole wheat in the starter and finisher diets had no effect on performance or carcass characteristics. There was no evidence of increased digestive organ weight or relative lengths of the small intestine segments. If whole grain inclusion is to provide a physiological advantage, it seems that the level would need to be more than 15%. However, higher percentages of whole grain are likely to cause issues with pellet quality, which has a crucial influence on duck performance. Using the total collection procedure, AME was lower for the whole wheat diet and so this could indicate decreased efficiency of energy digestion and potential problems if whole wheat is included at higher percentages.
8. The performance of commercial duck strains fed different dietary protein concentrations during the finisher phase

8.1. Introduction

The last research examining the effects of dietary crude protein under Australian environmental conditions was conducted by Siregar et al. in 1982a. These researchers reported that in terms of maximum growth rates, ducks needed a crude protein content of 18.7% in the starter diet and 16% in the grower diet. Presently in Australia, starter and grower diets fed to modern strains of Pekin duck have higher protein contents. In studies one and two, when ducks of the CV and GF strains were fed a grower diet containing 19% protein, nitrogen retention rate was found to be low. It was considered that the protein was being catabolised and used wastefully as a source of energy. In study three, starter and finisher diets containing approximately 3% lower protein concentrations were fed to ducks. In the first four weeks, ducks on the low-protein diet had significantly less weight gain than ducks on the commercial control diet, suggesting that you can’t use lower protein content in the earlier phases of the production period. But remarkably, in week five, ducks on the low-protein diet gained as much weight as ducks on the commercial control diet. Furthermore, in week six ducks on the low protein diet gained significantly more weight than ducks on the commercial control diet, suggesting that there was compensatory growth in these final weeks after consuming a low-protein diet at an earlier age. These findings suggested that less protein than is presently used in commercial diets could be fed in weeks five and six. Currently, commercial producers feed a starter diet in the first two weeks and a grower diet from week three to week six of production. The findings from study three suggested that perhaps the introduction of a finisher diet in these final weeks would be appropriate and formed the basis of one treatment in study four where a finisher diet having lower protein content than the grower diet was trialled. Ducks fed the lower protein finisher diet performed as well as those on the higher protein control diet. If a finisher diet was integrated into the feeding program, the question remained, as to what the protein concentration for this diet should be to achieve optimal performance. The possibility that protein can be reduced in the diet during weeks five and six of production means that the total feed costs to the industry could be reduced and this would help industry to achieve its main objective, which is cost-effective production of edible meat.

Due to genetic selection occurring in different countries, there has been diversification of the Pekin breed and development of specific commercial strains. One of the major challenges for the Australian industry is selecting a strain that meets consumer preferences but still has efficient growth. The highest yield of high-value breast meat is an a requirement for efficient duck-meat production (Micheal, 2001). Ideally, industry would like the increased growth seen from the GF strain coupled with the earlier maturity and meat quality characteristics of the CV strain to improve production efficiency in the hot Australian climate. The industry partners in this project, PEPE’S ducks Pty Ltd., have available one line of GF and two lines of CV ducks. One CV line has been selected with the aim of increasing breast muscle yield at six weeks of age.

8.2. Objective

The main objective of the present study was to investigate the protein content of the finisher diet that supports optimal performance. This project also investigated the performance and carcass composition of three different strains of duck during the summer to determine whether a new CV line can better meet consumer needs.
8.3. Material and Methods

8.3.1. Experimental Design

There were 48 pens allocated to the study. The experiment was conducted using a completely randomised design with blocking. Initially there were 36 ducks in each pen, but this number was reduced over time.

8.3.1.1. Treatments

There were 12 different treatments consisting of three strains and four diets.

The strains were one line of Grimaud Freres and two lines of Cherry Valley with all lines reared as mixed sexes.

The diets were formulated and supplied by Inghams Pty Ltd (Berrima, NSW, Australia). A starter crumble was fed to all ducks from day 1 to day 14 and had a protein content of 21.5% and energy density of 12.6 MJ/kg ME. The grower diet was fed as a pellet to all ducks from day 15 to day 28 and had a protein content of 17.5% and energy density of 12.5 MJ/kg ME and was the control diet (diet D) used in the finisher phase. Pelleted finisher diets were fed over days 29-41 and had the following specifications:

Diet A: Protein 16.8% and 12.5MJ/kg ME
Diet B: Protein 16.1% and 12.5MJ/kg ME
Diet C: Protein 15.4% and 12.5MJ/kg ME
Diet D: Protein 17.5% and 12.5MJ/kg ME

8.3.1.2. Husbandry

The husbandry procedures are as described in the sections 3.1.1 to 3.1.7.

8.3.1.3. Performance and carcass measurements

Briefly, on days seven (week one), 14 (week two), 21 (week three), 28 (week four), 35 (week five) and 41 (week six) all ducks were individually weighed. On days six, 13, 20, 27, 34 and 41 growth measurements were taken from an individual duck selected at random from each pen. Carcass and GIT measurements were made as described in section 3.1.9. At the end of the production period all remaining ducks were processed by PEPE’S Ducks Pty Ltd. On days 27(week four) and 41 (week six) the carcasses and all body parts used for growth measurements were retained. The carcasses were autoclaved, homogenised and after freeze-drying the crude fat, protein and ash were determined as described in section 3.1.10.

8.3.2. Metabolism study

At day 14 (week two), two ducks (one male and one female) were randomly selected and removed from each pen of the growth trial. Ducks from two pens of the same strain were grouped (four ducks) and were moved to 24 metabolism cages and fed ad libitum the same commercial grower diet supplied to the ducks in the growth trial, with the addition of an insoluble ash marker, Celite, at a concentration of 10 grams per kilogram of feed. Sampling was the same as described in section 3.2. In this study analysis was carried out using both the total collection and AIA procedures.
8.3.3. Statistical analysis

The mixed model REML procedure in GenStat Release 10 (www.vsni.co.uk) was used for the analysis of data. Data was loge transformed where necessary. The fixed model included the effects of strain, diet, sex and week and the random model included the effects of block, pen and bird identification.

For example the following mixed model was fitted to the duck liveweight data:

\[
\log_e \text{Weight} = \text{Constant} + \text{Diet} + \text{Sex} + \text{Strain} + \text{Week} + \text{Diet.Sex} + \text{Diet.Strain} + \text{Diet.Week} + \text{Sex.Strain} + \text{Sex.Week} + \text{Strain.Week} + \text{Block} + \text{Pen} + \text{Tag} + \varepsilon
\]

All significance testing of fixed effects was conducted using Wald chi-square tests with a significance threshold of \( P < 0.05 \). Non-significant interactions were removed from the model. Pairwise comparison of means was conducted using LSD-type procedures (LSD \( \approx 2 \times \text{SED} \)).

For the proximate carcass analysis and the metabolism study, differences between treatments were determined using ANOVA (SAS: Statview, version 5). When differences were significant individual comparisons were made using the least significant difference (LSD) procedure.

8.4. Results

For reasons of ‘commercial in confidence’ the strains have been designated as Strain A, Strain B, and C, with no particular order specified.

8.4.1. Liveweight

The effect of diet on the bodyweight is given in figure 8.1. The effect of diet changed with time and strain as indicated by the significant interactions of diet x week (\( P = 0.001 \)) and diet x strain (\( P < 0.001 \)). There was no significant interaction between diet and sex (\( P = 0.32 \)). During weeks one to four the birds were fed the same starter and grower diets. However, those birds allocated the finisher diet B (2004 ± 16 g) had a greater (\( P < 0.05 \)) weight than those allocated to diets A (1966 ± 16 g) and C (1960 ± 16 g).

At week five, the mean liveweight for birds fed diets A (16.8%), B (16.1%), C (15.4%) and D (17.5%) were 2550 ± 20 g, 2514 ± 20 g, 2492 ± 20 g and 2576 ± 21 g, respectively. The liveweight of birds fed diet C was lower than those fed diets A and D (\( P < 0.05 \)), while those fed diet B had lower liveweight than those fed diet D (\( P < 0.05 \)). In week six the mean liveweight for birds fed diets A, B, C and D were 2957 ± 24 g, 2960 ± 24 g, 2942 ± 23 g and 2995 ± 24 g, respectively. The only difference in week six was where birds on diet D were heavier than those on diet C (\( P < 0.05 \)).

The effects of strain on mean weekly liveweight are shown in figure 8.2. At the end of the production period the mean (± SEM) liveweights of strains A, B and C were 2799 ± 21 g, 3078 ± 21 g and 3023 ± 20 g, respectively. The strain effects were influenced by time, sex and diet as indicated by the significant interactions of strain x week, strain x sex and strain x diet (all \( P < 0.001 \)). Liveweight of strain A was lower than strain C at all weeks and strain B from week three to six (\( P < 0.05 \)). Strains B and C had similar liveweights in weeks one to four but in weeks five and six strain B was heavier (\( P < 0.05 \)).
Figure 8.1. The mean weekly liveweight (g) for birds fed the same diets during the first four weeks and then fed diets differing in protein concentration in weeks five and six. The diet x week interaction was significant (P = 0.001).

Figure 8.2. The effect of strain on mean weekly liveweight (g) when birds were fed the same diets during the first four weeks and then fed diets differing in protein concentration in weeks five and six. The strain x week interaction was significant (P < 0.001).

The diet x strain interaction is shown in figure 8.3. When strain A was fed diet C, birds were lighter than birds fed all other diets (P < 0.05). For strain B, birds fed diets C and D were heavier than birds fed diets A and B (P < 0.05). Birds of strain C fed diet B were heavier than birds fed the other diets (P < 0.05).
Figure 8.3. The effect of strain and diet on mean (± SEM) liveweight (g) when birds were fed the same diets during the first four weeks and then fed diets differing in protein concentration in weeks five and six.

The strain x diet interaction was significant (P < 0.001).

The effect of sex on liveweight is shown in figure 8.4. The interaction between sex and week was significant (P < 0.001). In all weeks except one, males were heavier than females. At the end of the production period the mean (± SEM) weight of females was 2864 ± 20 g and males 3069 ± 21 g. There was a significant (P < 0.001) strain x sex interaction (see Figure 8.5). For strain A both females and males were lighter than the same sexes in strains B and C (P < 0.05). For strains B and C, females were of similar weight but the males of strain B were heavier those of strain C (P < 0.05).

Figure 8.4. The mean liveweight (g) for male and female birds fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six.

The sex x week interaction was significant (P < 0.001).
8.4.2. Liveweight gain

The effect of diet on liveweight gain is given in figure 8.6. There was a significant interaction between diet and week (P < 0.001). As birds were fed the same diets in weeks 1 to 4, no differences in gain would have been expected during this period and this was the case. In week five, gain was lower (P < 0.05), for birds fed diet B (507 ± 11 g) and diet C (525 ± 11 g) compared to those fed diets A (586 ± 11 g) and D (605 ± 11 g). Interestingly, in week six the effects were reversed with the weight gain for birds fed diets B (440 ± 8 g) and C (440 ± 8 g) being greater (P < 0.05), than for birds fed diets A (407 ± 8 g) and D (410 ± 8 g) (P < 0.05). While there is evidence of some compensatory growth in week six, there remained some differences in the combined week five and six liveweight gains. The combined liveweight gain for the birds on the diet B (951 ± 19 g) was lower (P < 0.05) than for birds on diets D (1021 ± 24 g), A (1000 ± 23 g) and C (971 ± 27 g). The difference between the birds on diet D and diet C was also significant (P < 0.05).

The effect of strain on mean weekly gain is shown in figure 8.7. There was a significant interaction between strain and week, (P < 0.001). Except for week one, the gain for strain A was less than for both strains B and C (P < 0.05). For the first five weeks there was no difference in the weekly gain for strains B and C. However, in week six the gain for strain B was greater than for strain C (P < 0.05). There was no significant interaction between strain and diet (P = 0.12).
8.4.3. Feed Intake

There was no significant effect (P = 0.18) of diet on feed intake (see Figure 8.8). The effect of strain on weekly feed intake is shown in figure 8.9. There was as significant strain x week interaction (P = 0.04). Except for week one, the intake was lower for strain A than both strains B and C (P < 0.05). The only other difference was in week three were the intake of strain B was greater than strain C (P < 0.05).
Strain (P < 0.001) had significant effect on the total composite feed intake. The total feed intake of strain A (5.61 ± 0.04 kg) was lower (P < 0.05) than that of strains B (6.05 ± 0.05 kg) and C (5.94 ± 0.04). The effect of diet on total feed intake was not significant (P = 0.42). The total mean (± SEM) intakes for birds fed diets A, B, C and D were 5.86 ± 0.07 kg, 5.91 ± 0.09 kg, 5.80 ± 0.07 kg and 5.90 ± 0.07 kg, respectively.

