The Definition and Genetic Analysis of Feeding Behaviours Performed in Individual Feed Stations and their Relationship to Production Traits in Group-Housed Commercial Turkeys (*Meleagris gallopavo*)

by

Jennifer H. Proulx

A Thesis
Presented to
The University of Guelph

In partial fulfillment of requirement for the degree of
Master of Science in
Animal Biosciences

Guelph, Ontario, Canada

© Jennifer H. Proulx, December, 2016
ABSTRACT

The Definition and Genetic Analysis of Feeding Behaviours Performed in Individual Feed Stations and their Relationship to Production Traits in Group-Housed Commercial Turkeys (*Meleagris gallopavo*)

Jennifer H. Proulx
University of Guelph, 2016

Co-Advisor: Tina Widowski
Stephanie Torrey

Advisory Committee Member: Benjamin Wood
Cheryl Quinton

The use of automated feeders has allowed individual feed intake and behaviour data to be collected in group-housed birds. Clear definitions of feeding behaviours were achieved by calculating meal criterion. Differences in mean meal characteristics and aversions to feeders were observed between the sire and dam line. A genetic analysis revealed that feeding behaviours are moderately to highly heritable and there is low to high range in genetic correlations between feeding behaviours and production traits such as feed efficiency. Determining feeder preferences can lead to changes in management to optimize feeder access therefore decreasing aggressive behaviours often observed at the feeders. Clearly defining feeding behaviours can lead to a more accurate comparison of phenotypes between studies. Correlations would imply that selection for more efficient birds could have an effect on their feeding behaviours. Genetic variation of feeding behaviours should be examined to determine any drifts resulting from selection emphasis on feed efficiency.
Acknowledgements

This thesis was a collaboration between the University of Guelph and Hybrid Turkeys. I am truly lucky to have worked with both institutions which has taught me many aspects of the academic and private sector sides of the turkey industry. Thank you to the friendly staff, both at the University of Guelph and Hybrid Turkeys, for making my time as a Masters student memorable.

To Dr. Ben Wood, for his guidance and commitment to this thesis. To Dr. Stephanie Torrey, for the great deal of time and dedication in helping me with the completion of this thesis. Without the two of you this thesis would cease to exist and for that I will always be grateful. I also want to thank my other advisory committee members, Dr. Tina Widowski and Dr. Cheryl Quinton for their constant involvement. Although my committee members played a large part in the completion of this thesis, other members of the department also played an integral role in my success. To Dr. Margaret Quinton, Dr. Gord Vander Voort, and to Bill Szkotnicki, thank you for the statistical, modeling, and coding assistance that was an essential part in expanding my technical skills. I would also like to thank, Dr. Owen Willems, for his guidance and patience in the beginning of my program.

I would like to thank my parents, Nicole and Bob, for their unconditional love and encouragement throughout the completion of my thesis. To my good friend Anna, thank you for the many thought-provoking conversations and ongoing support.

To my financial supporters, the Poultry Industry Council, the Canadian Poultry Research Council, Hybrid Turkeys, and the University of Guelph, thank you. Without funding this project would not have been possible.
# Table of Contents

**Chapter 1 General Introduction**

1.1 Industry ........................................................................................................................................... 1
1.2 Mating system ................................................................................................................................. 2
1.3 Life cycle ......................................................................................................................................... 2
1.4 Pricing .............................................................................................................................................. 3
1.5 Production ........................................................................................................................................ 3

**Chapter 2 A review of feeding behaviours and their genetic relationship to production traits**

2.1 Abstract ........................................................................................................................................... 7
2.2 Introduction ..................................................................................................................................... 7
2.3 Defining Feeding Behaviours ......................................................................................................... 8
  2.3.1 Feeding Behaviours .................................................................................................................. 8
  2.3.2 Meal Criterion ........................................................................................................................... 9
2.4 External Effects on Feeding Behaviour ......................................................................................... 10
2.5 GeneticDisposition of Feeding Behaviours .................................................................................... 11
  2.5.1 Use of Electronic Feeders for Collecting Data on Feeding Behaviours ................................. 12
  2.5.2 Genetic Models used to Calculate Genetic Parameters ........................................................... 13
  2.5.3 Resulting Genetic Parameters .................................................................................................. 13
  2.5.4 Feed Efficiency and Feeding Behaviours ................................................................................. 14
2.6 Conclusion....................................................................................................................................... 15

**Chapter 3 Thesis Objectives** .............................................................................................................. 18

**Chapter 4 Defining Individual Feeding Traits and Patterns using Feeder Stations in Group-Housed Commercial Turkeys (Meleagris gallopavo)** ........................................................................................................ 19

4.1 Abstract ........................................................................................................................................... 19
Chapter 5 Genetic Parameters of Feeding Behaviours and Production Traits in the Commercial Turkey (*Meleagris gallopavo*)

5.1 Abstract ................................................................................................................................. 44

5.2 Introduction ............................................................................................................................ 44

5.3 Methods .................................................................................................................................. 45
List of Tables

Table 2.1 Genetic correlations (standard errors) between feeding behaviour traits in broiler chickens, Large White (LW), and French Landrace (LR) pigs (broilers: Howie et al., 2011; pigs: Labroue et al., 1997) ............................................................................................................................................. 17

Table 4.1 Feeding behaviour traits and production traits with their abbreviations and definitions. .............................................................................................................................................................................................. 31

Table 4.2 Meal criterion and summary of the average meal characteristics (± standard error) for the sire and dam lines............................................................................................................................................ 32

Table 5.1 Feeding behaviour traits and production traits with their abbreviations and definitions. ....................................................................................................................................................................................... 57

Table 5.2 Means (Standard Errors) of the feeding behaviour and production traits.................. 58

Table 5.3 Heritabilities (Standard Errors) (Diagonal), Phenotypic Correlations (Standard Error) (Above), and Genetic Correlations (Standard Error) (Below) of the feeding behaviour traits ........................................................................................................................................................................ 59

Table 5.4 Phenotypic correlations ($r_p$) (standard error), and genetic correlations ($r_g$) (standard error) between the feeding behaviour traits and the production traits. ....................... 60
List of Figures

Figure 1.1 Structure of the turkey production system (Wood, 2009)………………………………….4
Figure 1.2 A flow diagram representing costs and revenues associated with each production level as a means of calculating the overall company margin (Wood, 2009)…………………………5
Figure 1.3 Diagram representation of a 4-way line cross used in broiler and turkey breeding. ..... 6
Figure 4.1 Schematic of the floor pen housing system used for both the sire and dam lines. The numbers represent individual feeder spaces to which the sire line had access and the circles represent the drinkers. The dam line had access to feeders 5 through 32 only. ..... 30
Figure 4.2 The square-root of the relative frequency of the inter-visit duration and the intra-visit duration for the sire line. The point of intersect is at 13.93 minutes therefore, defining the meal criterion for this line……………………………………………………………………………………………33
Figure 4.3 The square-root of the relative frequency of the inter-visit duration and the intra-visit duration for the dam line. The point of intersect is at 7.37 minutes therefore, defining the meal criterion for this line…………………………………………………………………………………………………34
Figure 4.4 Average visit feed intake per bird per day (g) by hour for the a) sire line and b) the dam line. Lighting period from 06:00 to 20:00……………………………………………………………………………………..35
Figure 4.5 Average visit duration per bird per day (min) by hour throughout the light period (06:00-20:00) for a) the sire line and b) the dam line.……………………………………………………………………………………………36
Figure 4.6 Average number of visits per bird per day by hour throughout the light period (06:00-20:00) for a) the sure line and b) the dam line.……………………………………………………………………………………………37
Figure 4.7 The realized proportion of the square root of the average feed intake per bird per feeder for the ten high (▲), the ten average (●), and ten low (♦) feed intake birds at each feeder vs the expected (▬) proportion of feed intake per feeder for the sire line.………38
Figure 4.8 The realized proportion of the square root of the average feed intake per bird per feeder for the ten high (▲), the ten average (●), and ten low (♦) feed intake birds at each feeder vs the expected (▬) proportion of feed intake per feeder for the dam line.………39
Figure 4.9 Average a) visit feed intake per bird per day (g), b) visit duration per bird per day (min), and c) number of visits per bird per day by feeder for the sire line.…………………40
Figure 4.10 Average a) visit feed intake per bird per day (g), b) visit duration per bird per day (min), and c) number of visits per bird per day by feeder for the dam line.…………………41
Figure 4.11 The realized proportion of the square root of the average feed intake per bird per feeder for the two high occupancy hours (06:00-●, 18:00-♦) and the two low occupancy hours (11:00-▲, 13:00-■) vs the expected (―) proportion of feed intake per feeder for the sire line. ........................................................................................................................................ 42

Figure 4.12 Square root of the visit feed intake per bird per feeder (kg) during the two high (06:00, 18:00) and two low (11:00, 13:00) occupancy hours by feeder for the dam line. 43

Figure 5.1 Schematic of the floor pen housing system used for the experiment. The numbers represent individual feeder spaces to which the birds had access and the circles represent the drinkers................................................................. 56
Chapter 1  General Introduction

In the last 50 years, the growth rates observed in modern turkeys have doubled and the liveability of the birds has also increased. Through understanding the traits and the use of genetic selection, the turkey industry has been able to make significant advances. The turkey breeders aim to increase profitability while decreasing the cost of production. For this reason, it is important to monitor the breeding program in order to make appropriate genetic selection decisions that will benefit both the producers and the birds. The development of breeding objectives and a selection index are important in making and maintaining the proper goals of the breeding program. The breeding objective is determined by the economic importance of traits to the breeding program while the selection index will be a tool used throughout the program allowing proper selection decisions to be made in favour of the breeding objective. An initial overview of the turkey production system is first required in order to understand the traits that will be involved in both the breeding objective and the selection index.

1.1 Industry

The Canadian turkey industry has eight hatcheries, 535 turkey growers, and 20 slaughter plants; in Ontario, there are two of these hatcheries, 180 growers, and five slaughter plants. In 2015, the value of turkey production in Canada was $395,871,000 with Ontario having the highest provincial total of $170,112,000 (Turkey Farmers of Canada, viewed October, 2016).

The turkey industry is segregated into multiple levels that play an integral part in producing the commercial product. The primary breeder supplies the parent stock to the multiplier breeders in either the form of eggs or poults. The multipliers then supply poults for commercial production before being sent for slaughter and processing into the commercial product to be sold. In North America, the multiplier breeding, commercial hatch and slaughter plant are often controlled by a single breeding company and viewed as an integrated enterprise from an economic stand-point (Figure 1.1). Each level of the turkey industry has different cost variables associated to them such as purchase of parent stock, hatching and delivery costs, parent stock feed intake, parent stock selection and mortality, fertility and hatchability, and feed costs are important. For the commercial production level, variables such as the feed intake, mortality, slaughter age, housing density, housing production, and housing cost, as well as feed intake costs
are important. Feed costs upwards of 70% of production expenses, this drives the increase in research for identifying more feed efficient birds (Willems, 2015). Lastly, costs to the processing plant sector include labour and equipment. This allows the calculation of an overall company margin (Wood, 2009). Figure 1.2 represents the costs and revenues for each production level.

1.2 Mating system

The most common mating system in turkeys is known as a 4-way line cross (Figure 1.3). Initially, there are four different pure bred lines. Two of the breeds belong to the sire line, which are heavily selected for growth and commercial traits, and the other two lines belong to the dam line which are more heavily selected for reproduction traits such as hatchability and egg production. Within both the sire and dam lines, males from one pure bred line and females from the other line are selected for the grandparent lines. The two grandparent sire lines are crossed and the two grandparent dam lines are crossed to produce male and female parent stock. These parent stock lines are then crossed to produce the 4-way cross commercial turkey which is the marketable product of the industry (Wilton et al., 2013).

1.3 Life cycle

All reproduction at the primary breeder and parent stock levels is through the use of artificial insemination. Once the eggs have been laid, they are incubated for a period of 28 days. Turkeys are particularly sexual dimorphic and they are therefore separated after hatch into respective tom and hen groups. The poults are then taken from the hatchery and are moved to brood on a specific turkey farm. The first five weeks of a poult’s life is known as the brooding period; high environmental temperatures (25.5°C - 30°C) are used in order to allow the replacement of down feathers with contour feathers (Hybrid Turkey, Viewed October 2016). After the brooding period, at approximately six weeks of age, the poults are transferred to a “grow-out” facility where they will grow and mature for an additional 5 to 15 weeks. Once mature the birds are transported to processing plants where they are euthanized and processed according to market demands for either whole birds or parts (Statistics Canada, 2014).
1.4 Pricing

The birds involved in the turkey industry can be divided into four separate groups. The broilers, which mature at 10-12 weeks of age, are typically under 5 kg and are marketed as whole birds. The hens mature at 12-15 weeks of age, weigh between 5 and 9 kg and are also marketed as whole birds. The toms, which mature between 17 to 20 weeks of age, weigh over 9 kg and are sent to a processing plant to be sold as parts. Lastly, there are the breeders who are kept year round and are not classified by a specific weight. The four separate groups have different economic pricings based on their group. In Ontario the price for a tom is 3.43 $/kg (Turkey Farmers of Canada, viewed October, 2016).

1.5 Production

The main goal of the turkey industry is high meat production at low costs. In order to achieve this goal the sire line is heavily selected for growth rate, meat yield, and feed efficiency, whereas the dam line is heavily selected for reproductive traits such as egg production, hatchability, and fertility. The high egg production and meat yield both result in higher meat production and the selection for feed efficiency aids in lowering feed costs. As feed costs are one of the highest costs associated to turkey production, the research on accurately identifying and selecting feed efficient birds is of importance (Willems, 2015). More efficient birds will achieve a certain body weight utilizing less feed than a non-efficient bird. The turkey industry is always researching new technologies in order to achieve their production goals while lowering their costs of production. These technologies include forms of measuring individual feed intake data on group-housed birds, as well as calculating genetic and genomic parameters on specific traits of economic importance.
Figure 1.1 Structure of the turkey production system (Wood, 2009).
Figure 1.2 A flow diagram representing costs and revenues associated with each production level as a means of calculating the overall company margin (Wood, 2009).
Figure 1.3 Diagram representation of a 4-way line cross used in broiler and turkey breeding.
Chapter 2  A review of feeding behaviours and their genetic relationship to production traits

2.1 Abstract

Feed intake has been a focus of many studies within the meat bird industry. Yet, research on feeding behaviours that can provide insight on important feed-related production traits, is scarce. This literature review highlights the need for clear definitions of feeding behaviours as well as their genetic parameters in order to demonstrate the potential for genetic selection applications. The first step in defining feeding behaviours is to define a meal. A meal is defined as a series of feeding events, where the time between those feeding events does not exceed the meal criterion. The meal criterion is the longest period of time between two visits within a meal. While many methods have been used, quantitatively calculating the meal criterion was found to be the most biologically relevant. Genetic parameters calculated for feeding behaviours defined by the meal criterion show low to moderate heritabilities, high genetic correlations between the feeding behaviours, and low genetic correlations to production traits. Overall, the study of feeding behaviours can give us insight on social rankings as well as feed efficiency, in order to increase animal welfare and profitability.

2.2 Introduction

Measuring feed intake is an integral management practice in agricultural animal production. Although the collection and analysis of feeding behaviours has not been widely done (Forbes, 1995, Howie et al., 2010), some studies have identified different methodologies for the definition and calculation of feeding behaviours and meal characteristics (Tolkamp et al., 2000; Zorrilla et al., 2005). Other studies were conducted to examine variations in feeding behaviour traits, genetic parameters of these traits, as well as their relationships with other feeding and production traits in pigs (Labroue et al., 1997), dairy cattle (DeVries et al., 2003), and poultry (Howie et al., 2009a). As very few of these studies have been conducted in turkeys, the use of similar studies in other agricultural species may be of use in better understanding the relationship between feeding behaviour and important economic production traits. More specifically, research
into feeding behaviour can increase our knowledge of feed efficiency, as well as social interactions in order to increase both animal welfare and profitability (Brouns and Edwards, 1994; Willems, 2015).

2.3 Defining Feeding Behaviours

A visit is defined as a feeding event at the feeder and a meal is defined as a cluster of visits, which can be determined by calculating a meal criterion. A meal criterion is the longest interval of time between two visits within the same meal. Feeding behaviour involves the intake of feed and short-term feeding behaviours can be defined by different biological units, such as visits or meals (Tolkamp et al., 2000). A study of the behaviours in dairy cows found that visits were a less than ideal biological unit when analysing feeding behaviours because feeding visits were influenced by many different factors (Tolkamp et al., 2000). These factors included the social standing of the animal in the hierarchy, the presence of another cow, and the cow-to-feeder ratio (Tolkamp et al., 2000). Meal was found to be a more reliable biological unit, as an animal’s hunger and level of satiety determined the probability of the start or end of a meal (Barbato et al., 1980; Tolkamp et al., 2000). Yet, in order to quantify meals, the meal criterion has to be defined (Howie et al., 2009b; Zorrilla et al., 2005).

2.3.1 Feeding Behaviours

Meal intake patterns involve the organization of short-term feeding behaviours to achieve a desired daily feed intake (Tolkamp et al., 2000). These feeding behaviours include meal duration, number of meals per day, meal size, time spent feeding per meal, number of visits per meal, daily feed intake, and time spent feeding per day. Meal duration is the amount of time it takes to complete a series of visits, where the time interval between those visits does not exceed the meal criterion. Number of meals per day is the number of meals that occur throughout the course of the day. Meal size is the amount of feed consumed throughout the duration of the meal. Time spent feeding per meal is the duration of time engaged in feeding activity throughout the meal. Visits per meal is the number of visits that occur throughout the duration of the meal. Daily intake is the total amount of feed consumed throughout the day and the time spent feeding per day is the total duration of time throughout a day that consisted of feeding activity. These traits have been defined as such for the purpose of this thesis. It has been suggested that meal
intake patterns can differ between individuals with similar daily intakes through the alteration of feeding behaviours (Tolkamp et al., 2000).

**2.3.2 Meal Criterion**

The meal criterion is defined as the longest interval of time between two visits within a single meal. For example, if the interval of time between the first and second visits of the day is equal or less than the meal criterion calculated, then both visits belong to the same meal. As soon as the interval of time between two visits is greater than the meal criterion, the second visit in question becomes the start of a new meal. (Tolkamp et al., 2000). There are many different methods used in determining meal criterion (Tolkamp et al., 1999; Yeates et al., 2001; DeVries et al., 2003; Zorrilla et al., 2005; Howie et al., 2009b). Some of these methods include simply arbitrarily choosing a value (Masic et al., 1974), or estimating this value quantitatively (Tolkamp and Kyriazakis, 1999; DeVries et al., 2003, Zorrilla et al., 2005; Howie et al., 2009b).

One study investigated whether the log survivorship method was the most appropriate method for calculating a biologically relevant meal criterion (Zorrilla et al., 2005). A biologically relevant meal criterion takes into account drinking events as well as the level of satiety of the animals. As a meal ends, the probability of another meal starting right away is low, as the level of satiety of the animal has been achieved (Tolkamp et al., 1998). As time increased from the last meal, the level of satiety decreased and the probability of a new meal starting increased (Tolkamp et al., 1998). Since the log-survivorship method of calculating meal criterion does not take the level of satiety into account, it was concluded that it may not be the most biologically relevant way of determining meal criterion (Zorrilla et al., 2005).

Calculating meal criterion quantitatively may be more biologically relevant. Estimating meal criterion quantitatively can be achieved by determining the relative frequencies of the interval lengths both between and within visits and fitting these frequencies to a specific statistical model (Howie et al., 2009b; Tolkamp et al., 2011). Studies using this quantitative measure of meal criterion have examined the differences between measuring meal criterion on an individual basis versus with pooled data from multiple animals (DeVries et al., 2003; Howie et al., 2009b). Since the pooled and individual data yielded non-significant differences in meal characteristics based on the two meal criterions calculated, pooled data is most often used in calculating meal criterion for calculation simplicity. However, in light of experimental
differences between animals within the study, individual meal criterions may be more suitable (DeVries et al., 2003; Howie et al., 2009b).

One study assessed two different methods of quantitatively calculating meal criterion to determine any significant differences in meal characteristics (Howie et al., 2009b). The first method involved using a log-normal distribution to model the between-meal interval length distribution. The second method calculated meal criterion by taking the probability of a new meal starting based on the time since last feeding. The meal criterion was not significantly different between the two methods. They concluded that when the data does not depict a clear distribution of between meal interval lengths, the method based on the probability of starting a new meal will be biologically relevant and appropriate in calculating the meal criterion (Howie et al., 2009b).

2.4 External Effects on Feeding Behaviour

There are many environmental and management factors that play a role in the variation in feeding behaviours seen across and within different birds. A specific feeding behaviour pattern may be more ideal depending on the climate of the rearing environment (Yahav et al., 2005). For example, broilers in warmer climates may be at an evolutionary advantage by having smaller, more frequent meals throughout the day. This feeding behaviour pattern requires the birds to be standing more often, exposing their uncovered legs and therefore expelling more heat (Yahav et al., 2005). The smaller meals also minimize thermogenesis by decreasing the metabolic process that follows a small meal compared to a larger one (Swennen et al., 2006). For this reason, selection emphasis and broiler survival would lean towards birds who have this specific feeding behaviour pattern. In addition, poultry in rearing environments that have a high bird-to-feeder ratio may want to utilize a larger, but less frequent meal based feeding pattern to minimize aggressive, competitive behaviour at the feeders (Willems, 2015).