Figure 8.8. The effect of diet on mean weekly feed intake for birds fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six.

There were no significant diet effects (P = 0.18).

Figure 8.9. The effect of strain on mean weekly feed intake for birds fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six.

There was a significant strain x week interaction (P=0.04).
8.4.4. Food Conversion Ratio (FCR)

The effect of diet on the weekly FCR is shown in figure 8.10. The effect of diet changed during the production period as indicated by the significant diet x week interaction (P < 0.001). The main differences are seen in weeks five and six when the birds were being fed the different finisher diets. In week five, birds fed diets A (2.37 ± 0.05) and D (2.33 ± 0.05) had a better FCR than those fed diets B (2.73 ± 0.05) and C (2.60 ± 0.05) (P < 0.05). This trend was reversed in week six where FCR tended to be better for diet B (3.06 ± 0.06) and significantly better (P < 0.05) for diet C (2.91 ± 0.06) when compared to diets A (3.21 ± 0.06) and D (3.16 ± 0.06).

The effect of strain on the weekly FCR is given in figure 8.11. The strain effects varied over time as the strain x week interaction was significant (P = 0.005). Some differences were seen in week four where the FCR for birds of strain A (2.13 ± 0.03) was poorer (P < 0.05), than for birds of strain B (2.01 ± 0.03) and C (1.99 ± 0.03). In week five, birds of strain A (2.60 ± 0.04) continued to have higher FCR (P < 0.05), than birds of strain B (2.42 ± 0.04) while those of strain C were intermediate (2.49 ± 0.04). In week six, birds of strain B (2.92 ± 0.05) had a better FCR (P < 0.05), than those of either strains A (3.18 ± 0.05) or C (3.16 ± 0.05).

The mean (± SEM) total composite FCR for the production period was poorer (P < 0.05) for strain A (2.06 ± 0.052) than for strain B (1.99 ± 0.02) or strain C (1.99 ± 0.02). The effect of diet on the total composite FCR was not significant (P = 0.18). The values for strain A, B, C and D were 2.08 ± 0.02, 2.03 ± 0.02, 2.00 ± 0.02 and 1.98 ± 0.02, respectively.

Figure 8.10. The effect of diet on the weekly FCR for ducks fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six. There was a significant diet x week interaction (P < 0.001).
8.4.5. Water Intake

The effect of diet and strain on mean weekly water intake are shown in figures 8.12 and 8.13, respectively. The diets effect changed overtime as indicated by the significant diet x week interaction (P < 0.001). There were no dietary differences in the first four weeks as expected but there were differences in weeks five and six when the diets fed were changed. In week five, the water intake of birds on diets B (4587 ± 78 mL) and D (4652 ± 79 mL) were greater (P<0.05), than those on diets A (4320 ±73 mL) and C (4151 ± 71 mL) (P < 0.05). In week six, there was similar pattern where the intakes of birds on diets B (4920 ± 84 mL) and D (5192 ± 88 mL) were greater than those on diet C (4610 ± 78 g) (P < 0.05), but not in this case diet A (4774 ± 81 mL).

There was a significant strain x week interaction (P < 0.001). The main effects were seen in weeks five and six. In week five, the water intake of strain A (4125 ± 74 mL) was lower than for strains B (4624 ± 72 mL) and C (4532 ± 66 mL) (P < 0.05). In week six, there was a similar pattern of differences with strain A (4550 ± 83 mL) having a lower intake (P < 0.05) than strains B (5162 ± 79 mL) and C (4915 ± 72 mL) but here the differences between strains B and C were also significant (P < 0.05).

There was a significant diet x strain interaction (P = 0.04), this is shown in figure 8.14. For birds of strain C the consumption of water was similar on all diets. In the case of strain B the consumption of water by birds on diet D was greater than when fed diets A and C (P < 0.05). For strain A water consumption on diet C was lower than for birds on the other diets (P < 0.05).

Strain (P<0.001) and diet (P=0.02) had significant effects on the total water intake. The total water intake of strain A (18.12 ± 0.28 L) was lower (P<0.05) than that of strains B (19.46 ± 0.22 L) and C (19.18 ± 0.16 L). The total mean (± SEM) intake for birds fed diet C (18.48 ± 0.40 L) was lower (P<0.05) than for diet D (19.45 ± 0.31 L) but not diet A (18.62 ± 0.21 L) and B (19.13 ± 0.20 L).
Figure 8.12. The effect of diet on mean weekly water intake for birds fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six.

There was a significant diet x week interaction (P<0.001).

Figure 8.13. The effect of strain on mean weekly water intake for birds fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six.

There was a significant strain x week interaction (P<0.001).
Figure 8.14. The effect of the strain and diet on mean weekly water intake for birds fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six.

The interaction of strain x diet was significant (P=0.04).

8.4.6. Water to feed ratio

The effect of diet on the water to feed ratio (see Figure 8.15), changed with time as indicated by the significant diet x week interaction (P = 0.001). There were no differences in the first four weeks when the birds were on the same diets. There were differences in weeks five and six. In week five the ratio for birds on diet B (3.31 ± 0.09) and D (3.30 ± 0.09) were greater than for those of diets C (3.04 ± 0.08) (P<0.05), while the ratio for B was also higher than for A (3.11 ± 0.08) (P < 0.05). In week six, the ratio was higher (P < 0.05) for birds on diet D (4.01 ± 0.11) than birds on other diets (A, 3.65 ± 0.10; B, 3.65 ± 0.10; C, 3.60 ± 0.10).

The strain effects on water to feed ratio are given in figure 8.16. The effect of strain on the water to feed ratio changed with time as indicated by the significant diet x week interaction (P < 0.001). While there were differences in week one, these data are questionable because during this period birds have access to bell drinkers for the first few days and there is a lot of wastage associated with this practice. In weeks two and three, strain B (2.73 ± 0.07 and 2.56 ± 0.07, respectively) had a lower ratio (P < 0.05), than did strain A (2.92 ± 0.07 and 2.76 ± 0.06, respectively) or strain C (2.93 ± 0.07 2.70 ± 0.09, respectively). The only other differences was seen in week six were the ratio for strain B (3.85 ± 0.09) was higher (P < 0.05), than for strains A (3.65 ± 0.10) and C (3.67 ± 0.09). There was no interaction between strain and diet (P = 0.11).

Neither strain (P = 0.95) or diet (P = 0.18) had significant effect on the total composite water to feed ratio. The total mean (± SEM) water to feed ratio for strains A, B and C were 3.23 ± 0.07, 3.22 ± 0.07 and 3.23 ± 0.07, respectively. The values for the diet A, B, C and D were 3.18 ± 0.07, 3.24 ± 0.07, 3.19 ± 0.07 and 3.30 ± 0.07, respectively.
8.4.7. Muscle development and yield

Diet (see Figure 8.17), had no effect on the breast muscle weight to liveweight % (P = 0.36). At the end of the production period, the mean (± SEM) breast % for birds fed diet A was 10.1 ± 0.3%, diet B was 9.8 ± 0.3%, diet C was 9.9 ± 0.3% and diet D was 10.0 ± 0.3%. In absolute terms, at 41 days (week six), the mean (± SEM) weight of breast muscle yield was, diet A; 300 ± 15 g, diet B; 282 ± 13 g, diet C; 294 ± 14 g and diet D; 300 ± 15 g. Again diet had no significant effect on total breast weight at six weeks (P = 0.21).
Figure 8.17.  The effect of diet on the breast weight to liveweight (LW) % for ducks fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six.

There was a no significant diet effect (P = 0.36).

The effect of strain on the breast muscle weight to LW % is shown in figure 8.18. The interaction strain x week was significant (P < 0.001). While there was little difference in the first two weeks there were major differences thereafter. In weeks three to five the breast % was higher (P < 0.05) in strain C than the other strains and also higher in strain B than strain A (P < 0.05). In week six, the superiority of strain C continued (P < 0.05) but the difference between strains A and B was not significant. In absolute terms, at 41 days the mean (± SEM) weight of breast muscle yield was, strain A; 247 ± 10 g, strain B; 283 ± 12 g, and strain C; 361 ± 16 g. The total yield of breast muscle from strain C was significantly greater than it was from the other two strains (P < 0.05).

The effect of sex on the breast muscle weight to LW % was significant (P < 0.001). The females had a higher breast % than did the males (see Figure 8.19). At the end of the production period the mean (± SEM) for the females was 10.4 ± 0.3 % and for the males 9.4 ± 0.2 %. The absolute final yield in week six for females was 299 ± 11 g and for males was 289 ± 10 g with the difference not significant.
Figure 8.18. The effect of strain on the breast weight to liveweight (LW) % for ducks fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six. There was a significant strain x week interaction (P < 0.001).

Figure 8.19. The effect of sex on the breast weight to liveweight (LW) % for ducks fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six. There was a significant effect due to sex (P < 0.001).

The mean (± SEM) thigh muscle weight to liveweight (LW) % is given in table 8.1. There was a significant week effect (P < 0.001) with the % thigh muscle increasing from week one to three and then declining to week six. There were no significant effects due to diet (P=0.39), strain (P = 0.24) or sex (P = 0.50).
The mean (± SEM) leg muscle weight (drumstick) to liveweight (LW) % is given in table 8.2. There was a significant week effect (P < 0.001) with the maximum % being in week two and then there was a gradual decline to week six. There were no significant effects due to diet (P=0.73), strain (P =0.72) or sex (P = 0.77).

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<th>Week</th>
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<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
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<td>5.3 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
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Table 8.1: The mean (± SEM) thigh muscle weight to liveweight (LW) % for ducks fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six.

There was a significant week effect (P < 0.001) but no other significant effects. For week, values within the row with different superscripts are significantly different (P < 0.05).
Table 8.2: The mean (± SEM) leg muscle (drumstick) weight to liveweight (LW) % for ducks fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six.

There was a significant week effect (P < 0.001) but no other significant effects. For week, values within the row with different superscripts are significantly different (P < 0.05).

8.4.8. Abdominal fat yield

The abdominal fat weight to liveweight ratio expressed as % for the three strains is shown in figure 8.20. The interaction of strain and week just failed to reach significance (P = 0.06). After week three strain C tended to have a lower abdominal fat % compared to stains A and B. At the end of the study the fat % for the different strains were strain A, 1.32 ± 0.09 %; strain B, 1.31 ± 0.08 % and strain C; 1.09 ± 0.09 %.

The abdominal fat weight to liveweight % for birds on the different diets can be seen in figure 8.21. The diet effects were not significant (P = 0.30). At the end of the production period the mean (± SEM) fat % were diet A, 1.17 ± 0.10; diet B, 1.26 ± 0.10; diet C, 1.35 ± 0.11 and diet D, 1.17 ± 0.10.

The abdominal fat weight to liveweight % for the sexes was similar (P = 0.82) during the production period (see Figure 8.22). At week six, the mean (± SEM) fat % for females was 1.25 ± 0.08 and males 1.23 ± 0.07.
Figure 8.20. The effect of strain on the abdominal fat weight to liveweight (LW) % for ducks fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six.

The interaction of strain x week was marginally not significant (P = 0.06).

Figure 8.21. The effect of diet on the abdominal fat weight to liveweight (LW) % for ducks fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six.

The diet effect was not significant (P = 0.30).
8.4.9. Digestive organ weights and gastrointestinal tract measurements

Measurements of the GIT are expressed as cm per 100 g of liveweight.

8.4.9.1. Liver

The liver weight to liveweight % changed over the six week sampling period (P < 0.001). The liver % was highest in week one and decreased each week thereafter (P < 0.05). There were no significant effects due to diet (P = 0.62), strain (P = 0.93) or sex (P = 0.89). All values are given in table 8.3.
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<th>Week 3</th>
<th>Week 4</th>
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<td></td>
<td>2.96 ± 0.11</td>
</tr>
<tr>
<td>Diet C</td>
<td>7.00 ± 0.45</td>
<td>5.93 ± 0.32</td>
<td>4.83 ± 0.36</td>
<td>3.93 ± 0.15</td>
<td>3.38 ± 0.13</td>
</tr>
<tr>
<td>15.4%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.78 ± 0.11</td>
</tr>
<tr>
<td>Diet D</td>
<td>6.41 ± 0.30</td>
<td>5.44 ± 0.36</td>
<td>4.91 ± 0.25</td>
<td>4.19 ± 0.16</td>
<td>3.34 ± 0.13</td>
</tr>
<tr>
<td>17.5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.74 ± 0.10</td>
</tr>
<tr>
<td>Strain A</td>
<td>5.87 ± 0.33</td>
<td>6.14 ± 0.28</td>
<td>4.90 ± 0.24</td>
<td>4.00 ± 0.13</td>
<td>3.48 ± 0.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.87 ± 0.09</td>
</tr>
<tr>
<td>Strain B</td>
<td>6.57 ± 0.32</td>
<td>5.66 ± 0.31</td>
<td>4.93 ± 0.25</td>
<td>4.05 ± 0.13</td>
<td>3.40 ± 0.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.77 ± 0.09</td>
</tr>
<tr>
<td>Strain C</td>
<td>6.42 ± 0.28</td>
<td>5.64 ± 0.29</td>
<td>4.90 ± 0.23</td>
<td>4.12 ± 0.13</td>
<td>3.40 ± 0.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.87 ± 0.09</td>
</tr>
<tr>
<td>Female</td>
<td>6.14 ± 0.24</td>
<td>5.80 ± 0.21</td>
<td>4.78 ± 0.21</td>
<td>4.09 ± 0.11</td>
<td>3.42 ± 0.09</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>2.75 ± 0.07</td>
</tr>
<tr>
<td>Male</td>
<td>6.42 ± 0.27</td>
<td>5.82 ± 0.24</td>
<td>5.04 ± 0.23</td>
<td>4.03 ± 0.11</td>
<td>3.43 ± 0.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.92 ± 0.07</td>
</tr>
</tbody>
</table>

Table 8.3: The mean (± SEM) liver weight to liveweight ratio expressed as percentage for the effects of week, diet, strain and sex.

There was significant week effect \((P < 0.001)\). For week, values within the row with different superscripts are significantly different \((P < 0.05)\).

8.4.9.2. Proventriculus

The effect of week, strain, diet and sex on the ratio of proventriculus weight to liveweight expressed as a % is given in table 8.4. The proventriculus % changed with time as the effect of week was significant \((P < 0.001)\). The highest % was seen at week one and then this declined significantly each week thereafter \((P < 0.05)\). The effect of strain on the % proventriculus was significant \((P = 0.03)\) with it being lower \((P < 0.05)\), for strain C \((0.44 ± 0.01 \%)\) than for strain B \((0.46 ± 0.01 \%)\). Sex \((P = 0.13)\) and diet \((P = 0.93)\) had no significant effects on the proventriculus %.
<table>
<thead>
<tr>
<th>Week</th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week</td>
<td>0.77 ± 0.02&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.57 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.44 ± 0.01&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.38 ± 0.01&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.37 ± 0.01&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.32 ± 0.01&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Diet A</td>
<td>0.83 ± 0.04</td>
<td>0.57 ± 0.03</td>
<td>0.43 ± 0.02</td>
<td>0.38 ± 0.01</td>
<td>0.35 ± 0.01</td>
<td>0.32 ± 0.01</td>
</tr>
<tr>
<td>16.8%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diet B</td>
<td>0.74 ± 0.04</td>
<td>0.56 ± 0.02</td>
<td>0.45 ± 0.02</td>
<td>0.38 ± 0.01</td>
<td>0.36 ± 0.01</td>
<td>0.32 ± 0.01</td>
</tr>
<tr>
<td>16.1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diet C</td>
<td>0.76 ± 0.04</td>
<td>0.58 ± 0.02</td>
<td>0.42 ± 0.03</td>
<td>0.38 ± 0.01</td>
<td>0.39 ± 0.01</td>
<td>0.31 ± 0.01</td>
</tr>
<tr>
<td>15.4%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diet D</td>
<td>0.76 ± 0.03</td>
<td>0.59 ± 0.03</td>
<td>0.45 ± 0.02</td>
<td>0.38 ± 0.01</td>
<td>0.36 ± 0.01</td>
<td>0.31 ± 0.01</td>
</tr>
<tr>
<td>17.5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strain A</td>
<td>0.76 ± 0.03</td>
<td>0.60 ± 0.02</td>
<td>0.45 ± 0.02</td>
<td>0.38 ± 0.01</td>
<td>0.38 ± 0.01</td>
<td>0.31 ± 0.01</td>
</tr>
<tr>
<td>Strain B</td>
<td>0.80 ± 0.03</td>
<td>0.57 ± 0.02</td>
<td>0.44 ± 0.02</td>
<td>0.40 ± 0.01</td>
<td>0.37 ± 0.01</td>
<td>0.33 ± 0.01</td>
</tr>
<tr>
<td>Strain C</td>
<td>0.76 ± 0.03</td>
<td>0.56 ± 0.02</td>
<td>0.42 ± 0.02</td>
<td>0.36 ± 0.01</td>
<td>0.35 ± 0.01</td>
<td>0.32 ± 0.01</td>
</tr>
<tr>
<td>Female</td>
<td>0.76 ± 0.02</td>
<td>0.58 ± 0.02</td>
<td>0.44 ± 0.01</td>
<td>0.39 ± 0.01</td>
<td>0.37 ± 0.01</td>
<td>0.33 ± 0.01</td>
</tr>
<tr>
<td>Male</td>
<td>0.78 ± 0.02</td>
<td>0.57 ± 0.02</td>
<td>0.44 ± 0.02</td>
<td>0.37 ± 0.01</td>
<td>0.36 ± 0.01</td>
<td>0.31 ± 0.01</td>
</tr>
</tbody>
</table>

Table 8.4. The proventriculus weight to liveweight expressed as % during the six week production period for the effects of week, diet, strain and sex.

Birds were fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six. Within the row for the effect of week, values with different superscripts are significantly different (P < 0.05).

8.4.9.3 Gizzard

The effect of week, diet, strain and sex on the ratio of gizzard weight to liveweight expressed as % is given in table 8.5. Gizzard as a percentage of liveweight changed with week (P < 0.001). The % gizzard was highest at week one and then declined thereafter (P < 0.05). There was no effect of strain (P = 0.87) on gizzard %. There was significant diet x sex interaction (P = 0.02). For males the gizzard % was higher than females when fed diets B and C but not when fed diets A and D (P < 0.05). Females on diet A (3.76 ± 0.09) had a higher gizzard % (P < 0.05), than females on diet B (3.43 ± 0.09) and diet C (3.45 ± 0.08). Males on diet B (3.84 ± 0.09) had a higher gizzard % (P < 0.05) than males on diet A (3.59 ± 0.09) and diet D (3.58 ± 0.09).
Table 8.5. The gizzard weight to liveweight expressed as % during the six week production period for the effects of week, diet, strain and sex.

Birds were fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six. Within the row for the effect of week, values with different superscripts are significantly different (P < 0.05).

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week</td>
<td>4.93 ±</td>
<td>4.40 ±</td>
<td>3.52 ±</td>
<td>3.29 ±</td>
<td>3.00 ±</td>
<td>2.82 ±</td>
</tr>
<tr>
<td>**</td>
<td>0.11\textsuperscript{a}</td>
<td>0.10\textsuperscript{b}</td>
<td>0.08\textsuperscript{c}</td>
<td>0.06\textsuperscript{d}</td>
<td>0.05\textsuperscript{e}</td>
<td>0.05\textsuperscript{f}</td>
</tr>
<tr>
<td>Diet A</td>
<td>5.10 ±</td>
<td>4.38 ±</td>
<td>3.41 ±</td>
<td>3.53 ±</td>
<td>3.06 ±</td>
<td>2.88 ±</td>
</tr>
<tr>
<td>16.8%</td>
<td>0.23</td>
<td>0.21</td>
<td>0.16</td>
<td>0.12</td>
<td>0.10</td>
<td>0.09</td>
</tr>
<tr>
<td>Diet B</td>
<td>4.82 ±</td>
<td>4.40 ±</td>
<td>3.66 ±</td>
<td>3.32 ±</td>
<td>3.05 ±</td>
<td>2.89 ±</td>
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<tr>
<td>16.1%</td>
<td>0.27</td>
<td>0.21</td>
<td>0.19</td>
<td>0.11</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>Diet C</td>
<td>4.95 ±</td>
<td>4.37 ±</td>
<td>3.38 ±</td>
<td>3.19 ±</td>
<td>2.93 ±</td>
<td>2.99 ±</td>
</tr>
<tr>
<td>15.4%</td>
<td>0.28</td>
<td>0.20</td>
<td>0.22</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>Diet D</td>
<td>4.84 ±</td>
<td>4.49 ±</td>
<td>3.58 ±</td>
<td>3.14 ±</td>
<td>2.96 ±</td>
<td>2.54 ±</td>
</tr>
<tr>
<td>17.5%</td>
<td>0.20</td>
<td>0.26</td>
<td>0.16</td>
<td>0.10</td>
<td>0.10</td>
<td>0.08</td>
</tr>
<tr>
<td>Strain A</td>
<td>4.95 ±</td>
<td>4.36 ±</td>
<td>3.55 ±</td>
<td>3.25 ±</td>
<td>2.98 ±</td>
<td>2.85 ±</td>
</tr>
<tr>
<td>0.22</td>
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<td>0.10</td>
<td>0.09</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Strain B</td>
<td>4.94 ±</td>
<td>4.34 ±</td>
<td>3.57 ±</td>
<td>3.41 ±</td>
<td>3.05 ±</td>
<td>2.74 ±</td>
</tr>
<tr>
<td>0.22</td>
<td>0.20</td>
<td>0.16</td>
<td>0.09</td>
<td>0.09</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Strain C</td>
<td>4.89 ±</td>
<td>4.53 ±</td>
<td>3.39 ±</td>
<td>3.22 ±</td>
<td>2.96 ±</td>
<td>2.87 ±</td>
</tr>
<tr>
<td>0.21</td>
<td>0.18</td>
<td>0.15</td>
<td>0.09</td>
<td>0.09</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>4.77 ±</td>
<td>4.28 ±</td>
<td>3.47 ±</td>
<td>3.25 ±</td>
<td>2.93 ±</td>
<td>2.72 ±</td>
</tr>
<tr>
<td>0.16</td>
<td>0.14</td>
<td>0.13</td>
<td>0.08</td>
<td>0.07</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>5.09 ±</td>
<td>4.54 ±</td>
<td>3.55 ±</td>
<td>3.34 ±</td>
<td>3.08 ±</td>
<td>2.92 ±</td>
</tr>
<tr>
<td>0.18</td>
<td>0.17</td>
<td>0.14</td>
<td>0.08</td>
<td>0.07</td>
<td>0.07</td>
<td></td>
</tr>
</tbody>
</table>

8.4.10. Gastrointestinal tract measurements

Measurements of the GIT are expressed as cm per 100 g of liveweight.

8.4.10.1. Duodenum length (DL)

The effects of week, diet, strain and sex on the length (cm) of the duodenum (DL) per 100g liveweight is given in table 8.6. Week (P < 0.001), strain (P < 0.001) and sex (P = 0.02) all had significant effects on the relative length of the DL. The length of the DL declined rapidly after week one with the difference for each week thereafter being significant (P < 0.05). Males (2.26 ± 0.02 cm) had a shorter (P < 0.05) DL length than females (2.34 ± 0.02 cm). Birds of stain A (2.40 ± 0.03 cm) had greater length (P < 0.05) than birds of strains B (2.30 ± 0.03 cm) and C (2.21 ± 0.03 cm) with the differences between stains B and C also different (P < 0.05). Diet had no significant effects (P = 0.58).
Table 8.6. The mean (± SEM) DL length (cm) per 100g liveweight during the six week production period for the effects of week, diet, strain and sex.

Birds were fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six. Week (P < 0.001), strain (P < 0.001) and sex (P = 0.02) all had significant effects. Within the row for the effect of week, values with different superscripts are significantly different (P < 0.05).

8.4.10.2. Length of the jejunum (Duodenum to Merkle’s Diverticulum: (DL-MD)

The effects of week, strain, sex and pen-sex on the length (cm) of small intestine from the duodenal loop to Merkles Diverticulum (DL-MD) per 100g liveweight are given in table 8.7. The relative DL-DM length changed each week (P < 0.001). The values were highest in week one and declined each week thereafter (P < 0.05). The effect of sex was significant (P < 0.001) with males (6.00 ± 0.06 cm) having a shorter (P < 0.05) average length than females (6.28 ± 0.06 cm). There were no effects due to diet (P = 0.73) or strain (P = 0.15).
### Table 8.7: The mean (±SEM) length in cm of small intestine from DL-MD per 100g liveweight during the production period for the effects of week, diet, strain and sex.