In swine, feeding practices, such as feed restriction or different feed composition, play a role in the feeding behaviours observed (Knap, 2009; Jensen et al., 1993). Although these studies found no significant changes in feeding behaviours between pigs, the study conducted using different feed compositions saw a decrease in feed efficiency between pigs fed different diets (Jensen et al., 1993). Standing and exploratory behaviours were also observed in conjunction and they found that pigs get restless and increase their standing and exploratory behaviours when
they do not meet their nutrient requirements. Some breeds may be more susceptible than others to changes in behaviour due to feeding practices. For example, Meishan pigs spend less time standing compared to Large White pigs when they are feed restricted (Kyriazakis and Emmans, 1995).

In many species, animals may alter their short-term feeding behaviours in competitive situations in order to attain their required daily feed intake (Dairy cattle: Zobel et al., 2011; Pigs: Nielsen, 1995; Beef steers: Corkum et al., 1994). A study conducted on sow feeding behaviours and their relationship to social rankings within the group, revealed that more subordinate sows ate more frequently throughout the day compared to more dominant sows. In addition, the more subordinate sows ate at the least preferred area of the feed trough (Brouns and Edwards, 1994). This implies that the study of feeding behaviours and feeder usage may lead to a more in depth understanding of the social rankings in hierarchal animals. As turkeys are also hierarchal animals, this connection between feeding behaviours and social rankings should also be observed (Appleby et al., 2004).

Knowledge on feeding behaviours, feeder preferences, and social rankings can aid in management practices. There is a minimal amount of research conducted on feeder preference within group-housed animals. Competition for resources, including preferred feeders, can lead to aggressive behaviour between the animals (Moinard et al., 2001; Huzzey et al., 2012). Therefore, identifying the least preferred feeders, which undesirably increases the bird to feeder ratio, can help in determining the cause for the aversion. It is necessary to understand the reasons for feeder avoidance in order to increase preference for a specific feeder. Feeder preference may therefore be able to help us indirectly quantify aggressive behaviour within large groups. This can provide insight on potential methods to mitigate aggressive behaviour that can lead to economic and welfare losses (Brouns and Edwards, 1994; Moinard et al., 2001).

2.5 Genetic Disposition of Feeding Behaviours

In order for a trait to be used in a selection program, trait variation, heritability, and genetic correlations to other traits need to be determined. Short-term feeding behaviours not only vary between individuals but there are also differences observed between poultry species. A study examined the differences in feeding behaviours between broilers, turkeys, and ducks (Howie et al., 2010). They found significant differences between species in feeding rate and meals per day,
and they hypothesized the differences to be due to the physical differences between species, and variations in the environment (Howie et al., 2010). As for within-species variation, a study observed the differences in feeding behaviours between four strains of broilers selected at varying intensities for growth rate (Howie et al., 2009a). The two fast growing strains had fewer, larger meals throughout the day compared to the two slower growing strains. This variation in feeding behaviours between the four strains demonstrates the potential for an underlying genetic disposition. Yet, few studies calculating genetic parameters of feeding behaviours have been conducted to date.

2.5.1 Use of Electronic Feeders for Collecting Data on Feeding Behaviours

In previous studies with turkeys, feed intake and feeding behaviours were observed in either individually-housed turkeys or averaged across an entire flock (Hulsey and Martin, 1991; Xin et al., 1993; Yo et al., 1997; Savory and Mann, 1999; Puma et al., 2001). Although data on individual animals or entire flocks is useful, a more accurate way of collecting individual feeding data under commercial group-housing environments would be greatly beneficial to a turkey breeding program. In 2011, a real-time automated turkey feed intake and body weight monitoring system was tested in order to aid in the determination of individual turkey feeding behaviours in a group-housed environment (Tu et al., 2011). Systems such as this has allowed research to be conducted on either feed conversion ratio (FCR) and residual feed intake (RFI), both measures of feed efficiency (Willems, 2015). This type of monitoring system uses radio frequency identification (RFID) technology to individually identify turkeys entering and exiting the feeding stations. This monitoring system can record the turkey’s identification tag, which feed station the turkey is using, pecking force distribution, number of visits, and real-time visit duration (Tu et al., 2011).

Small differences in the way the feeders are built, and the software programs used in collecting the feeding data can have large effects on the collection of short-term feeding behaviours (Tolkamp et al., 2000). Some of these differences can be the lag time between when the tag reader detects a bird and the feed weight measurement taken; this can affect the amount of feed recorded for that visit. The range of the readers can also influence results, as some can potentially record the wrong animal, or multiple animals, in the feeder. In addition, some feeders are built to deliver a certain amount of feed when it detects an animal whereas others weigh the
feed at the beginning and end of each visit (Tu *et al.*, 2011). For this reason, comparisons between the few studies that have been conducted have their limitations.

### 2.5.2 Genetic Models used to Calculate Genetic Parameters

Feeding behaviour data collected from electronic feeders can be used to calculate meal characteristics and production traits (Howie *et al.*, 2009a,b; 2010; Willems, 2015). Examples of these traits include number of meals per day, meal duration, meal size, growth, and feed efficiency. Once these traits are calculated, a genetic analysis can be run to calculate different genetic parameters such as heritability and genetic correlations. Commonly, genetic parameters of meal characteristics are calculated using an animal model. The animal models used in these studies typically have some variation of hatch, pen, mating group, and sex as fixed effects while environment, and animal genetics are set as random effects (Labroue *et al.*, 1997; Howie *et al.*, 2011). The genetic parameters calculated in these studies, in both pigs and broilers, revealed variations between different strains within a species and some similarities in feeding behaviours between species.

### 2.5.3 Resulting Genetic Parameters

Research on the genetic parameters of feeding behaviours from four different lines of broiler hens, selected for different growth intensities, was conducted (Howie *et al.*, 2011). Heritability estimates for feeding behaviour traits ranged from moderate to high (0.24 to 0.57) and the genetic correlations between behaviours varied widely (0.00 to -0.96). In addition, genetic correlations between feeding behaviours and performance traits such as body weight at 35d and FCR, were found to be in the lower range (-0.20 to 0.18) (Howie *et al.*, 2011). This means that the feeding behaviours should respond to selection pressures placed on other feeding behaviours. Due to the presence of some moderate to high genetic correlations between a few of the feeding behaviour traits, it would only be necessary to include a few of these traits in the selection index in order to make selection decisions. Since birds with similar FCR had a variety of feeding behaviour patterns and genetic correlations were low, selection for a specific feeding behaviour pattern can therefore be achieved without compromising FCR, a production trait of interest to the industry (Howie *et al.*, 2011).

Two studies calculated heritability estimates on feeding behaviours in monogastric species (Howie *et al.*, 2011; Labroue *et al.*, 1997; Table 1). The feeding rate and number of
meals per day had the largest heritability estimates (Howie et al., 2011; Labroue et al., 1997). There are some similarities in the range of genetic correlations between the two breeds of swine and broilers (Table 2.1). Feeding rate was negatively correlated with total feeding time per day and number of meals per day, and was positively correlated with meal size. Which means that animals that eat quickly, also eat larger meals. Number of meals per day was also negatively correlated with meal size in both species. Some of the differences observed between the broilers and the two breeds of swine are either with the differences in the level of genetic correlation (e.g., meal duration and total feeding time per day), or a difference in the direction of the relationship (e.g., all the time traits). For this reason, the differences observed between these correlations could be due to the fact that the researchers defined their feeding time traits using different methods.

2.5.4 Feed Efficiency and Feeding Behaviours

The turkey industry has been collecting and analysing data on production traits, such as growth rate and meat yield, for as long as genetic analyses have been run. More recently, one of the more important economical production traits has become feed efficiency. Feed efficiency is defined as the amount of feed it takes to increase one unit of body mass (Tu et al., 2011). It can be calculated two different ways, as a feed conversion ratio (FCR) or as a residual feed intake (RFI). The FCR is calculated by taking the amount of feed consumed throughout a specific period of time and dividing it by the weight gained in the same period. Although FCR is a useful measure of feed efficiency, incorporating a ratio trait into a selection index is not ideal. A selection index containing FCR would result in more selection pressure being put on the trait in the place of the numerator which would greatly affect the ratio as an outcome (Gunsett, 1984). For this reason, RFI is more widely used when incorporating feed efficiency into a selection index. RFI is defined as the difference in actual feed intake and the expected feed intake, based on weight gain throughout the time period. This allows differences in feed efficiency to be observed across animals with the same weight gains (Koch et al., 1963).

Comparing the previously mentioned broiler and pig studies, there are difference between species involving the genetic correlations between feeding behaviour traits and production traits (Labroue et al., 1997; Howie et al., 2011). In the broiler study (Howie et al., 2011), there is a low genetic correlation between feeding behaviour and performance traits (-0.20 to 0.18). In the
swine study (Labroue et al., 1997), these traits were within similar range to the ones in the broiler study except for meal size and average daily feed intake with feed conversion ratio which were both higher in the broiler study. The genetic correlation between daily feed intake, feeding rate, and meal size with average daily gain also in a higher range (0.29-0.87) than the correlations found in the broiler study. The discrepancies could be due to different production traits being used between the two studies. When the same trait was studied (FCR), the genetic correlation found between feeding behaviour traits and the FCR production trait was found to be low in both studies (0.00 to 0.24). The results found in the swine study are in agreement with other studies that found low correlations between feeding behaviour and FCR traits (Von Felde et al., 1996; Kyriazakis, 2011; Aggrey et al., 2010). In turkeys, however, moderate correlations were identified between feeding behaviour traits and production traits (Willems, 2015). The similarities and differences among monogastric species highlights the need for more research conducted with turkeys in order to observe the level of genetic correlation between feeding behaviour and production traits. This information is necessary before we can conclude whether including feeding behaviour traits in a breeding program selection index would improve our selection decisions for production traits, and to what extent.

As feed efficiency is an economically important trait in the turkey industry, studies on feeding behaviour can be beneficial. Determining genetic correlations between feeding behaviours and feed efficiency will allow us to make more informed selection decisions in the future. The addition of certain feeding behaviours in the selection index can potentially aid in increasing the accuracy of selection for efficiency birds which in turn will increase the rate of genetic change. More efficient birds would benefit not only the production companies by reducing the cost on feed, but could also have environmental benefits. These benefits include a decrease in ammonia and greenhouse gases emitted from manure (Willems, 2015).