Birds were fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six. Week (P < 0.001) and sex (P < 0.001) had significant effects. Within the row for the effect of week, values with different superscripts are significantly different (P < 0.05).

8.4.10.3. Length of the Ileum (Merkle’s Diverticulum to the ileo-caecal junction: MD-ICJ)

The effects of week, strain, diet and sex on the length (cm) of small intestine from the Merkle’s Diverticulum to the ileo-caecal junction (MD-ICJ) per 100g liveweight are given in table 8.8. The relative DM-ICJ length changed with week (P < 0.001). The values were high in week one and decreased each week thereafter (P < 0.05). There were no effects due to diet (P = 0.75), strain (P = 0.08) or sex (P = 0.44).
## Table 8.8: The mean (± SEM) length in cm of small intestine from MD-ICJ per 100g liveweight during the production period for the effects of week, diet, strain and sex.

Birds were fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six. There was a significant effect of week (P < 0.001) and values within the row with different superscripts are significantly different (P < 0.05).

### 8.4.10.4. Total Caecal length (CL)

The effects of week, diet, strain and sex on the total caecal (CL) length (cm) per 100g liveweight are given in Table 8.9. The relative (CL) length changed with week (P < 0.001). The values were greatest in week one and then declined each week thereafter (P < 0.05). Strain had significant (P = 0.002) effect on relative CL length. The length for strain A (2.80 ± 0.04 cm) was greater (P < 0.05) than for the strain B (2.62 ± 0.03 cm) and strain C (2.68 ± 0.03 cm). There was a significant diet x sex interaction (P = 0.04). Males on diet B (2.84 ± 0.05 cm) had a greater length (P < 0.05) than females on diet B (2.69 ± 0.06 cm). Males on diet B (2.84 ± 0.05 cm) had greater length (P < 0.05) than males on diet A (2.60 ± 0.05 cm) and C (2.64 ± 0.06 cm). Males on diet D (2.74 ± 0.05 cm) had greater length (P < 0.05) than males on diet A (2.60 ± 0.05 cm).

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week</td>
<td>22.0 ± 0.4a</td>
<td>9.8 ± 0.2b</td>
<td>5.8 ± 0.1c</td>
<td>4.3 ± 0.1d</td>
<td>3.4 ± 0.1e</td>
<td>2.7 ± 0.1f</td>
</tr>
<tr>
<td>Diet A 16.8%</td>
<td>23.6 ± 1.0</td>
<td>9.6 ± 0.4</td>
<td>5.5 ± 0.2</td>
<td>4.4 ± 0.1</td>
<td>3.3 ± 0.1</td>
<td>2.7 ± 0.1</td>
</tr>
<tr>
<td>Diet B 16.1%</td>
<td>21.5 ± 1.0</td>
<td>9.7 ± 0.4</td>
<td>6.1 ± 0.3</td>
<td>4.3 ± 0.1</td>
<td>3.4 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Diet C 15.4%</td>
<td>21.3 ± 1.0</td>
<td>9.9 ± 0.4</td>
<td>5.9 ± 0.3</td>
<td>4.3 ± 0.1</td>
<td>3.5 ± 0.1</td>
<td>2.8 ± 0.1</td>
</tr>
<tr>
<td>Diet D 17.5%</td>
<td>21.9 ± 0.8</td>
<td>10.1 ± 0.5</td>
<td>5.9 ± 0.2</td>
<td>4.2 ± 0.1</td>
<td>3.5 ± 0.1</td>
<td>2.7 ± 0.1</td>
</tr>
<tr>
<td>Strain A</td>
<td>22.4 ± 0.8</td>
<td>9.6 ± 0.3</td>
<td>6.1 ± 0.2</td>
<td>4.4 ± 0.1</td>
<td>3.5 ± 0.1</td>
<td>2.7 ± 0.1</td>
</tr>
<tr>
<td>Strain B</td>
<td>22.5 ± 0.8</td>
<td>9.8 ± 0.4</td>
<td>5.7 ± 0.2</td>
<td>4.3 ± 0.1</td>
<td>3.3 ± 0.1</td>
<td>2.7 ± 0.1</td>
</tr>
<tr>
<td>Strain C</td>
<td>21.0 ± 0.8</td>
<td>9.9 ± 0.3</td>
<td>5.8 ± 0.2</td>
<td>4.1 ± 0.1</td>
<td>3.3 ± 0.1</td>
<td>2.7 ± 0.1</td>
</tr>
<tr>
<td>Female</td>
<td>22.6 ± 0.6</td>
<td>9.9 ± 0.3</td>
<td>5.9 ± 0.2</td>
<td>4.3 ± 0.1</td>
<td>3.4 ± 0.1</td>
<td>2.7 ± 0.1</td>
</tr>
<tr>
<td>Male</td>
<td>22.4 ± 0.7</td>
<td>9.6 ± 0.3</td>
<td>5.8 ± 0.2</td>
<td>4.3 ± 0.1</td>
<td>3.3 ± 0.1</td>
<td>2.6 ± 0.1</td>
</tr>
</tbody>
</table>
Table 8.9: The mean (± SEM) length in cm of CL per 100g liveweight during the production period for the effects of week, diet, strain and sex.

Birds were fed the same diets until week four and then fed diets differing in the protein concentration in weeks five and six. Week (P < 0.001) and strain (P = 0.002) had significant effects. There was a significant diet x sex interaction (P =0.04). Within the row for the effect of week, values with different superscripts are significantly different (P < 0.05).

8.4.11. Proximate analysis of Carcass Composition

The effects of strain, diet and sex on carcass composition of birds sampled at week four and week six are given in table 8.10 and 8.11, respectively. There was a significant effect of strain (P = 0.03) on the carcass water % with strain C (65.3 ± 0.5) having a higher (P < 0.05) % than the strain A (63.9 ± 0.5) but not strain B (64.2 ± 0.5). The strain X week interaction was not significant (p = 0.58). Both sex (P = 0.32) and diet (P = 0.68) had no effect on carcass water %.

Diet (P = 0.02) but no sex (P=0.11) effects on carcass fat %. The diet x sex interaction was marginally not significant (P = 0.06). The carcass fat % for birds fed diet C (15.9 ± 0.4) was higher (P < 0.05) than for those fed diet D (14.4 ± 0.4). This effect is confusing as the analysis suggests that the difference existed at week four where the birds were consuming the same diet. The diet sex
interaction was almost significant and may help explain this seemingly odd finding. Males of all allocations groups had similar carcass fat % but for females allocated to diet C the fat % was significantly higher than females allocated to other groups (P < 0.05).

There were a significant strain effect (P = 0.006) on carcass fat but no strain x week interaction (P = 0.27). Strain C (14.1 ± 0.3) had lower carcass fat 5 (P < 0.05), than strains A (15.4 ± 0.4) and B (15.5 ± 0.4).

There was significant effect of week (see Figure 8.23) on the carcass of water, protein and fat % (all P < 0.0001) but not the ash (P = 0.13). The carcass water % was lower but the protein and fat % were higher in week six compared to week four (all P < 0.05).

<table>
<thead>
<tr>
<th>Week 4</th>
<th>Water %</th>
<th>Protein %</th>
<th>Fat %</th>
<th>Ash %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allocated to Diet A</td>
<td>66.6 ± 0.5</td>
<td>17.1 ± 0.2</td>
<td>13.1 ± 0.5</td>
<td>3.1 ± 0.1</td>
</tr>
<tr>
<td>Allocated to Diet B</td>
<td>66.3 ± 0.3</td>
<td>16.7 ± 0.1</td>
<td>13.8 ± 0.2</td>
<td>31.1 ± 0.1</td>
</tr>
<tr>
<td>Allocated to Diet C</td>
<td>64.8 ± 0.6</td>
<td>17.1 ± 0.1</td>
<td>14.9 ± 0.6</td>
<td>3.2 ±0.1</td>
</tr>
<tr>
<td>Allocated to Diet D</td>
<td>67.1 ± 0.4</td>
<td>16.8 ± 0.4</td>
<td>13.2 ± 0.3</td>
<td>3.0 ± 0.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strain</th>
<th>Water %</th>
<th>Protein %</th>
<th>Fat %</th>
<th>Ash %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain A</td>
<td>65.6 ± 0.6b</td>
<td>16.9 ± 0.2</td>
<td>14.1 ± 0.5a</td>
<td>3.3 ± 0.1</td>
</tr>
<tr>
<td>Strain B</td>
<td>66.2 ± 0.5ab</td>
<td>16.9 ± 0.3</td>
<td>13.9 ± 0.3a</td>
<td>13.1 ±0.1</td>
</tr>
<tr>
<td>Strain C</td>
<td>66.8 ± 0.3a</td>
<td>17.0 ± 0.2</td>
<td>13.2 ± 0.3b</td>
<td>3.1 ± 0.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sex</th>
<th>Water %</th>
<th>Protein %</th>
<th>Fat %</th>
<th>Ash %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>66.3 ± 0.3</td>
<td>16.8 ± 0.2</td>
<td>14.1 ± 0.4</td>
<td>3.0 ± 0.1</td>
</tr>
<tr>
<td>Male</td>
<td>66.1 ± 0.5</td>
<td>17.1 ± 0.2</td>
<td>13.4 ± 0.2</td>
<td>3.2 ± 0.1</td>
</tr>
</tbody>
</table>

Table 8.10. The effects of diet, strain and sex on the composition of the carcass for ducks at four weeks of age.

The birds were allocated to dietary treatment groups at day-old and fed the same starter (weeks one and two) and grower diets (weeks three and four).
Table 8.11: The effects of diet, strain, and sex on the composition of the carcass for ducks at six weeks of age.

The birds were allocated to dietary treatment groups at day-old and fed the same starter (weeks one and two) and grower diets (weeks three and four). In weeks five and six they were fed diets differing in protein content.

Week 6

<table>
<thead>
<tr>
<th></th>
<th>Water %</th>
<th>Protein %</th>
<th>Fat %</th>
<th>Ash %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diet A</td>
<td>62.3 ± 0.5</td>
<td>18.0 ± 0.3</td>
<td>16.5 ± 0.3&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>3.2 ± 0.1</td>
</tr>
<tr>
<td>Diet B</td>
<td>62.9 ± 0.7</td>
<td>17.9 ± 0.3</td>
<td>16.0 ± 0.6&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>3.2 ± 0.1</td>
</tr>
<tr>
<td>Diet C</td>
<td>62.3 ± 0.6</td>
<td>17.6 ± 0.3</td>
<td>16.8 ± 0.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.2 ± 0.1</td>
</tr>
<tr>
<td>Diet D</td>
<td>63.2 ± 0.8</td>
<td>17.8 ± 0.5</td>
<td>15.7 ± 0.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.3 ± 0.1</td>
</tr>
</tbody>
</table>

| Strain A      | 62.1 ± 0.4<sup>b</sup> | 17.9 ± 0.3 | 16.7 ± 0.4<sup>a</sup> | 3.3 ± 0.1 |
| Strain B      | 62.2 ± 0.6<sup>ab</sup> | 17.6 ± 0.2 | 17.1 ± 0.5<sup>b</sup> | 13.1 ± 0.1 |
| Strain C      | 63.8 ± 0.6<sup>c</sup> | 17.9 ± 04  | 15.1 ± 0.4<sup>c</sup> | 3.1 ± 0.1 |

| Female      | 62.1 ± 0.5 | 17.8 ± 0.3 | 16.7 ± 2.1 | 3.3 ± 0.1 |
| Male        | 63.1 ± 0.4 | 17.8 ± 0.2 | 15.9 ± 0.3 | 3.1 ± 0.1 |

Figure 8.23. The effect of week on the carcass water, protein, fat and ash %.

Week had a significant effect on water, protein and fat % (all P < 0.0001) but not the ash (P = 0.13). Columns with a * are significantly different (P < 0.05).
8.4.12 Metabolism study

The apparent metabolisable energy (AME) and the nitrogen corrected apparent metabolisable energy (AMEn) values on an ‘as fed’ basis, determined using the total excreta collection and the insoluble ash marker techniques are given in table 8.12. There was a difference in both AME and AMEn using the two procedures to determine these values. Both AME and AMEn values were higher using the total excreta method. Strain had no effect on the excreta derived AME (P = 0.10), the marker derived AME (P = 0.53) and marker derived AMEn (P = 0.17). However, the strain effect on total excreta derived AMEn was significant (P = 0.04). Strain C had an AMEn higher (P < 0.05) than strain B.