2.6 Conclusion

There are very few studies conducted on feeding behaviours in domestic turkeys. Once the short-term feeding behaviour data and meal criterion have been collected and calculated, meal characteristics can be defined. In studies with other monogastric species, low to moderate heritabilities were found for the feeding behaviour traits, genetic correlations between feeding behaviours were high, and low genetic correlations were found between feeding behaviour and
production traits. These findings imply that there is promise in genetic analyses between feeding behaviour and productivity traits. Overall, the study of feeding behaviours can give us insight on social rankings and therefore, management practices, as well as feed efficiency, in order to increase animal welfare and profitability.
Table 2.1 Genetic correlations (standard errors) between feeding behaviour traits in broiler chickens, Large White (LW), and French Landrace (LR) pigs (broilers: Howie et al., 2011; pigs: Labroue et al., 1997).

<table>
<thead>
<tr>
<th>Feed Behaviour</th>
<th>Breed</th>
<th>Feeding rate</th>
<th>Meal size</th>
<th>Meal duration</th>
<th>Meals per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total feeding time per day</td>
<td>Broiler</td>
<td>-0.95 (0.01)</td>
<td>-0.21 (0.03)</td>
<td>0.90 (0.01)</td>
<td>0.23 (0.04)</td>
</tr>
<tr>
<td></td>
<td>LW</td>
<td>-0.78 (0.04)</td>
<td>0.11 (0.09)</td>
<td>0.50 (0.06)</td>
<td>-0.11 (0.09)</td>
</tr>
<tr>
<td></td>
<td>LR</td>
<td>-0.86 (0.03)</td>
<td>0.08 (0.10)</td>
<td>0.58 (0.07)</td>
<td>0.00 (0.11)</td>
</tr>
<tr>
<td>Feeding rate</td>
<td>Broiler</td>
<td>-</td>
<td>0.26 (0.03)</td>
<td>-0.85 (0.02)</td>
<td>-0.24 (0.04)</td>
</tr>
<tr>
<td></td>
<td>LW</td>
<td>-</td>
<td>0.28 (0.07)</td>
<td>-0.19 (0.08)</td>
<td>-0.12 (0.08)</td>
</tr>
<tr>
<td></td>
<td>LR</td>
<td>-</td>
<td>0.16 (0.09)</td>
<td>-0.40 (0.08)</td>
<td>-0.12 (0.10)</td>
</tr>
<tr>
<td>Meal size</td>
<td>Broiler</td>
<td>-</td>
<td>-</td>
<td>0.10 (0.05)</td>
<td>-0.96 (0.01)</td>
</tr>
<tr>
<td></td>
<td>LW</td>
<td>-</td>
<td>-</td>
<td>0.87 (0.02)</td>
<td>-0.93 (0.02)</td>
</tr>
<tr>
<td></td>
<td>LR</td>
<td>-</td>
<td>-</td>
<td>0.83 (0.04)</td>
<td>-0.94 (0.02)</td>
</tr>
<tr>
<td>Meal duration</td>
<td>Broiler</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-0.09 (0.06)</td>
</tr>
<tr>
<td></td>
<td>LW</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-0.88 (0.03)</td>
</tr>
<tr>
<td></td>
<td>LR</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-0.79 (0.04)</td>
</tr>
</tbody>
</table>
Chapter 3  Thesis Objectives

The first objective of this thesis is to accurately calculate a representative meal criterion in order to define a meal and with this information to determine meal characteristics. Once defined, the meal criterion aids in the second objective of this study which is to clearly define feeding behaviours in a sire and dam line of commercial turkey. It is hypothesised that there are differences in the feeding behaviours between the sire and dam line due to the difference in selection emphasis. These feeding behaviours will be used in determining preferences or aversions to specific feeders. This, in turn, can give insight on improving feed station placement to maximize feeder utilization. It is hypothesized that there are aversions to specific feeders due to their placement within the barn. It is also hypothesized that there will be a difference in the severity of the aversion to feeders between the sire and dam lines due to differences in selection pressures as well as between birds that differ in their total feed intake.

Genetic parameters such as heritability, as well as phenotypic and genetic correlations, will be calculated for feeding behaviours and certain production traits of interest in a sire line. It is hypothesized that feeding behaviours will have low to moderate heritabilities and be moderately to highly correlated to one another. Heritabilities for production traits have also been hypothesized to fall in a low to moderate range and correlations between feeding behaviours and production traits will be low to moderate.
Chapter 4  Defining Individual Feeding Traits and Patterns using Feeder Stations in Group-Housed Commercial Turkeys (*Meleagris gallopavo*)

4.1 Abstract

Although feed intake has been widely studied in the poultry industry, research on feeding behaviours is limited. The aim of this study was to 1) determine the meal criterion by which to define a meal and additional meal characteristics, 2) determine if there were any differences in feeder preferences at different times of the day, and 3) determine if there was a difference between average feed intake per bird and feeder preference of birds differing in total feed intake. The sire line had a meal criterion of 13.93 min whereas for the dam line it was 7.11 min. The means calculated for the meal characteristics revealed differences between the sire and dam lines. Aversions to specific groups of feeders were also found among the two lines. When looking at the different times of the day, the aversion to feeders in the dam line was more apparent than the sire line. Turkeys with low feed intake had a wider variation in feeder usage than expected compared to birds with high or average feed intake. Defining feeding behaviours lays the foundation for future research relating these traits to production traits. In addition, determining feeder preferences through feeding behaviours can give us insight on social rankings and optimum feeder placement to mitigate aggressive behaviour.

4.2 Introduction

The turkey industry has made significant advances in growth rate and body size over the past fifty years. These improvements have predominantly been due to changes in genetics (Havenstein *et al.*, 2007). Feed efficiency in turkeys has a low to moderate genetic correlation with feeding behaviours such as number of meals per day, meal duration, and meal size (Willems, 2015). Consequently, selection emphasis placed on either feeding behaviours or feed efficiency may have an effect on the other. Increased knowledge of feeding behaviours could therefore be used in selecting for more efficient birds and therefore increase the accuracy of the selection process (Howie *et al.*, 2009b; Wood and Willems, 2014; Willems, 2015). Identifying these feeding behaviour traits can not only lead to further advancements in feed efficiency, but
also improve our knowledge on growth rate and body size, social interactions, and better management practices (Brouns and Edwards, 1994; Hoy et al., 2012; Willems, 2015).

Previous studies, in both broiler and layers, concluded that there is a difference in feeding behaviours between birds that differ in body weight, as well as between birds from different genetic strains for growth rate (Masic et al., 1974; Barbato et al., 1980; Howie et al., 2009b). In addition, variations in feeding behaviours, in swine, have been observed in animals of different social rankings (Brouns and Edwards, 1994; Hoy et al., 2012). Social rankings in a group of sows was determined and feeding behaviours were observed between them. The feeding behaviours revealed that more subordinate sows ate more frequently throughout the day and at the least preferred location (Brouns and Edwards, 1994). Turkeys, also being a highly social animal, may also have variations in their feeding behaviours, and feeder preference depending on their social ranking within the flock (Appleby et al., 2004). Since social rankings, feeding behaviour and feeder preference are linked in some group-housed animals, it may be possible to use feeding behaviour and feeder preference data to better understand social behaviours and liveability in turkeys.

Modern commercial turkeys are generally housed in groups of 1,000 – 10,000 birds, making quantification of individual feeding behaviour difficult. Recently developed technology in electronic feeding stations makes it possible to study individual feeding behaviour within a large group (Tu et al., 2011). The aims of our study were therefore to 1) determine the meal criterion by which to define a meal and additional meal characteristics, 2) determine if there were any differences in feeder preferences at different occupancy hours, and 3) determine if there was a difference between average feed intake per bird and feeder preference of birds differing in total feed intake.

4.3 Methods

4.3.1 Animals

Data were collected from two hatch groups of turkeys belonging to two different lines and were raised under commercial rearing conditions.
4.3.2 Sire Line

Three hundred and twenty large white turkey toms, from a sire line of breeders, were used in the trial. Selection emphasis, in the sire line, is placed on production traits such as growth rate, feed efficiency, and meat yield. Birds were reared under standard commercial barn conditions and moved to a single group pen (7.32m × 15.85m) at 16 weeks of age. Individual birds were identified with a Radio-Frequency IDentification (RFID) wing band. Light cycles alternated between a 14L: 10D with a light intensity of 10 foot candles (107.64 LUX). Birds had *ad libitum* access to feed and water throughout the 35 day trial.

4.3.3 Dam Line

Two hundred and sixty-nine large white turkey toms, from a dam line were also used in the trial. Selection emphasis, in the dam line, is placed more heavily on reproductive traits such as egg production, fertility, and hatchability but also commercial traits. Birds were reared under standard commercial conditions and moved to a single group pen (7.32m × 13.41m) at 12 weeks of age. Individual birds were identified with RFID wing bands. Light cycles alternated between a 14L: 10D with a light intensity 10 foot candles (107.64 LUX). Birds had *ad libitum* access to feed and water throughout the 27 day trial.

4.3.4 Defining Feeding Behaviours

Feeding data were recorded with an Electronic Feed Intake Measurement System (EFIMS) which consisted of 32 feeders for the sire line and 28 feeders for the dam line, that were activated by the unique RFID in each bird. Schematics have been previously reported for this feeder system (Tu *et al.*, 2011). The feeders were set up in an “L” shaped pattern with 24 feeders across the back of the pen and 8 across the side for the sire line and 20 feeders across the back of the pen and 8 across the side for the dam line (Figure 4.1). There were approximately 10 birds per feeder and 80 birds per bell drinker for the sire line, and 9.4 birds per feeder and 90 birds per bell drinker for the dam line. The data were recorded in fragments, caused by either a bird moving to a different feeder or a loss in connectivity between the RFID tag and the reader. Fragments resulting from a loss of connectivity were corrected via compression into a single visit. A visit is defined as a bird having a single feeding event at the feeder. A meal was defined as a series of events, both feeding and non-feeding, that were compressed using a set meal
criterion (Yeates et al., 2001; Zorrilla et al., 2005). A meal criterion was defined as the longest interval of time between two visits within a meal. Similarly described in a previous study, meal criterion was calculated by finding the point of intersect between the square roots of the relative frequency of the inter-visit duration and the square root of the relative frequency of the intra-visit duration (DeVries et al., 2003). With this information visits were compressed into meals in the following way: the first visit to the feeders of the day was denoted as the start of the first meal. If the length between the first visit and the second visit was equal or shorter than the meal criterion calculated, the second visit was also part of the first meal. This adding of visits into a meal continued until the interval of time between two visits was longer than the meal criterion. At this point, the second visit signaled the start of the second meal and it begins again. Meal characteristics can then be defined (Table 4.1) and means and standard errors calculated.

Data with calculated feed intakes smaller than 10 g were deleted as this was considered to fall within the scale variance. Feeding duration and feed intake were extrapolated from the raw data. Outliers were determined as records that were equal or greater than one and a half times the length of the first and third quartile of the boxplot for the total daily feeding duration and total daily feed intake traits. Records above the 118.67 min threshold for total daily feeding duration and 1015 g threshold for the total daily feed intake for the sire line, and 66 min threshold for the total daily feeding duration and 748 g threshold for the total daily feed intake for the dam line were considered outliers and deleted from the final data set. The final data set held, on average 3422 visit records/day and 2398 meal records/day for the sire line and 3504 visit records/day and 2865 meal records/day for the dam line. Visit records were used in the feeding pattern and feeder preference analysis, and meal records were used in defining meal characteristics.

4.3.5 Feeder Preference Analysis

4.3.5.1 Feeding Behaviour per Hour

Average visit intake (g), visit duration (min), and number of visits per bird per day, throughout the whole trial, were used in determining two low and two high occupancy feeding hours throughout the day.
4.3.5.2 Feeding Behaviour per Feeder

To determine feeding behaviour at individual feeders, only data from the light period (06:00-20:00) were used. Although a meal was determined to be a more biologically relevant unit compared to a visit when analysing short-term feeding behaviours, feeder preference analysis was conducted using data from visits because one meal could take place at multiple feeders (Tolkamp et al., 2000). Total feed intake from each bird was calculated, and the ten birds with the highest, mid-range, and lowest total feed intake were studied further and identified as ‘High FI’, ‘Average FI’ and ‘Low FI’ group, respectively. In order to meet the assumptions of normality, the feed intake data was transformed using the square root of the means. Feeder preferences and aversions were then described for all three FI groups by plotting the proportion of expected feed intake per bird per feeder against the actual proportion of feed intake observed. Feeder preferences and aversions were also described for all four occupancy hours using the proportion of the average feed intake per bird. A comparison between the sire and dam line was then described in all cases.

4.4 Results

4.4.1 Defining Feeding Behaviour

The meal criterion was calculated as 13.93 minutes for the sire line, and 7.11 minutes for the dam line (Figures 4.2 and 4.3, respectively). Means and standard errors were calculated for each of the meal characteristics for the sire and dam line (Table 4.2). Turkeys from the sire line consumed approximately twice the volume of feed in the average meal compared to the dam line, and spent approximately twice the amount of time feeding per meal. Both lines had similar feeding rates and number of visits per meal.

4.4.2 Feeder Preference Analysis

4.4.2.1 Feeding Behaviour per Hour

To demonstrate the low feeding activity level during the dark period, average visit intake (g) was plotted throughout the course of a 24 hour period (Figure 4.4a, b). Average visit duration (min), and average number of visits were plotted throughout the course of the light period only (from 06:00 to 20:00) (Figures 4.5 and 4.6). As soon as the lights came on (06:00), there was a large increase in the average feed intake per visit, average visit duration, and average number of
feeding visits per bird per day in both lines (Figures 4.4, 4.5, and 4.6). Another peak in average visit feed intake, average visit duration, and average number of feeding visits was observed at 18:00, two hours prior to the lights going out in anticipation of the lights going out (20:00). For the sire line, the two high occupancy hours were determined to be between 06:00 and 07:00 and 18:00 to 19:00, while the two low occupancy hours were in the middle of the day from 11:00 to 12 and 13:00 to 14:00. For the dam line, the two highest occupancy hours were at the same time, at 06:00 to 07:00 and 18:00 to 19:00, while the two low occupancy hours were at 12:00 through to 14:00.

4.4.2.2 Feeding Behaviours by Feeder

The proportion of the average visit feed intake patterns for the High, Average and Low FI groups were plotted by feeder for both the sire and dam lines (Figures 4.7 and 4.8, respectively). The proportion of the average feed consumed by the High and Average FI groups, for both the sire and dam lines, were consistent across all feeders. In both the sire and dam lines, the proportion of average feed intake of the Low FI grouped birds were more widely spread from the expected intake line. Although, the dam line appeared to have an aversion to more feeders than the sire line, all three FI groups for both lines seemed to show an aversion to the first feeder in the row.

The average visit feed intake per bird per day by feeder, average visit duration per bird per day by feeder, and the average number of visits per bird per day by feeder is depicted in Figure 4.9 for the sire line, and Figure 4.10 for the dam line. Clear preferences and aversions to specific feeders were found for both the sire and dam line. In the sire line, two feeders stood out as preferred feeders. These feeders had a high number of visits where the birds consumed a lot of food in a short period of time. Birds in the sire line also showed an aversion to a few feeders. These feeders had a low number of visits where birds consumed very little in a short period of time. A clear identification of preferred feeders among the dam line could not be concluded; however, an aversion to specific groups of feeders was apparent. The turkeys from the dam line had a low number of visits to those feeders where there was little feed consumed (Figure 4.10).

The proportion of the average visit feed consumed at all four occupancy hours for the sire and dam lines is shown in Figures 4.11 and 4.12, respectively. The trends, as seen in Figure 4.11 and 4.12, demonstrate that certain aversions and preferences to specific feeders may exist within both the sire and dam lines.
4.5 Discussion

4.5.1 Defining Feeding Behaviours

Feeding behaviours have been defined using different methods including feeding visits and meals. The average meal characteristics found in this study, for both sire and dam lines, were similar to previous findings on turkey feeding characteristics (Howie et al. 2010; Willems, 2015). However, both daily feed intake and meal size were larger in the previous broiler study compared to those found in both lines of our study (Howie et al., 2010). In addition, both meal duration and meal size were larger in the previous sire line of turkeys studied compared to the dam line of this study (Willems, 2015). These differences between the current study and the previous study may be directly attributable to the age and weight of the birds at the start of the trials (Howie et al., 2010, Willems, 2015). Additionally, the difference in the definition of meal between the studies may have contributed to the differences observed. The present study included both feeding and non-feeding events in the meal whereas in a previous study, only feeding events were considered (Willems, 2015).

The differences observed in the meal characteristics between the sire and dam line in the current study may be related to differences in age, but most likely the biggest contributing factor is the difference in the traits emphasised in the selection process of each line. While the sire line was selected more heavily for growth rate, yield, and feed efficiency, the dam line was selected more heavily on reproductive traits such as egg production. The proportion of the time spent feeding per meal compared to the overall meal duration for both sire and dam lines were roughly the same (94% and 95%, respectively) and were found to be higher than the proportion found previously, 82% (Howie et al., 2010). This difference suggests that the turkeys in the current study had shorter non-feeding durations during meals compared to the previous study, although the turkeys in the previous study had a faster feeding rate and more visits per meal compared to those in the current study. These differences may reflect differences in barn management. The aforementioned study had 12.9 birds per feeder, whereas the current study had 10 birds per feeder for the sire line and 9.4 birds per feeder for the dam line (Howie et al., 2010). This decrease in bird-to-feeder ratio may decrease levels of competition for feed, resulting in differences in short-term feeding behaviours (Emmans and Kyriazakis, 2001). There were also differences between the two genetic lines in feeding behaviour, as the dam line had a faster
feeding rate (+ 6 g/min) than the sire line, and the sire line had more visits per meal and fewer meals per day than the dam line, which may reflect the differences in selection pressure for feed efficiency.

4.5.2 Feeder Preference Analysis

4.5.2.1 Feeding Behaviour per Hour

A semi-diurnal pattern in feeding behaviour has been previously described for laying hens (Billard and Biellier, 1975). Laying hens had two peak feeding times, one at first light and one before the dark period, and low levels of feeding activity at mid-day. Similarly, in the current study, turkeys consumed less than 0.02% of their feed during the dark period, and displayed a peak in feeding behaviour within the first hour or two of the day, and a second peak two hours prior to the dark period. With this clearly defined pattern, analysis of feeding behaviours solely during the light period is ideal. A look for any feeding activity during the dark period however, is always a good practice. As it is evident that birds eat their meals throughout the light period, a bird having its meals throughout the dark period may indicate an underlying problem and should be investigated.

4.5.2.2 Feeding Behaviour per Feeder

Not many studies have had the ability to determine an animal’s feeder preference within a group housing setting. Determining an animal’s ability to access individual feeders, and access preferred feeders can inform us about its status within an established dominance hierarchy (Brouns and Edwards, 1994). In group-housed sows, sows of different social rankings frequented specific areas of the feed trough and avoided others. Competition for resources, including preferred feeders, can lead to aggressive behaviour between the animals (Moinard et al., 2001). Feeder preference may therefore help us indirectly quantify social behaviour within large groups, providing insight on potential methods to decrease aggressive behaviour that might lead to economic and welfare losses (Brouns and Edwards, 1994; Moinard et al., 2001). Due to the design of the study with only two pens of turkeys, statistical comparisons were not possible. However, trends can be observed in the feeding behaviour of both the sire and dam lines. Based on the results for the sire line, the proportion of average feed consumed by turkeys in the High and Average FI groups was generally closer to the expected proportion of average feed intake.
The proportion of the average feed consumed by the Low FI birds however, was widely variable, indicative of birds who may be subject to displacement. Social ranking has been previously found to affect birds’ access to resources (Wood-Gush, 1971). Thus, lower feed intake birds may be more subordinate, and forced to visit a wider range of feeders in order to fulfill their meal size requirements. In other species, animals may change their short-term feeding behaviours in competitive situations in order to attain their required daily intake (dairy cattle: Zobel et al., 2011; pigs: Nielsen, 1995; beef steers: Corkum et al., 1994). We can hypothesize that birds in the Low FI group are the more subordinate ones and therefore must consume their feed wherever they can, not through their own choice. This is more evident when observing feeders where the least amount of feed is consumed among the Low FI birds. These feeders would be classified as the more preferred feeders for both the High and Average FI groups. This suggests that the Low FI birds may be avoiding feeders that are preferred by the High and Average FI groups. Alternatively, Low FI birds may just move around more than the High and Average FI birds. Research observing patterns between feed intake and feed efficiency may result in determining if Low FI birds tend to be less efficient. The variability in feed consumed between feeders by the Low FI birds was also apparent in the dam line. We see similarities in the feeding behaviour at certain feeders, where less feed is being consumed between the two lines by all three FI groups. These feeders are found close to either end of the row. We can hypothesize that there may be an environmental factor, such as lighting, or high worker traffic, that is resulting in the aversion to these feeders. Further investigation would be needed to determine the cause of the aversion in order to rectify it and re-establish an equal distribution of birds to feeder.