<table>
<thead>
<tr>
<th>Strain</th>
<th>AME Total Excreta Method (MJ/kg)</th>
<th>AME Insoluble Marker Method (MJ/kg)</th>
<th>AMEn Total Excreta Method (MJ/kg)</th>
<th>AMEn Insoluble Marker Method (MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain A</td>
<td>14.36 ± 0.05</td>
<td>13.63 ± 0.14</td>
<td>12.91 ± 0.07&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>12.14 ± 0.14</td>
</tr>
<tr>
<td>Strain B</td>
<td>14.25 ± 0.03</td>
<td>13.59 ± 0.11</td>
<td>12.71 ± 0.04&lt;sup&gt;b&lt;/sup&gt;</td>
<td>11.94 ± 0.10</td>
</tr>
<tr>
<td>Strain C</td>
<td>14.45 ± 0.09</td>
<td>13.78 ± 0.13</td>
<td>12.98 ± 0.10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.28 ± 0.13</td>
</tr>
</tbody>
</table>

Table 8.12. The mean (± SEM) apparent metabolisable energy (AME) and nitrogen corrected apparent metabolisable energy (AMEn) for three strains of ducks fed the grower diet using the total excreta collection and insoluble marker methods.

Within columns, the values with different superscripts are significantly different (P < 0.05).

The % ileal nitrogen (protein) digestibility (see Table 8.13) using the marker procedure was not different for the three strains (P = 0.10). Strain had no effect on the % nitrogen retention (Table 8.13) determined using the total excreta collection method (P = 0.70) or the insoluble ash marker procedure (P = 0.55). There was a significant difference between the two procedures.
Table 8.13. The mean (± SEM) nitrogen retention rates (%) for three strains of ducks fed the grower diets using the total excreta collection and insoluble marker methods and the ileal nitrogen digestibility (%) using the insoluble marker method.

8.5. Discussion

A persistent challenge for the duck-meat industry is to formulate diets that meet duck requirements for optimal growth in a cost-effective manner. The nutritional requirements of broiler chickens gives limited insight into the requirements of ducks, and feeding ducks diets based on the nutritional requirements of chickens may not promote optimal growth. Consequently, lack of understanding on the nutritional requirements of ducks may be contributing to higher FCRs in ducks than broilers. Results from previous chapters have suggested that excessive levels of protein are being fed in weeks five and six in commercial production. This study investigated the protein requirements of ducks in weeks five and six.

The liveweights were significantly different in weeks three and four. Ducks allocated to be fed the 16.1% protein diet in the finisher phase had significantly greater liveweight than ducks allocated to the groups to be fed the 16.8% and 15.4% protein finisher diets. As all ducks were being fed the same diet in these first four weeks, there should have been no diet effects. It was concluded that the difference in liveweight in weeks three and four were actually random effects from allocation at placement. Consequently, mean liveweight for the four treatment groups varied before the four finisher diets were fed. In the study, we randomly allocated ducks at day one as one objective was to investigate the effects of strain over the six week production period. To get a more accurate assessment of the effect of protein content of the diet on liveweight, it would have been better to allocate ducks at week four based on liveweight, just prior to feeding the four finisher diets but this was not possible.

Because of the difference in liveweight at week four, it was more appropriate to compare weekly liveweight gain during the finisher phase. In week five, weekly gain was significantly greater for ducks on the 16.8 and 17.5% protein diets than those fed on the 16.1% and 15.4% protein diets. In week six, this was reversed and the weekly gain was significantly greater for ducks fed the 16.1% and 15.4% diets. While for the low protein diets there is drop in liveweight gain following the feeding of the finisher diets in week five there does appear to be a degree of compensatory growth in week six. This compensatory growth was also observed following the feeding of the low protein diet detailed in chapter seven. When we combined the liveweight gain for weeks five and six there were significant differences. The birds fed the 16.1% protein diet had lower combined gain than birds on the other diets and birds fed 15.4% protein had lower total week five plus six gain than those fed 17.5% protein. In terms of 41 day final weight, the only difference was where birds on the 15.4% diet had a lower liveweight than those on 17.5% protein diet. The data indicate that there is the potential for the
introduction of a three phase feeding program in commercial duck production with the finisher diet having a protein content of 16-17%. Feeding 15.4% protein appears to be too low. There are economic benefits to feeding the minimal protein content that gives optimal growth as feed makes up 65-70% of total production costs in the duck-meat industry and protein is the most expensive component of feed (Cherry and Morris, 2008). By introducing a finisher diet with reduced protein content, total production costs would be reduced making duck-meat production more sustainable.

As there was no significant difference in feed intake between strains, FCR is not a very useful indicator of duck performance. In week five, FCR was lower for ducks on 16.8% protein and 17.5% protein diets. This was a direct consequence of the greater weight gains for these ducks as feed intakes were not different in week five. In week six, weight gain was greater for ducks on 16.1% and 15.4% protein and so FCRs were lowest for ducks on these diets. Previous trials have shown that increasing protein lowered the FCR in a roughly linear manner by about 1.3% for every 1% increase in protein (Cherry and Morris, 2008), but these findings were not substantiated in the present study as there was no difference in the composite FCR. As feed intake didn’t vary between ducks on different diets, FCR was a direct representation of differences in weight gain.

Although there were differences in breast muscle yield between the three strains, the same pattern was observed whereby breast muscle development increased rapidly after week four. This late deposition of breast muscle seen in ducks suggests that protein in the diet may be more important at this stage than earlier on in the production period. Yet the present study found that protein content of the diet in week five and six had no effect on breast muscle yield. There was also no effect of protein content in the diet on carcass crude protein content in weeks five and six. This suggested that feeding as little as 15.4% crude protein in the diet has no effect on breast muscle yield. Besides having no effect on breast muscle yield, protein content of the finisher diet also had no effect on thigh and leg muscle yield as well as carcass crude fat levels.

A major challenge presently facing the duck-meat industry is selecting strains that meet the specific requirements of the Australian market. In the present study a new ‘Producer-selected’ CV strain was compared to the two Pekin strains used in commercial production. Previous studies in ducks have revealed that genotype has a significant effect on growth rates (Maruyama, et al., 1999; Baeza, 2006). Strain B and C out performed strain A, having higher liveweights at days 41. It is know that the GF strain achieves higher final liveweight than the CV but the results indicate that one CV line is performing as well as the GF strain. It appears that through selection programs, producers could improve the growth rate of the CV strain.

Total FCR over the whole six week period was also significantly improved, as indicated by the significant decrease in FCR from 2.06 ± 0.01 for ducks of strain A to 1.99 ± 0.01 for Strain C. Despite the FCR being lower in strain C, they are still substantially higher than FCRs obtained for broilers at six weeks of age which have been reported to be as low as 1.62 (Havenstein, et al., 2003). If the duck-meat industry is to achieve the efficiency seen in broiler industry more investigation into improving FCR will be required.

Not only did strain C have high growth performance it also had improved carcass composition when compared to strain A and B. Of significance is the improvement in breast muscle yield. At market age, the predicted mean for the proportion of breast muscle for ducks of strain C was 12.03 ± 0.03% which was substantially higher than for ducks of strain A (8.71 ± 0.03%) and strain B (9.36 ± 0.03%). Breast muscle yield on a liveweight basis was significantly greater for ducks of strain C than the other two strains from day 20 to day 41. Despite ducks of strain C having greater breast muscle development than ducks of strain B from weeks three to six, the feed intakes were not significantly different. This suggests that ducks of strain C more efficiently convert feed to breast muscle than ducks of strain B. Ducks of strain C yielded a mean of 364 ± 0.9g of breast muscle which was 75.8 ± 0.9g more than ducks of strain B and 119.8 ± 0.8g more than ducks of strain A. In light of these differences, perhaps FCR is not the best indicator of duck performance as it doesn’t account for breast muscle yield.
muscle development. Following on from this argument the predicted feed to breast muscle ratio (FBR), measured as g of feed per g of breast muscle, for strain A was 23.0, strain B was 21.0 and for strain C was 16.3. As similar FBR calculations for the 16.8 %, 16.1 % 15.4% and 17.5% diets were 18.8, 20.9, 20.4 and 19.6. This would give a better economic evaluation of performance for producers as it represents how much feed is converted into breast muscle. However in practice, obtaining this feed to breast muscle ratio would be more difficult than obtaining conventional FCRs as ducks would need to be slaughtered to measure breast muscle yields. Using strains with higher breast muscle yield will be essential when the industry decides to develop the ‘cut up’ market. Extending the production period for ducks similar to strain B, would be needed if this strain was to be used in the further development of the ‘cut-up’ market. This would not be ideal, as conventional FCR increases substantially after week five but especially after week six. Furthermore, studies have shown that over six weeks of age ducks have increased fat deposition (Siregar, et al., 1982a & b). The fact that ducks of strain B less efficiently convert feed into breast muscle than strain C, may explain the greater carcass crude fat levels of strain B. Ducks of strain C had a carcass crude fat of 15.1 ± 0.4% which was significantly lower than the mean carcass crude fat level for ducks of strain B (17.1 ± 0.5%).

Previously, producers selected for relatively high carcass fat levels as this was preferred for the ‘Roast Pekin duck’ restaurant market (Micheal, 2001; Cherry & Morris, 2008). Fat content of the carcass remains a critical issue for the present restaurant market and it influences cooking and eating quality. If the industry intends to expand the ‘cut-up’ market the demand for lean product will probably increase as society becomes increasingly health conscious (Micheal, 2001). Although ducks of strain C had lower carcass crude fat levels than ducks of the other strains, there was no significant difference in abdominal fat levels between the three strains.

As there have been no previous studies which have analysed carcass crude fat content in modern commercial strains of duck at six weeks of age reared under Australian conditions, there is no previous literature with which to compare the present results to. In the first study, the mean crude lipid content of carcasses was 18.27% at five weeks of growth (Chapter 4). This is substantially higher than levels obtained in the present study and may be a consequence of the high protein diet which was fed in study one. Similar proportions of carcass fat found in ducks at six weeks of age in the present study are not evident until at least eight weeks of age in broilers (Hunton, 1995). Maximum growth rate in the Pekin duck occurs between twenty four and twenty eight days of age, and this advanced maturity compared to broiler chickens may explain the greater fat reserves found in ducks at market age (Hunton, 1995). High carcass fat deposition has been thought to be a contributing factor to the poor FCR seen in ducks compared to broiler chickens (Siregar, et al., 1982b). Our research supports this theory as lower carcass fat levels were observed for strain C compared to strain A and this was associated with differences in FCR.

There was no significant difference in leg muscle or thigh muscle yield on a bodyweight basis between the three strains. Although breast muscle is the predominant component taken from the carcass of the duck at market age, thigh and leg muscle are still important production characteristics. In Western countries, where emphasis is starting to be placed on further processing for the sale of duck portions such as the breast, thigh and drumstick (Fuller, 2004). There is potential for consumer preferences to change in the next few years and increasing the proportion of the leg and thigh muscle may be a challenge that duck producers are faced with in the future. Selection in ducks will be driven by changing consumer preferences and the industry must continually evolve in order to meet these needs.

The present study found a relationship between poorer performing animals and longer intestinal lengths to liveweight proportions which concurred with earlier observations. For both the length of the DL and combined caeca, ducks of strain A had the longest, followed by ducks of strain B strain and then ducks strain C. This might suggest that ducks with shorter gut lengths as a proportion of liveweight may be more efficient in assimilating nutrients from the ingested food. However, as has been emphasised earlier it could just be a measure on differences in liveweights.
Strain had no effect on the excreta derived AME the marker derived AME and marker derived AMEn. However, the strain effect on excreta derived AMEn just reached significance ($P = 0.04$). Strain C had an AMEn higher than strain B with strain A being intermediate. Both AME and AMEn values were higher using the total excreta method.