We identified a few feeders that were utilized less often than expected. For both the sire and dam lines, the first feeder in the row (feeder 1 for the sire line, and feeder 5 for the dam line) were both among the least preferred feeders across all three feeding traits observed. The first feeder was on the end, adjacent to either the walkway containing the feed hopper and workers or adjacent to another pen. This visual contact may have made these feeders less desirable; adding partitioning near the feeders may increase the use of these feeders. Other environmental factors that may have contributed to feeder preference include drinker placement within the floor pen, the location of the ventilation system or a fan, or lighting casting shadows on the feeders. Additionally, two of the feeders within the corner were found to be least preferred. These feeders in the corner may have been less desirable if the turkeys perceived themselves to be ‘cornered’
and a potential target for agonistic interactions. Unlike the dam line, the sire line consumed less feed from the last feeder in the row, feeder 32, than from other feeders. This feeder was located at the barn entrance, where high human traffic may have caused the birds to avoid this feeder. Since turkeys from the dam line had more low-occupancy feeders than turkeys in the sire line, they may have considered the feeder near the human traffic not nearly as aversive as the others. In addition, turkeys from the sire line also showed a slight aversion to the feeders that make up the corner in the barn. The feeders have since been repositioned into rows to eliminate the aversive effect the corner feeders were creating. Since other farm animal species, including sows, choose specific areas of a feed trough based on their social rank (Brouns and Edwards, 1994), turkey feeder preference within a group housing setting should be studied further to determine what makes one feeder preferred over another, and to adjust management strategies to more evenly distribute the number of visits per feeder throughout the flock, and potentially reduce aggression.

Since the turkeys followed a clear semi-diurnal pattern in feeding behaviour, data from high and low occupancy hours could potentially yield more details regarding feeder preferences (Billard and Biellier, 1975). The sire line showed great variability in the proportion of average feed consumed across all four occupancy hours. There seemed to be no definitive pattern suggesting feeding preferences or aversion, although the lack of feed intake at any given occupancy hour may be representative. The dam line however, showed a clear pattern in feed consumption across all four occupancy hours. Within this line there may be an aversion for the groups of feeders found at either end as well as two groups of feeders in the middle. The first group of feeders in the middle could indicate an environmental factor causing the aversion such as lighting or ventilation. The second group of feeders showing signs of being unfavourable were the feeders that made up the corner of the “L” shaped feeder placement. This corner forces birds to be in closer proximity to one another and also back into each other upon leaving their respective feeders. This clear feed consumption pattern in the dam line could imply that this line may have a higher level of competition compared to the sire line. As seen in both dairy cattle and sows, high levels of competition are usually associated with high levels of displacements by means of aggressive behaviours (Brouns and Edwards, 1994; Huzzey et al., 2012). For this reason, identifying unfavourable feeders and the factors that create the aversion could aid in reversing the preference. By making a least preferred feeder more favourable, we could restore
the even distribution of feeder occupancy and potentially mitigate aggressive behaviour associated with competition for resources.

4.6 Conclusions

Within group housing, turkeys followed a semi-diurnal feeding pattern. Differences were observed in meal characteristics as well as feeder preference between the sire and dam lines. There was more variance in feeder usage than expected among the ‘Low FI’ birds compared to the ‘High FI’ and ‘Average FI’ birds. If the factors contributing to preferences for feeders can be identified, then those factors can potentially be manipulated to distribute the feeding activity more evenly across all feeders. This could improve body weight uniformity and potentially reduce the occurrences of aggressive behaviour related to feeding. Next steps will include determining if there are any correlations between these defined feeding traits and other desirable production traits or behavioural traits that may be harder to measure directly, such as aggression.
Figure 4.1 Schematic of the floor pen housing system used for both the sire and dam lines. The numbers represent individual feeder spaces to which the sire line had access and the circles represent the drinkers. The dam line had access to feeders 5 through 32 only.
Table 4.1 Feeding behaviour traits and production traits with their abbreviations and definitions.

<table>
<thead>
<tr>
<th>Traits</th>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Meals per Day</td>
<td>MLNB</td>
<td>The number of meals that occurred throughout the day</td>
</tr>
<tr>
<td>Meal Size (g)</td>
<td>MLSZ</td>
<td>The feed intake throughout the duration of the meal</td>
</tr>
<tr>
<td>Meal Duration (min)</td>
<td>MLDR</td>
<td>The amount of time to complete a series of visits where the time interval did not exceed the meal criterion</td>
</tr>
<tr>
<td>Time Spent Feeding per Meal</td>
<td>TSFM</td>
<td>The time spent in the feeder, feeding, throughout the meal</td>
</tr>
<tr>
<td>Feed Rate (g/min)</td>
<td>FR</td>
<td>The rate at which the meal size was consumed</td>
</tr>
<tr>
<td>Number of Visits per Meal</td>
<td>VIMB</td>
<td>The number of visits throughout the duration of the meal</td>
</tr>
<tr>
<td>Average Daily Feed Intake (g)</td>
<td>ADFI</td>
<td>The total amount of feed consumed throughout the day</td>
</tr>
<tr>
<td>Time Spent Feeding per Day</td>
<td>TSFD</td>
<td>The total time spent in the feeder throughout the day</td>
</tr>
<tr>
<td>Body Weight at 16 Weeks (kg)</td>
<td>BW16</td>
<td>Body weight at 16 weeks of age</td>
</tr>
<tr>
<td>Body Weight at 20 Weeks (kg)</td>
<td>BW20</td>
<td>Body weight at 20 weeks of age</td>
</tr>
<tr>
<td>Average Daily Gain (g)</td>
<td>ADG</td>
<td>Average daily body weight gain</td>
</tr>
<tr>
<td>Feed Conversion Ratio</td>
<td>FCR</td>
<td>The efficiency of converting feed mass into body gain</td>
</tr>
</tbody>
</table>
Table 4.2 Meal criterion and summary of the average meal characteristics (± standard error) for the sire and dam lines.

<table>
<thead>
<tr>
<th>Category</th>
<th>Sire Line</th>
<th>Dam Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meal Criterion (min)</td>
<td>13.93</td>
<td>7.11</td>
</tr>
<tr>
<td>Meal Duration (min)</td>
<td>6.10 ± 0.02</td>
<td>2.60 ± 0.01</td>
</tr>
<tr>
<td>Number of Meals per Day</td>
<td>9.42 ± 0.03</td>
<td>11.63 ± 0.05</td>
</tr>
<tr>
<td>Meal Size (g)</td>
<td>68.81 ± 0.17</td>
<td>31.87 ± 0.11</td>
</tr>
<tr>
<td>Time Spent Feeding per Meal (min)</td>
<td>5.76 ± 0.03</td>
<td>2.48 ± 0.01</td>
</tr>
<tr>
<td>Feeding Rate (g/min)</td>
<td>20.49 ± 0.36</td>
<td>26.65 ± 0.55</td>
</tr>
<tr>
<td>Visit per Meal</td>
<td>1.17 ± 0.00</td>
<td>1.10 ± 0.00</td>
</tr>
<tr>
<td>Daily Intake (g)</td>
<td>627.74 ± 1.85</td>
<td>363.76 ± 1.73</td>
</tr>
<tr>
<td>Time Spent Feeding per Day (min)</td>
<td>48.85 ± 0.23</td>
<td>27.12 ± 0.15</td>
</tr>
</tbody>
</table>
Figure 4.2 The square-root of the relative frequency of the inter-visit duration and the intra-visit duration for the sire line. The point of intersect is at 13.93 minutes therefore, defining the meal criterion for this line.
Figure 4.3 The square-root of the relative frequency of the inter-visit duration and the intra-visit duration for the dam line. The point of intersect is at 7.37 minutes therefore, defining the meal criterion for this line.
Figure 4.4 Average visit feed intake per bird per day (g) by hour for the a) sire line and b) the dam line. Lighting period from 06:00 to 20:00.
Figure 4.5 Average visit duration per bird per day (min) by hour throughout the light period (06:00-20:00) for a) the sire line and b) the dam line.
Figure 4.6 Average number of visits per bird per day by hour throughout the light period (06:00-20:00) for a) the sure line and b) the dam line.
Figure 4.7 The realized proportion of the square root of the average feed intake per bird per feeder for the ten high (▲), the ten average (♦), and ten low (●) feed intake birds at each feeder vs the expected (▬) proportion of feed intake per feeder for the sire line.
Figure 4.8 The realized proportion of the square root of the average feed intake per bird per feeder for the ten high (▲), the ten average (♦), and ten low (●) feed intake birds at each feeder vs the expected (▬) proportion of feed intake per feeder for the dam line.
Figure 4.9 Average a) visit feed intake per bird per day (g), b) visit duration per bird per day (min), and c) number of visits per bird per day by feeder for the sire line.
**Figure 4.10** Average a) visit feed intake per bird per day (g), b) visit duration per bird per day (min), and c) number of visits per bird per day by feeder for the dam line.
Figure 4.11 The realized proportion of the square root of the average feed intake per bird per feeder for the two high occupancy hours (06:00-●, 18:00-♦) and the two low occupancy hours (11:00-▲, 13:00-■) vs the expected (—) proportion of feed intake per feeder for the sire line.
Figure 4.12 Square root of the visit feed intake per bird per feeder (kg) during the two high (06:00, 18:00) and two low (11:00, 13:00) occupancy hours by feeder for the dam line.
Chapter 5 Genetic Parameters of Feeding Behaviours and Production Traits in the Commercial Turkey (*Meleagris gallopavo*)

5.1 Abstract

The use of automated feed intake systems has allowed individual feed intake data to be collected in group-housed flocks. This technology has improved our selection for more efficient birds. These systems also permit the study of feeding behaviours which may be correlated to feed efficiency. Data on 1669 large white turkey toms were used in defining feeding behaviours. Heritabilities and correlations of these feeding behaviours and specific production traits, such as feed conversion ratio (FCR) were calculated using a univariate and bivariate model, respectively. All heritabilities for feeding behaviours ranged from moderate to high with the highest belonging to time spent feeding per meal (0.60±0.07), time spent feeding per day (0.58±0.07), and daily meal duration (0.58±0.07). Correlations between feeding behaviours ranged from moderate to high whereas correlations between feeding behaviours and productions traits ranged from low to moderate. These results suggest that selection emphasis on feeding behaviours would result in genetic change and that placing selection pressures on FCR would have an effect on feeding behaviours.

5.2 Introduction

Genetic selection has played a key role in improving production and welfare within the commercial turkey industry (Havenstein *et al.*, 2007). Increasing changes in technology have allowed different traits to be measured or traditional traits to be measured more accurately, making the potential rates of genetic improvement greater. The use of automated feed recording systems in group-housed turkeys has allowed for the collection of data on individual birds reared within a group environment (Tu *et al.*, 2011). This data can be used to identify the most feed efficient birds as well as capture many feeding behaviours that can be used in breaking feed efficiency down into individual feeding behaviour components (Willems, 2015).

There are many studies that have examined the relationships between feeding behaviours and production traits, such as body weight, meat yield, and feed efficiency (pigs and broilers: Kyriazakis, 2011; broilers: Aggrey *et al.*, 2010; Howie *et al.*, 2011; turkeys: Willems, 2015; pigs:...
Labroue et al., 1997). Feed efficiency is a measure of an animals’ ability to convert feed into body mass and an animal who is more feed efficient can gain more body mass per unit of feed. Identifying and understanding the relationship between feeding behaviours and feed efficiency could be beneficial as feed efficiency is an economically important trait (Willems, 2015). Previous studies on these relationships have been most common in pigs and broilers and these have found low genetic correlations between feeding behaviour traits and commercially important traits (Kyriazakis, 2011; Aggrey et al., 2010; Howie et al., 2011; Labroue et al., 1997). In turkeys, however, moderate correlations were identified between feeding behaviour traits and production traits (Willems, 2015).