The % ileal nitrogen (protein) digestibility using the marker procedure was not different for the three strains. Strain had no effect on the % nitrogen retention using either using total excreta collection method or the insoluble ash marker procedure. However, as described in study three (chapter six) there were large differences in the calculated nitrogen retention rates using the two procedures. Again it was much higher using the total collection method. The values calculated using this method are similar to the ileal nitrogen digestibility values and as mentioned in chapter six this can’t be correct. This difference was not noted in the winter trial described in chapter seven.
9. Overall Results – Some Integration

The duck industry is relative new and research specific to Australian conditions is scarce. Even in countries where the industry has been established for sometime the volume of research available is nominal in comparison to the broiler chicken (Baeza et al., 2000). Of the available overseas research much is of limited relevance to Australian conditions because of the differences in climatic conditions and especially the type of housing being used. For the Australian industry there is an urgent need for relevant information on growth rates, feeding efficiencies, diet composition, welfare and factors limiting processing efficiency.

Considering there are differences in growth rates, carcass composition, digestive anatomy and rate of passage of feed through the gut between ducks and broilers, it should be expected that the nutritional requirements of the two species would differ (Siregar and Farrell 1980). While there is documented evidence from overseas on the nutritional requirements of ducks (Oluyemi and Fetuga, 1978; NRC, 1994; Xu et al., 2002; Adeloda 2006); the information is often contradictory and scarce for Australian conditions. The question remains as to how relevant overseas observations are to Australian conditions especially nutrient requirements.

Chapters Four and Five (Studies one and two)

Presently, the Australian duck industry relies on genotypes developed overseas (UK and France) for the strains used in commercial production. The Australian market has very specific requirements to meet the needs of the Asian restaurant trade. This is for a 2.85 kg bird at a slaughter age of six weeks. The CV and GF have very different growth characteristics. The GF has a faster growth rate and reaches greater liveweight at six weeks. The CV has strong consumer acceptance for its cooking quality, especially the attributes of the skin. The industry has to work hard to manage these two strains to produce a bird meeting high consumer acceptance. An essential part of this project was to evaluate the present strains and the crosses of these strains under Australian summer and winter conditions. This was promoted by the consideration that the crosses might better meet the needs of producers, to supply a 2.85 kg bird with higher breast yield at six weeks, than is being achieved using the parent strains.

The duck industry practices mixed sex rearing. Males and female have different growth characteristics. The males have greater growth rate while females mature earlier with greater breast weight to liveweight % and have more abdominal fat. The difference in slaughter weight between males and females creates problems at processing, as the greater the variation in liveweight, the more difficulties encountered on the production line. With these issues in mind, an objective of the current project was to evaluate the performance of the two sexes reared in separate pens or in mixed sex pens.

Studies one and two were designed to evaluate the performance of the GF and CV strains and the reciprocal crosses of these two parent strains. Birds from the four strains were reared as single sex groups or as mixed sex groups. Also the growth characteristics and carcass composition was determined during the production period. The same experimental protocol was used for both studies with the first being under summer conditions and the second under winter conditions.

For reasons of ‘commercial in confidence’ the parent strains have been identified as A and B and the crosses as A X B and B x A. In both summer and winter, at day 41, strain B had the greatest liveweight followed then by strain A x B. In summer strains A and B X A has similar weight but in winter strain B X A was heavier than strain A. There was no evidence of hybrid vigour from the two crosses as the liveweight of these fell within the range of the parent strains. In general, the crosses had higher slaughter liveweight than strain A and if they have equivalent cooking attributes as strain A they could provide an growth rate advantage to the industry. Following these observations it was decided to further evaluate these crosses in study three.

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In summer, only strain B reached market weight at 41 days although strain A X B was close. In winter, all strains reached market weight by 41 days. The slower growth rate of all strains in summer is an issue for the duck industry. In summer ducks of strain A need to be grown out to 45-46 days if they are to achieve market weight. This is a major cost to duck producers because of the extra feed used but also the poorer FCR experienced as the birds’ age. The poorer growth of ducks during periods of high temperature and what might be done to alleviate this is identified as an important research area as presently there is no relevant information.

As expected, males were heavier than females. However, of interest was the observation that the differential, approximately 200 g, was similar irrespective of season. So while mixed sex rearing and processing at a single age results in greater variation in processing weight, the sex variation is similar in winter and summer. Rearing ducks in mixed sex pens is routine in the duck industry. The results from studies one and two show that both sexes achieve the same liveweight whether reared in single sex groups or as mixed sex groups.

Weekly liveweight gain increases from week one to week there and is at a maximum in weeks three and four and then tends to decrease in weeks five and six. In weeks five and six, the decrease in liveweight gain was slightly different in winter and summer. It decreased more rapidly in week five in summer than winter. The more rapid decrease in week five in summer could be related to shed temperature having an effect on feed intake at a time when birds have sufficient body size to produce high metabolic heat load.

The weekly FCR decreased with age, with the decreased efficiency rising rapidly after week four. The only strain effects on FCR were identified in summer where strain B X A had a better FCR than strains B and B x A and strain A was more efficient than strain A X B. In winter, there were no strain effects on FCR. This might suggest that the smaller liveweight strains are capable of handling the summer conditions more efficiently than the heavier strains. In summer the FCR (1.90-2.00) was better than in winter (2.06-2.10). While this might on the surface, suggests increased economic gain, the reality is that under summer conditions strains A and B x A would need be to grown out to greater ages to reach market weight. From week six on, FCR increases rapidly so marketing at older ages is inefficient. The higher FCR in winter is probably related to the birds of all strains being heavier at an equivalent age and so having increased basal metabolic requirements and increased energy needs to maintain body temperature. The FCR achieved under the experimental conditions here are superior to the 2.2-2.3 being achieved in commercial sheds. The duck industry like any other enterprise is challenged to become more efficient in an effort to remain sustainable. For the industry to improve FCR it will need to follow the strategy taken by the broiler industry to rear birds in environmentally controlled tunnel ventilated sheds. This would require a large investment of capital on the behalf of producers and is probably not an option presently. The present system of measuring efficiency as the ratio of feed (kg) needed to produce one kg of liveweight has failings. Larger birds have higher maintenance energy requirements and so higher feed intakes. Breast meat has high economic value and so it is probably more appropriate to determine efficiency of production as the feed required to produce a unit of saleable breast meat. While this might be a better measure it is more difficult to determine as breast muscle weight needs to be determined. An alternative could be to determine breast meat depth at the breast bone on the live animal. Breast muscle depth has been used as means of selection for increased breast muscle weight.

Previous studies in ducks have reported water to feed ratios of up to 4.2:1 (Scott and Dean, 1991, Siregar and Farrell, 1980). In summer, the total composite water to feed ratio was around 3.3:1 and in winter 2.7. These values remain higher than for broilers but not as high as others have identified for ducks. This higher water to feed ratio for ducks, highlights the necessity to maintain adequate access to water at all times. Maintaining litter quality in duck sheds is difficult and producers are tempted to limit water intake to help prevent wet litter. This is poor practice as limiting water intake will decrease feed digestion and so increase FCR.
The stringent market specification for a duck of 2.85 kg creates a further problem for the Australian industry and this has to do with the poor breast muscle yield during the early weeks of development. The proportion of breast muscle is low at an early age and reached its peak at a later age than did the development of the leg and thigh muscle. While the proportion of breast muscle increased significantly each week, the most rapid rate of increase occurred from day 27 to day 41. In summer the predicted mean for the proportion of breast muscle at market age ranged from 8.52 to 9.44 % with females having a higher % (9.64) than males (8.50). In winter the proportion of breast muscle at market age ranged from 8.24 to 9.37 % with females (8.92) having a higher % than males (8.67). The low yield of breast muscle at market age indicates the bird is still maturing when it reaches market weight with processing occurring prior to maximum rate of breast muscle deposition. Although the proportion of breast muscle could be increased substantially by processing at a later age, the whole duck restaurant market has strict regulations concerning carcass size and rearing to an older age also increases FCR. Ideally the industry needs to identify and use a strain that has earlier breast muscle development especially if development of a ‘cut-up’ becomes an industry goal. In the summer study, no strain effects on breast to LW % were observed. In winter, there were some strain effects with strain B having a higher breast % than other strains. The average difference at week six between strain B and strain A X B, with the lowest breast %, was 1.13%. This is a relatively large difference and would be a significant negative towards using the A X B cross commercially. The lack of difference in summer makes such a decision questionable and so further evaluation of this crosses was needed.

Carcass composition is economically important. The ideal is for highest protein content and a fat content which meets consumer preferences for cooking and eating quality but is not excessive. There were no significant strain effects on carcass composition. Therefore, the crosses provided no advantage or disadvantage in terms of carcass composition. The carcass analysis failed to identify any significant differences in the proportion of carcass components between males and females at week five. However, since most studies recognise five weeks of age as the beginning of sexual dimorphism (Bochno et al., 2005; Farhat & Chavez, 2000) these findings should not be considered unusual. Rearing ducks as single sexes or as mixed sexes had no influence on carcass composition. Rearing ducks in the different pen-sex groups had no effect on the relative abdominal fat deposition. Larger ducks had more total abdominal fat. While the analysis suggests that there is no effect of sex on the relative abdominal fat weight there is an indication that a difference is starting to emerge in week six. Females mature earlier than males and this pattern in fat deposition would be indicative of this difference.

In both summer and winter the experimentally determined AME values were 0.2-0.5 MJ/kg higher than the diet formulated value of 12.77 MJ/kg. This was a difference of approximately 1.5 to 4%. So the formulated values were relatively accurate. While the formulated dietary energy values were accurate, potential problems with the protein content were identified. In summer, the apparent ileal nitrogen digestibility ranged from 71.3 to 76.2 % for the different strains and 72.6 to 74.1 % for the different pen-sex groups. The nitrogen retention rate ranged from 50.0 to 51.2 % for the different pen-sex groups and ranged from 46.8 to 52.9 % for the effect of strain. In winter, the apparent ileal nitrogen digestibility ranged 68.7 to 73.4 % for the different strains and 71.1to 73.0 % for the different pen-sex groups. The nitrogen retention rate ranged from 49.9 to 57.6 % for the different strains and ranged from 52.1 to 55.0 % for the pen-sex groups. The differences in ileal nitrogen digestibility and nitrogen retention suggested that the protein content of the diet is high and that protein in is catabolised and probably wasted.

A theory of high protein catabolism rates is consistent with the large differences in ileal nitrogen digestibility and nitrogen retention between the strains in these studies. As a consequence of increased protein catabolism more non-protein nitrogen is released from the body, which is reflected by the lower nitrogen retention rate. These findings are of particular interest to the duck industry. Protein is an expensive feed ingredient and although it is a necessary component for its role in tissue development, much cheaper and efficient sources of energy are available. Furthermore, high rates of nitrogen excretion have negative effects in terms of creating an increase in nitrogenous waste. High ammonia levels in the shed can reduce animal production rates through its adverse affects on health.
The low nitrogen retention rates suggest that the grower diet has too high a protein content. This excessive protein content is a large economic cost to the industry and warranted further investigation.

Chapter Six (Study Three)

The low nitrogen retention rates observed from the metabolism studies of experiments one and two suggested that the protein content of the commercial diets fed to ducks was too high. From these results, it was proposed that the protein content of the starter and grower diets could be reduced. Presently, commercial duck diets rely heavily on wheat as the main source of dietary energy. With competition for wheat grain being high, intensive animal industries will be required to use alternative grain sources. An alternative being evaluated in the broiler industry is sorghum. There was a need to evaluate the suitability of sorghum as an alternative for duck diets. The objective of study three was to investigate the performance of commercial CV, GF and their crosses when fed diets with lower protein concentrations than is presently being used and whether some of the wheat grain in the diet can be replaced with sorghum, without compromising performance.

As reported in studies one and two, again strain B was persistently heavier than other strains. The crosses had 41 day liveweight that laid within the range of the parent strains with strain A x B being superior to B X A. The differences in liveweight during the production period were also observed in weekly gain, with the heavier strains having the greatest weekly liveweight gain. The differences in liveweight were also mirrored by the differences in feed intake with the heavier strains having the highest consumption. The pattern of differences in liveweight and feed intake resulted in the composite FCR for the production period being similar for all strains (2.10 to 2.16). The differences in water intake were similar to the feed intake with it being higher for strains B and A X B than for strains A and B X A. The differences in feed and water intake resulted in there being no difference in the water to feed ratio (2.8-2.9) when the strains are compared. At the conclusion of study three, it was decided that the A X B cross was not going to provide the industry with any advantage and further evaluation was not warranted.