As feed efficiency is an economically important trait in a turkey breeding program, additional knowledge on the heritability and correlations between this trait and feeding behaviours would be beneficial. Possible benefits could include the use of feeding behaviours in breeding program. The aim of this study was to calculate the genetic parameters of various feeding behaviour traits and their correlations with some important production traits.

5.3 Methods

5.3.1 Animals

Data was collected from six flocks of turkeys, hatched at different times of the year and raised at a primary breeder pedigree facility. One thousand six hundred and sixty-nine large white turkey toms from a sire line of breeders were used in the trial. Sire lines are selected for a mixture of production traits such as growth rate, feed efficiency, meat yield and reproductive traits. Birds were reared under standard commercial barn conditions and moved to a single, group pen (7.32m × 15.85m) at 16 weeks of age. Individual birds were identified with a Radio-Frequency IDentification (RFID) wing band. Birds remained on trial for 35 days. Light cycles alternated between a 14L: 10D with a light intensity of approximately 60 LUX. Birds had ad libitum access to feed and water throughout the 35 day period.

5.3.2 Feeding Behaviours

Feeding data was recorded with an Electronic Feed Intake Measurement System (EFIMS) which consisted of 32 feeders, and was activated by the unique RFID attached to each bird. Schematics have been previously reported for this feeding system (Tu et al., 2011). The feeders
were set up in an “L” shaped pattern with 24 and 8 across each arm as shown in Figure 5.1. There were approximately 10 birds per feeder, and 80 birds per bell drinker. The data was received in fragments, caused by either a bird moving to a different feeder or a loss in the connection between the RFID tag and the reader on the feeder. Once it was determined that a fragment was caused by a connection being lost, the fragment was compressed into the same visit.

Total daily feeding duration and feed intake were calculated for each individual bird. Outliers were defined as records that were greater than one and a half times the length of the boxplot from either end for the total daily feeding duration and total daily feed intake traits. On days that this threshold was exceeded, the entire day was removed from the data set for the affected individual birds.

A meal was defined from a series of events that consisted of both feeding and non-feeding, which were compressed into meals using a set meal criterion (Yeates et al., 2001; Zorrilla et al., 2005). The meal criterion is defined as the longest interval of time between two visits within a meal. It was calculated by finding the intersection between the square root of the relative frequency of the inter-visit duration and relative frequency of the intra-visit duration, respectively (DeVries et al., 2003). Once the meal criterion was determined, visits were then compressed into meals in the following way: the first visit to the feeders of the day was denoted as the start of the first meal. If the length between the first visit and the second visit was equal or shorter than the meal criterion calculated, the second visit was also part of the first meal. This adding of visits into a meal continued until the interval of time between two visits was longer than the meal criterion. At this point, the second visit signaled the start of the second meal and it begins again. Feeding behaviours were then calculated. Feeding behaviour traits and production traits are defined in Table 5.1. Means and standard errors were then calculated for all the traits.

5.3.3 Genetic Analysis

ASReml 3.0 was used to estimate the genetic and phenotypic parameters (Gilmour et al., 2009). The following model was used for the genetic analysis:

\[ \text{Trait} = \text{hatch} + \text{animal} + e \]
Where *Trait* is the individual phenotype for each trait, *hatch* is a fixed effect of hatch group, *animal* is the random additive animal effect, and *e* is the random residual error. Assumptions of the model include:

\[
a \sim A, \quad \sigma_a^2 \sim N(0, A\sigma_a^2), \text{ where } A \text{ is an additive relationship matrix, and } \sigma_a^2 \text{ is an additive genetic variance.}
\]

\[
e \sim N(0, I\sigma_e^2), \text{ where } I \text{ is an identity matrix, and } \sigma_e^2 \text{ is a residual variance.}
\]

Heritability values, and their corresponding standard errors, were calculated for the following feeding behaviours: number of meals per day, meal size, meal duration, time spent feeding per meal, feed rate, number of visits per meal, average daily feed intake, and time spent feeding per day. In addition, heritability values, with standard errors, were also calculated for the following production traits: body weight at 16 and 20 weeks of age, average daily gain, and feed conversion ratio. For each trait, heritability was calculated as the proportion of additive genetic variance out of total phenotypic variance, where variances were estimated from univariate models. The distribution of the random effects in the univariate models were assumed as follows:

\[
\text{Var}(a) = \begin{bmatrix} A\sigma_a^2 & 0 \\ 0 & \sigma_e^2 \end{bmatrix}
\]

Where *A* is an additive genetic relationship matrix for all animals and *I* is an identity matrix. The animal genetic variance is represented by $\sigma_a^2$ whereas the residual variance is represented by $\sigma_e^2$.

Phenotypic and genetic correlations, with corresponding standard errors, were calculated between feeding behaviours, as well as with the production traits. Correlations for all trait pairs of interest were calculated using bivariate models. The distribution of the random effects in the bivariate models were assumed as follows:
\[
\text{Var} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} \sigma_1^2 & \sigma_{12} \\ \sigma_{12} & \sigma_2^2 \end{bmatrix} A = G_0 \otimes A
\]

\[
\text{Var} \begin{bmatrix} e_1 \\ e_2 \end{bmatrix} = \begin{bmatrix} \sigma_{e1}^2 & \sigma_{e12} \\ \sigma_{e12} & \sigma_{e2}^2 \end{bmatrix} I = E_0 \otimes I
\]

Where A is an additive genetic relationship for all animals; I is an identity matrix; \(G_0\) is a 4x4 additive genetic variance-covariance matrix between the two traits, and \(E_0\) is a 4x4 variance-covariance matrix between the residual components of the two traits. \(\sigma_1^2\) and \(\sigma_2^2\) are the variances of the additive genetic components of trait 1 and 2, respectively and \(\sigma_{12}\) is the covariance between the two traits. Similarly, \(\sigma_{e1}^2\) and \(\sigma_{e2}^2\) are the variances of the residual components of the two traits with \(\sigma_{e12}\) representing the covariance between the traits.

5.4 Results

Table 5.2 shows means and standard errors of all the feeding behaviour and production traits.

5.4.1 Heritability

Heritabilities, with standard errors, of all the feeding behaviour traits are shown in Table 5.3 and production traits in Table 5.4. Average daily feed intake (0.16±0.05), average daily gain (0.18±0.05), and feed conversion ratio (0.14±0.04) had the lowest heritabilities and the traits with the highest heritabilities were time spent feeding per day (0.58±0.07), total daily meal duration (0.58±0.07), and time spent feeding per meal (0.60±0.07).

5.4.2 Correlations with Production Traits

Most feeding behaviours had positive genetic and phenotypic correlations with body weight at 16 weeks of age and at 20 weeks of age (Table 5.4). Negative correlations between the number of meals per day with both body weight at 16 weeks of age and 20 weeks of age were the only exceptions. Most correlations between the feeding behaviour traits, and with average daily gain, and feed conversion ratio were low to moderate. Exceptions among correlations with average daily gain include the genetic correlation between average daily gain and average daily feed intake (0.57±0.15).
5.4.3 Correlations between Feeding Behaviour Traits

Phenotypic and genetic correlations between feeding behaviours are shown in Table 5.3. Some of the highest positive genetic correlations were time spent feeding per day with total daily meal duration (0.98±0.005), and with time spent feeding per meal (0.88±0.03), and total daily meal duration with time spent feeding per day (0.79±0.05). Highest negative genetic correlations were meal size with number of meals per day (-0.92±0.03), total daily meal duration (-0.40±0.09), and number of visits per day (-0.37±0.12).

5.5 Discussion

5.5.1 Heritability

Feeding behaviour heritability values were generally higher compared to the values found for production traits. This trend was also observed in previous studies across different species (pigs: Labroue et al., 1997; broilers: Howie et al., 2011; turkeys: Willems, 2015). The moderate to high heritabilities of the feeding behaviours would make them excellent candidates for their inclusion in the selection index. However, determining their correlation to the production traits that are part of the breeding goals of the program, will determine which feeding behaviours traits would be the most appropriate. The number of meals per day, meal size, and total daily meal duration heritabilities were all slightly higher than what was reported in a previous study conducted in turkeys (Willems, 2015). The heritability for meal size was similar to what was found in broilers (Howie et al., 2011). The heritability for total daily meal duration was higher than both previously mentioned studies by approximately 0.3. This could be due to the way total daily meal duration is defined as a trait. In the present study, total daily meal duration encompasses both feeding and non-feeding events throughout the entire day into the time whereas previous studies calculated total daily meal duration as time spent at the feeder (Willems, 2015). The remainder of the feeding behaviour heritabilities were slightly higher than what was found in a previous study (Howie et al., 2011). The previous study was done with broilers which could explain the observed difference in heritability values. Heritability values were within the same range as reported in other agricultural species such as pigs and lambs (Labroue et al., 1997; Cammack et al., 2005). Looking specifically at the heritabilities of the production traits, the feed conversion ratio value was lower than previously reported in the literature with broilers (Aggrey et al., 2010; Howie et al., 2011). A previous study conducted
using turkeys found feed conversion ratio heritability values slightly lower but within the same range as reported in the current study (Willems, 2015). An additional study, using turkeys, yielded similar heritabilities for feed conversion ratio, body weight around 15-19 weeks of age, and average daily gain (Case et al., 2012)

5.5.2 Correlations with Production Traits

Genetic correlations between feeding behaviours and body weight ranged from low to high, with the only negative correlation being with number of meals per day. Although there is a negative genetic correlation between body weight and number of meals per day, the correlation itself is not necessarily unfavourable. Birds who have more meals per day have smaller body weights. Number of meals per day could therefore be indicative of less efficient birds. Although they are, seemingly, eating more, they are the smaller birds in the flock. In a previous study with broilers, the genetic correlations were all found to be low between body weight and feeding behaviours (Howie et al., 2011). The genetic correlations between the feeding behaviours and feed conversion ratio, reported in this study, were for the most part equal or higher to the correlations in the previous study (Howie et al., 2011), which implies that selection on feeding behaviours in turkeys would result in a greater effect on the production traits compared to broilers.