From week one, feeding a starter diet with a lower protein content resulted in significantly lower liveweight. This persisted until processing and at 41 days the ducks on the lower protein diet were around 70-80 g lighter than ducks fed the control and high sorghum diets. There was, approximately, a 2.5% reduction in final liveweight. The difference in liveweight was much greater in week two (approximately 6%) and week four (approximately 5%). It appeared that there was some degree of compensatory growth for the ducks on the low protein grower diets with the effect of the low protein diet being more severe in early life. This observation was supported by the pattern of weekly liveweight gain. At weeks one to four, ducks on the low protein diet had significantly lower weekly liveweight gain. However, in week five there were no differences in gain and then in week six, the gain for ducks on the low protein diet was significantly greater than for ducks on the control or high sorghum diets. The larger difference in liveweight during the earlier part of the production period (weeks one to three) for ducks on the low protein diet was associated with lower feed intake. After week three the feed intakes were similar for all diets. For the entire production period, total feed consumption of ducks was similar for all diets. The poorer growth earlier and similar total feed intakes resulted in a significantly higher FCR for ducks fed the low protein diets. The differences in feed and water intakes resulted in the water to feed ratio being less when ducks were fed the low protein diet (2.65 Vs 2.9). It is obvious that a high protein diet is needed in the starter period but a lower protein diet could be fed in weeks five and six. These observations raised the possibility of introducing a three phase feeding program for commercial ducks consisting of a starter (days 1-14), grower (days 15-28) and finisher (days 29-41) diets, all having different protein contents. During weeks five and six, approximately half of the total feed intake is consumed. So feeding a lower protein diet during this period would result in a large economic advantage to the duck industry. The use of a lower protein finisher diet was investigated in studies four and five.
Wheat makes up 50% of the raw material of commercial duck-meat diets in Australia with sorghum accounting for the rest of the grain component. At the time of the study three, wheat price was excessively high and this had generated interest in replacing wheat with sorghum in duck diets. While sorghum is a good source of crude protein, the protein may not be completely available to the animal (Okoh et al., 1989; Selle et al., 2010). The low digestibility of sorghum protein is believed to be due to anti-nutritional factors which limits its potential as a feed ingredient for poultry (Jacob et al., 1997, Selle et al., 2010). There are no studies comparing Australian grown sorghum and wheat as a grain source in duck diets. In study three, part of the wheat component of the diet was replaced with sorghum. This alteration in the grain component did not affect duck performance as ducks on the higher sorghum diets performed just as well as those fed the commercial control diets. The calculated AME and AMEn values were similar for both diets. Replacing wheat with sorghum had no effect on energy metabolism. There was a decrease in ileal nitrogen digestion when the sorghum content was increased and a tendency for the nitrogen retention to be slightly lower but these differences had no effect on performance. From these results, it appears that ducks can cope with increased sorghum grain within the diet, and still perform at a consistent level.

The eating patterns of ducks are very different to broilers. Mash diets are unsuited to feeding ducks and so pellet quality is very important and influences growth rate and FCR. Diets having high sorghum contents are considered more difficult to process and form a stable pellet because of the lower binding capacity of sorghum compared to wheat. While this has been an issue in broiler diets, developments in processing have alleviated some of the earlier pelleting issues associated with high sorghum diets. The duck industry should consider trialling higher sorghum diets under commercial conditions as in the long term it may be forced to use alternative grains to wheat.

After evaluation of the performance and carcass characteristics of the A x B cross from the first three studies it was decided that this strain would not suit the industry needs and so no further evaluation was warranted.

**Chapter Seven (Study four)**

The results from study three suggested that the protein content of the diet fed in weeks five and six could be reduced and warranted the introduction of finisher diet to the feeding program of commercial ducks. It is now common practice to replace some of the ground wheat in broiler diets with whole wheat as an effort to improve gut function and feed utilisation. This is a practice which could be employed with preparation of duck diets, reducing milling costs and having the potential to improve feed utilization. The earlier studies detailed in this report have used diets with the energy content set at 12.2 to 12.5MJ/kg ME which is level used in commercial starter and grower diets. The effect of using a higher dietary energy content on growth and carcass yield is of significant interest to the industry. The objectives of study four were to evaluate the performance of commercial Peking ducks fed diets differing in protein, energy and form of the wheat fed. The effect of using a higher dietary energy content on growth and carcass yield is of significant interest to the industry. The objectives of study four were to evaluate the performance of commercial Peking ducks fed diets differing in protein, energy and form of the wheat fed. Pekin ducks were fed the standard starter and finisher diets and their performance compared to ducks fed a low protein diet during weeks five and six (finisher phase), a high energy diet fed in the starter and grower phases and a diet where part of the ground wheat component of the diet was fed as whole wheat.

The strains used were Grimaud Freres and Cherry Valley and the reciprocal cross between the Grimaud Freir (male) and Cherry Valley (female), all reared as mixed sexes. For reasons of commercial in confidence the crosses have been designated as Strain A, Strain B, and C. The control diet fed was the commercial starter (d 1-14) and grower (d15-41). A second treatment group was fed the commercial starter (d 1-14) and grower (d15-28) and then lower protein diet (d29-41). A third group was fed a high energy starter (d1-14) and the high energy grower diet (d15-41). A final treatment group was fed a starter diet (d1-14) with 29.0% ground wheat and 15% whole wheat and grower diet with 28.5% ground wheat and 15% whole wheat.
Strain B had superior day 41 processing weight and this is the same strain as performed best in the earlier studies. All strains achieved at least market weight (2.85 kg) at 41 days and this was the same as the previous winter study were the same strains were used (chapter 5). The average difference between males and females was 204 g and this was similar to the difference observed in the previous studies. A very relevant finding was that on day 41 there was no differences in processing weight between different dietary treatments. Feeding the low protein diet on days 29-41 produced similar results to feeding the higher protein control diet. The total liveweight gain in weeks five and six were similar for all diets. Over the 41 days there was no effect of diet on total FCR. The FCR ranged from 2.06-2.08 and this was similar to the values achieved in the earlier winter study (Chapter 5). Diet had no effect on the breast to liveweight % with it being around 9.5%.

Females fed the high energy diet were heavier than those fed the low protein diet but not those on the control diet. Males on the high energy diet were never heavier than the control birds. Feeding the high energy diet had no effect on 41 day liveweight. There was a tendency for birds fed the high energy diet to have a lower feed intake in week six but they had a higher FCR in week six than the birds on the control diet. The results suggest that there is no performance advantage to feeding more than 12.5 MJ/kg ME to any of the three strains used in this study.

There were no effects of diet on the digestive organ (liver, proventriculus and gizzard) weight to liveweight %. This was a little surprising as one reported consequence of feeding whole grain is enhancement of gizzard development. The starter and grower pellet size of duck feed is greater than used to feed broilers and so it’s possible the larger pellets are sufficient to promote gizzard function. There were minimal differences in the relative length of the small intestinal segments. There were no diet and sex effects on the relative length of the duodenum, jejunum and ileum.

There were no significant effects of strain, sex or diet on proximate carcass composition. As seen in the earlier studies carcass water content in higher in younger ducks and carcass fat % increases with age.

As seen in study three, the values determined for AME and AMEn are slightly higher when using the AIA method than the total collection method. There were no diet or strain effects on AME or AMEn, ileal using the AIA procedure. Using the total collection method, strain had no effect on AME but the high energy diet had a higher value than the whole wheat diet. When adjusted for zero nitrogen retention the AMEn for the high energy was higher than for the control and whole wheat diets. There were no diet or strain effects on ileal nitrogen digestibility. There were no diet or strain effects on nitrogen retention using the either procedure. Unlike the large differences in nitrogen retention seen for the two procedures in study three, the difference in the present study was only 2-3%. In the present study the ileal nitrogen digestibility was similar to values reported in study three (chapter six).

However, there are large differences in nitrogen retention between the two studies using the total excreta method. In the present study the average faecal nitrogen for the total collection and oven drying procedure was 4.56 ± 0.10 % and for the freeze dried samples collected for the AIA method was 4.84 ± 0.06 %. This compares with values of 3.62 ± 0.07 % and 4.62 ± 0.09 % for the total collection and AIA procedures reported in chapter six. So for the two studies, the values for the AIA (freeze drying) are similar but there is big discrepancy for the total collection (oven drying) method. This places serious reservations on using the oven dried samples used in the total collection method for determination of faecal nitrogen. Really for the total collection method a faecal sample should be freeze dried and used for determination of nitrogen.

One reason for feeding whole grain in broiler diets is to improve gut development and function. Using 15% whole wheat in the starter and finisher diets had no effect on performance or carcass characteristics. There was no evidence on increased digestive organ weight or relative lengths of the small intestine segments. If whole grain inclusion is to provide a physiological advantage, it seems the level would need to be more than 15%. Higher percentages of whole grain are likely to caused issues of pellet quality which is crucial in duck performance.
Chapter eight (Study Five)

Currently, commercial producers feed a starter diet in the first two weeks and a grower diet from week three to week six of production. The findings from study three suggested that perhaps the introduction of a finisher diet in the final weeks of production would be appropriate and formed the basis of one treatment in study four. Ducks fed the lower protein finisher diet performed as well as those on the higher protein control diet. If a finisher diet was integrated into the feeding program, the question remained as to what the protein concentration for this diet should be to achieve optimal performance. The possibility that protein can be reduced in the diet during weeks five and six of production means that the total feed costs to the industry could be reduced and this would help industry to achieve its main objective, which is cost-effective production of edible meat. One of the major challenges for the Australian industry is selecting a strain that meets consumer preferences but still has efficient growth. To meet consumer demands, the highest yield of high-value breast meat is an a requirement for efficient duck-meat production (Micheal, 2001). The CV strain meets consumer acceptance for eating quality, yet in order to reach the preferred 2.85kg liveweight within the standard six week production period, a faster growth rate is required especially during summer when heat stress influences growth. The industry partners in this project. PEPE’S ducks Pty Ltd., had available one line of GF and two lines of CV ducks in production. One CV line has been selected with the aim of increasing growth rate and breast muscle yield at six weeks of age.

The main objective of study five was to investigate the amount by which the protein content of the finisher diet can be reduced without impacting on growth and performance and to determine the performance and carcass composition of three different strains of duck during the summer and to determine whether the new CV line can better meet consumer needs.

In study five there were 12 different treatments, consisting of three strains and four diets. The strains were one line of Grimaud Freres and two lines of Cherry Valley with all lines reared as mixed sexes. For reasons of ‘commercial in confidence’ the strains have been designated as Strain A, Strain B, and C. A starter crumble was fed to all ducks from day 1 to day 14 and had a protein content of 21.5% and energy density of 12.6 MJ/kg ME. The grower diet was fed as a pellet to all ducks from day 15 to day 28 and had a protein content of 17.5% and energy density of 12.5 MJ/kg ME. Pelleted finisher diets were fed over days 29-41 and had 17.5, 16.8, 16.1 or 15.4% protein with 12.5MJ/kg ME. The finisher diet with 17.5% protein was considered to be the control as it contained the same specifications as the grower diet.

As allocation effects confounded the effect of protein content of the finisher diet on liveweight, it was more appropriate to compare weekly liveweight gain. In week five, weekly gain was significantly greater for ducks on the 16.8 and 17.5% protein diets than those fed on the 16.1% and 15.4% protein diets. In week six, this was reversed and the weekly gain was significantly greater for ducks fed the 16.1% and 15.4% diets. While for the low protein diets there is drop in liveweight gain following the feeding of the finisher diets in week five, there does appear to be a degree of compensatory growth in week six. This compensatory growth was also observed following the feeding of the low protein diet detailed in chapter seven. When the liveweight gain for weeks five and six are combined, there were significant differences. The birds fed the 16.1% protein diet had lower combined gain than birds on the other diets and birds fed 15.4% protein had lower total gain than those fed 17.5% protein. In terms of 41 day final weight, the only difference was where birds on the 15.4% diet had a lower weight than those on 17.5% protein diet. The data indicate that there is the potential for the introduction of a three phase feeding program in commercial duck production with the finisher diet having a protein content of 16-17%. Feeding 15.4% protein appears to be too low. There are economic benefits to feeding the minimal protein content that give optimal growth as feed makes up 65-70% of total production costs in the duck-meat industry and protein is the most expensive component of feed (Cherry and Morris, 2008). By introducing a finisher diet with reduced protein content, total production costs would be reduced making duck-meat production more sustainable. As feed intake didn’t vary between ducks on different diets, FCR was a direct representation of differences in weight gain.
Although there were differences in breast muscle yield between the three strains, the same pattern was observed as in the previous studies, whereby breast muscle development increased rapidly after week four. This late deposition of breast muscle seen in ducks suggests that protein in the diet may be more important at this stage, than earlier on in the production period. Yet the present study found that protein content of the diet in weeks five and six had no effect on breast muscle yield. There was also no effect of protein content in the diet on carcass crude protein content at week six. This suggested that feeding as little as 15.4% crude protein in the diet has no effect on breast muscle yield.

Strain B and C out performed strain A, having higher liveweights at days 41. It is know that the GF strain achieves higher final liveweight than the CV strain but the results indicate that one CV line is performing as well as the GF strain. It appears that through selection programs, producers could improve the growth rate of the CV strain. Total FCR over the whole six week period was also significantly improved, as indicated by the significant decrease in FCR from 2.06 ± 0.01 for ducks of strain A to 1.99 ± 0.01 for those of strain C.

Not only did strain C have high performance it also had improved carcass composition when compared to strain A and B. Of significance is the improvement in breast muscle yield. Breast muscle yield on a liveweight basis was significantly greater for ducks of strain C than the other two strains from day 20 to day 41. At market age, the predicted mean for the proportion of breast muscle for ducks of strain C was 12.03 ± 0.03% which was substantially higher than for ducks of strain A (8.71 ± 0.03%) and strain B (9.36 ± 0.03%). Despite ducks of strain C having greater breast muscle development than ducks of strain B from weeks three to six, the feed intakes were not significantly different. This suggests that ducks of strain C more efficiently convert feed to breast muscle than ducks of strain B. Ducks of strain C yielded a mean of 364 ± 0.9 g of breast muscle which was 75.8 ± 0.9 g more than ducks of strain B and 119.8 ± 0.8 g more than ducks of strain A. In light of these differences, perhaps FCR is not the best indicator of duck performance as it doesn’t account for breast muscle development. Following on from this argument, the predicted feed to breast muscle ratio (FBR) measured as g of feed per g of breast muscle, for strain A was 23.0 strain B was 21.0 and for strain C was 16.3. As similar FBR calculations for the 16.8 %, 16.1 % 15.4% and 17.5% diets were 18.8, 20.9, 20.4 and 19.6. This would give a better economic evaluation of performance for producers as it represents how much feed is converted into breast muscle. However, in practice, obtaining this feed to breast muscle ratio would be more difficult than obtaining conventional FCRs as ducks would need to be slaughtered to measure breast muscle yields. Using strains with higher breast muscle yield will be essential when the industry decided to develop the cut up market. Extending the production period for ducks similar to strain B would be needed if this strain was to be used for the ‘cut-up’ market. This would not be ideal as conventional FCR increases substantially after week five but especially after week six. Furthermore, studies have shown that over six weeks of age ducks have increased fat deposition (Siregar, et al., 1982 a & b). The fact that ducks of strain B are less efficient at converting feed into breast muscle than strain C, may explain their greater carcass crude fat levels. Ducks of strain C had a carcass crude fat of 15.1 ± 0.4% which was significantly lower than the mean carcass crude fat level for ducks of strain B (17.1 ± 0.5%). Fat content of the carcass remains a critical issue for the present restaurant market and it influences cooking and eating quality. If the industry intends to expand the ‘cut-up’ market the demand for lean product will probably increase as society becomes increasingly health conscious (Micheal, 2001). Although ducks of strain C had lower carcass crude fat levels than ducks of the other strains, there was no significant difference in abdominal fat levels between the three strains. The performance of strain C provides hope for the industry in its efforts to find a strain of Pekin duck that better meets the market needs.
10. Implications

The strains of Pekin ducks, the Cherry Valley and Grimuard Freres, being used in the Australian duck industry are not ideal as they fail to meet some of the specific requirements of the local industry. Each strain has some individual characteristics which are desired. It was a feasible proposition that crossing these two strains might produce a line which better met the market needs. However, after using the parent strains and reciprocal crosses in extensive studies using different diets and in different seasons, the crosses did not meet the industries needs. While not tested for, there seems to be little evidence that the crosses display heterosis for growth rate. There continues a strong need for the industry to source a strain of duck that meets its needs more fully. The high feed prices experienced in 2007-2008 has prompted overseas breeding companies to select birds for earlier market age (six weeks) and greater muscle yield. Strains developed with these criteria could be better suited to Australian needs and this does provide promise for the future. In study five (chapter eight), selection within the current CV strain produced a line that had better growth performance and much improved breast yield than the strain from which it was selected. This provides strong evidence that there is sufficient variation with current strains for selection to improve economically important traits.

The metabolism studies undertaken in experiments one and two indicated low nitrogen retention rates for ducks fed diets with commercial specifications. One explanation for this was that the commercial grower diet contained too much protein and that the excess protein was possibly being used to provide energy. Protein is an expensive feed ingredient and cheaper sources of energy are available to meet the birds’ needs. Furthermore, high rates of nitrogen excretion have negative affects in terms of creating an increase in nitrogenous waste. High ammonia levels in the shed can reduce animal production rates through its adverse affects on health and has negative effects on the environment. Decreasing the protein content of the commercial starter diet is not possible as it has an immediate impact of growth rate. However, decreasing the protein content of the grower diet is feasible and an economic necessity. Following the studies detailed in this report it is possible to introduce a three phase feeding program with the introduction of finisher diet on days 29-42. A starter fed days 1-14 would contain the present protein content, a grower fed days 15-28, and contain a protein content lower than the present 19%, say 17.5%, and a finisher diet fed days 29-42 and contain 16-17% protein.

Studies one and two provided strong evidence as to the significant effect season has on duck performance. Growth rate is lower in summer than winter. This is a significant economic cost to the industry. While conventional measures of FCR are lower in summer, the economic reality is that ducks of strain A, need to be kept on farm until 45-46 days of age to reach market weight. The FCR increases rapidly after week five so keeping ducks beyond the ideal 42 days processing age becomes expensive. The depressed growth rate of ducks in summer is an issue the industry needs to address and requires further research effort.

Using the tunnel ventilated shed available for the current studies provide an environment where conventional FCR was 1.9 to 2.16 depending on strain and season. Most commercial contract growers are using conventional broilers sheds with limited control over the shed environment. Commercial growers are achieving FCR of 2.2 to 2.3. While it’s not going to happen in the near future, eventually the duck industry will need to follow the move to tunnel ventilated sheds seen in the broiler industry. The savings in feed efficiency are too large to ignore for much longer. A 0.1 improvement in FCR would save 2400 tonnes of feed yearly, equivalent to $1.2 million. So an improvement from 2.3 to 1.9 would be saving of close to $5 million.

In this report, argument is made that the conventional measure of FCR (g feed/g liveweight) might not be the best measure of efficiency. Birds’ reaching a higher liveweight at a fixed age will have higher maintenance metabolic requirements and this decreases their efficiency. Calculations of efficiency based on feed needed to produce sale product, such as breast meat, would be a better measure of
efficiency although more difficult to determine. As part of future studies our intention is to incorporate this measure of efficiency as fundamental to measuring performance.

Different dietary modifications were made to determine their effect on performance. Feeding a higher energy specification in the starter and grower phase was found to have no effect on performance. Feeding the higher energy grower diet in week three resulted in a higher determined AME using the total excreta collection procedure but not the AIA procedure. The higher energy diet had no effect on nitrogen digestibility or retention. There was a non-significant decrease in feed intake in week six for ducks on the high energy diet. This could suggested that if ducks are grown out to an older age, better FCR might be possible using a higher energy diet but this would need to be tested. The high energy diet had no effect on nitrogen digestibility or retention. There was a non-significant decrease in feed intake in week six for ducks on the high energy diet. This could suggested that if ducks are grown out to an older age, better FCR might be possible using a higher energy diet but this would need to be tested. The high energy diet had no effect on carcass fat or abdominal fat values. Replacing part of the ground wheat component of the diets had no effect on performance. Studies in broilers suggest that feeding whole wheat improves gizzard size and gut function. This was not seen in the present project.

Industry practice is to rear ducks in mixed sex groups. Sexual dimorphism does not really occur until after week five and so sex differences are considered to be minimal up till this time. Rearing ducks in mixed sexes had minimal effects on the performance or carcass qualities of either males or females compared to rearing then separately. Males were heavier than females in all studies. It was evident from carcass characteristics that females matured earlier than males. They had higher relative abdominal fat % in most studies. As ducks mature, muscle deposition rate decreases and the abdominal fat accumulation increases. The variation in weight between males and females at processing age creates problems on the processing line. Rearing ducks as single sex groups would overcome this problem. It would also allow for single sex feeding ensuring better diet formulation to better meet the needs of the different sexes. While these would be beneficial, the lack of any performance or carcass advantages to either sex with singles sex rearing probably negates the potential advantages. After including the cost of sexing, single sex rearing is probably not an industry priority at this point.
11. Recommendations

The duck industry is constrained because it relies on overseas genotypes (GF and CV) developed for markets which don’t have the same requirements as those in Australia. The industry works hard at managing these strains to meet the Australian market needs. Crossing the existing strains failed to produce a line that better meets the market needs of the industry. There will be a continued need for the industry to identify a strain which meets its specific market requirements. This might be done by selection from within the current strains or identify new genetics from overseas. There is sufficient variation in the existing strains for selection to improve growth rate and especially breast yield. Whether such selected lines perform in commercial practice would need to be determined.

Rearing ducks as separated sexes provided no benefits in terms of performance or carcass quality. There could be advantages at the processing end and being able to provide sex-specific diets, but these benefits would need to be evaluated against the cost of vent sexing and maintaining different flocks of males and females.

Growth rate of ducks is lower in summer. With the type of housing presently being used this will continue to be an industry problem. There is a need to identify nutritional or physiological strategies which help to limit the growth retardation occurring in summer. Having to grow birds for an extra 4-6 days in summer just to reach market weight is costing the industry substantially in added feed costs. Further research support is needed for the industry to find solutions to heat stress in ducks.

Limiting water intake of ducks will decrease feed efficiency and so it is important for producers to maintain adequate water intake. There is a tendency for producers to limit water intake in an effort to maintain litter quality. This is false economy and producers should have meters on the water lines to measure water use and ensure supply is adequate.

The industry currently uses a two phase feeding program. The research detailed in this report indicates that a three phase feeding program might be more suited to the nutritional requirements of commercial Pekin ducks. The research has identified that the protein content of the grower diet (19%) is too high and that substantial saving could be made by reducing this even if a two phase feeding program continues to be used. The energy needs of ducks under Australian conditions have not been investigated extensively. The present research has indicated that increasing the energy content of the existing diets has no effect on performance. This has identified that the industry recommendations for energy content of the starter and grower diets are adequate although it hasn’t investigated whether these are the optimal.

The duck industry, as the broiler industry has recognised, will need to find new sources of grain and move away from their reliance on wheat. Currently, wheat and sorghum are used in formulation of duck diets at a ratio of 2:1. Increasing the ratio to 1:1 had not negative effects on duck performance. So it is possible to use more sorghum in duck diets. The industry has reservations about this because of effects on pellet stability. Ducks feed in a manner different to broilers. Correct pellet size and low levels of fines is important for good performance. For the industry to use more sorghum in diet formulations, pellet quality would need to be maintained. It is important that the industry consider what alternative grains are suitable because this is an issue it will have to face and deal with soon. Use of whole wheat has become common practice in the broiler industry. The energy costs for processing is a substantial cost in feed preparation. These energy costs can be reduced by using whole grain. In the current work, adding 15% whole wheat grain to the diet had no advantages or disadvantages in terms of performance. The data do suggest that adding more than 15% might have a detrimental effect on protein digestibility and AME.

The industry lives with a high FCR in commercial production. The values achieved using the tunnel ventilated shed reported on here have identified that improvements in FCR can be achieved with greater environmental control. To be sustainable the industry will need to improve the degree of environmental control in duck sheds.
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Presently, duck meat accounts for 5% of world poultry production with most of this being produced in regions of Asia. For the Australian duck industry, the majority of consumer demand comes from Asian restaurant trade or during special occasions such as Easter, Christmas and Chinese New Year. The success of the duck industry depends on meeting consumer expectations for high quality and healthy meat.

The report details the results of five studies that investigated the effects of genotype, sex, pen-sex, season and nutrition on performance of Pekin ducks under Australian conditions. The research efforts attempted to address some of the factors limiting efficiency in the local duck industry.
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