Some reasons for the differences in the correlations could be similarly due to the aforementioned differences in barn management practices, diet, and the calculation of meal criterion. In addition, the body weights used in the broiler study were from day 35 as opposed to the current study which used body weights at 16 and 20 weeks of age. The weights collected on these two species were done at different stages of their growth curves and would therefore impact their correlations to feeding traits (Knizetova et al., 1995). When comparing the correlations to a previous study using turkeys, there were some differences in the phenotypic correlations (Willems, 2015). In the previous study, feed conversion ratio correlations with number of meals per day, meal size, total daily meal duration, and average daily feed intake were 0.27±0.03, 0.22±0.03, 0.15±0.04, and 0.76±0.02, respectively. In the current study correlations between these traits were 0.11±0.03, 0.10±0.03, 0.10±0.02, and 0.38±0.02, respectively. Both studies used turkeys but the standard errors of the current study were smaller than in the previous. These differences could be due to the different methods of calculating meal criterion or
the differing definitions of some of the feeding behaviours. For example, in the present study, meal incorporated both feeding and non-feeding events. This leads to longer total daily meal durations and consequently larger meals compared to the previous turkey study.

Two previous studies analysed the correlations between feeding behaviours and production traits such as feed conversion ratio and residual feed intake (Howie et al., 2010; Willems, 2015). They found weak genetic correlations between the two groups of traits and concluded that selection on feeding behaviours would have relatively no effect on feed efficiency. However, some moderate and strong genetic correlations were observed between feeding behaviour traits and production traits within this study. For example, the genetic correlations between meal size and body weight at 20 weeks of age (0.38±0.11) and ADG (0.42±0.14), and the correlation between daily intake and body weight at 20 weeks of age (0.59±0.13), ADG (0.57±0.15), and FCR (0.30±0.21). This would imply that selection for feed efficiency would lead to changes in feeding behaviours. As feed efficiency is a trait of economic importance it would be beneficial to keep feeding behaviour traits in mind as selection criteria in order to maximize selection output. Although daily intake has the highest genetic correlation with the production traits, meal size has a larger correlation with ADG compared to daily intake with FCR. For this reason, and the fact that the trait’s heritability is 0.55±0.07, meal size may be of value in a selection index. It has also been discussed that a specific feeding behaviour pattern may be more ideal depending on the rearing environment (Willems, 2015). For example, birds in warmer climates may be at an advantage by having smaller, more frequent meals as it requires them to be standing more often, enabling them to expel heat. In addition, birds in rearing environments that have a high bird to feeder ratio may want to utilize a larger, but less frequent meal based feeding pattern. However, as shown in Chapter 4, turkeys on a flock basis tend to have two peak feeding times throughout the day, potentially making longer, larger meals more difficult and result in more aggressive attacks.

There were some differences between some of the phenotypic correlations and their genetic correlations between feeding behaviours and production traits. These include the correlations between average daily gain and number of meals per day ($r_p = 0.07±0.03$, $r_g = -0.27±0.17$), and between feed conversion ratio and meal size ($r_p = 0.10±0.03$, $r_g = -0.02±0.18$), time spent feeding per day ($r_p = 0.07±0.03$, $r_g = -0.04±0.17$), and time spent feeding per meal ($r_p = 0.01±0.03$, $r_g = -0.17±0.17$). Both average daily gain and feed conversion ratio were among the
traits with their residual variance making up the highest percentage of their phenotypic variance (82% and 86%, respectively). Similarly described above, the variability in the social dynamics between the flocks could be adding to the residual variance. Feed conversion ratio, being a ratio trait, may also have that as an added component contributing to the residual variance.

5.5.3 Correlations between Feeding Behaviours Traits

The highest genetic correlations found between feeding behaviours were as expected and can give some insight on the phenotypic correlations observed for those traits. As total daily meal duration is the total duration of the meal (visits plus interval between visits), and time spent feeding per meal is only the portion of the total daily meal duration that are visits, we would expect that as the total daily meal duration increases so does the time spent feeding per meal and per day. Likewise, as the time spent feeding per meal increases, so does the time spent feeding per day. Although the correlation between these three traits would suggest that they are in fact the same trait, in future research these traits should still be calculated and considered as they are phenotypically different and can vary.

According to the phenotypic correlations, a larger meal size is associated with birds having fewer meals per day. This pattern could reflect a more dominant bird within the flock as seen in a study conducted with sows. When grouped sows were feed restricted, the more subordinate ones not only had smaller meals more frequently than the dominant sows, but consequently gained less weight due to displacement (Brouns and Edwards, 1994). In the same study with sows fed ad libitum, animals lower in the hierarchy had more, smaller meals throughout the day, however were able to maintain similar weight gains to the dominant sows in the group. Although the phenotypic correlation patterns can potentially give insight on the social ranking system of animals within the hierarchy, the high negative genetic correlations between these traits would imply that selection for any of these traits would have an opposing directional effect however, not necessarily unfavourable. As previously mentioned, selecting for birds who have more, smaller meals throughout the day could be more beneficially for birds in warmer climates.

Most correlations were within the range of previous reports in the literature; however, some differences were observed (Howie et al., 2011; Willems, 2015). Examples of these differences are with the genetic correlations between number of meals and average daily feed
intake, total daily meal duration and meal size; where they are negative correlations in the present study in comparison to the previous (Willems, 2015). Yet, the negative correlation between meals per day and average daily feed intake is not unfavourable. For examples, this correlation simply implies that birds who have more meals per day actually consume less throughout the day. As seen in a study conducted with swine, the more subordinate sows ate more frequently throughout the day and gained the least amount of weight compared to their more dominant counter-parts (Brouns and Edwards, 1994). This negative correlation, along with the positive correlation observed between body weight and average daily feed intake and the negative correlation between number of meals per day and body weight, therefore provides an explanation to this phenomena observed in pigs. In addition, the genetic correlations between meal size and average daily feed intake were lower in the Willems (2015) study.

Compared to the Howie et al. (2011) study, the biggest differences were in the range of the values. The present study had more moderate phenotypic and genetic correlations compared to the low correlations of the broiler study. These differences were most likely due to the fact that management practices, nutritional components of the feed, the methodology for calculating meal criterion differed, as well as the difference in poultry species (Howie et al., 2011). A study found that when heat stress was a factor for turkeys, birds on high energy and low protein feed had different feeding behaviour patterns compared to those on low energy and high protein diets (Havenstein et al., 2007). In an additional study conducted with broilers, 10-15 % of the increase in growth performance in a 37 year period was attributed to diet (Havenstein et al., 2003). For this reason, diet and barn management conditions may be a factor contributing to differences observed in feeding behaviours.

The methodology in calculating meal criterion differed between the present study and the broiler study (Howie et al., 2011). In the previous study, the probability of starting a new meal was incorporated into the calculation of meal criterion as that was the appropriate approach for the data that was available. However, using this method or simply calculating meal criterion using the distribution of between-meal interval length yielded small differences in meal characteristics. Using different methods of calculating the meal criterion therefore could result in differences in the phenotypes of the feeding behaviour traits being measured (Howie et al., 2009a). Another factor potentially contributing to difference among the studies is the difference in sample sizes. The sample size used in the previous turkey study was smaller than the current
study and the standard errors were also larger (Willems, 2015). Overall, we found higher phenotypic and genetic correlations than what were previously reported in the literature for broilers, but the differences in correlation ranges with the turkey study did not show any specific trends (Howie et al., 2011; Willems, 2015).

Upon observing the correlations between feeding behaviours, we see some differences between some of the phenotypic correlations and their genetic correlation counterparts. In all instances, the phenotypic correlations were positive while their genetic correlations were negative. These occurrences are with the correlations between average daily feed intake and number of meals per day \( r_p = 0.22 \pm 0.03, r_g = -0.25 \pm 0.18 \), and time spent feeding per day \( r_p = 0.02 \pm 0.03, r_g = -0.24 \pm 0.16 \). This could be due to the fact that for average daily intake, the percentage of phenotypic variance that is due to the residual variance is substantial (84%). This large residual variance could be due to multiple components such as variations in management or the environment, in addition to the variation in the social component. Animals may alter their short-term feeding behaviours in order to achieve their required daily intake. As turkeys are highly social animals with well-established hierarchies in small groups, the social effect on the hierarchy could lead to these changes in short-term feeding behaviour thus increasing the residual variance component. In larger groups however, a “tolerance” system is adapted rather than a hierarchy (D’Eath and Keeling, 2003). Dominant aggressive behaviour has been observed in these larger groups although it is suggested that it is on an individual assessment basis (D’Eath and Keeling, 2003). In addition, the large standard errors on the genetic correlations could also be representative that the correlations are closer to zero rather than a negative correlation.

5.6 Conclusion

The moderate to high heritabilities of feeding behaviour traits suggest that genetic change would be apparent if these traits were emphasized in a selection program. The genetic correlations between feeding behaviour traits and production traits, which ranged from low to high, imply that selection for more efficient birds would have an effect on feeding behaviours. Although the main focus of any agricultural animal is production, there are some advantages to certain feeding behaviours depending on climate, housing densities, and social interactions. As feed efficiency selection becomes more accurate with genomics, monitoring the variance of
feeding behaviours would be beneficial to the breeding program in order to mitigate any negative outcomes and maximize production.
Figure 5.1 Schematic of the floor pen housing system used for the experiment. The numbers represent individual feeder spaces to which the birds had access and the circles represent the drinkers.
<table>
<thead>
<tr>
<th>Traits</th>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Meals per Day</td>
<td>MLNB</td>
<td>The number of meals that occurred throughout the day</td>
</tr>
<tr>
<td>Meal Size (g)</td>
<td>MLSZ</td>
<td>The feed intake throughout the duration of the meal</td>
</tr>
<tr>
<td>Total Daily Meal Duration (min)</td>
<td>MLDR</td>
<td>The daily total amount of time to complete a series of visits where the time interval did not exceed the meal criterion</td>
</tr>
<tr>
<td>Time Spent Feeding per Meal (min)</td>
<td>TSFM</td>
<td>The time spent in the feeder, feeding, throughout the meal</td>
</tr>
<tr>
<td>Feed Rate (g/min)</td>
<td>FR</td>
<td>The rate at which the meal size was consumed</td>
</tr>
<tr>
<td>Number of Visits per Meal</td>
<td>VIMB</td>
<td>The number of visits throughout the duration of the meal</td>
</tr>
<tr>
<td>Average Daily Feed Intake (g)</td>
<td>ADFI</td>
<td>The total amount of feed consumed throughout the day</td>
</tr>
<tr>
<td>Time Spent Feeding per Day (min)</td>
<td>TSFD</td>
<td>The time spent in the feeder, feeding, throughout the day</td>
</tr>
<tr>
<td>Body Weight at 16 Weeks (kg)</td>
<td>BW16</td>
<td>Body weight at 16 weeks of age</td>
</tr>
<tr>
<td>Body Weight at 20 Weeks (kg)</td>
<td>BW20</td>
<td>Body weight at 20 weeks of age</td>
</tr>
<tr>
<td>Average Daily Gain (g)</td>
<td>ADG</td>
<td>Average daily body weight gain</td>
</tr>
<tr>
<td>Feed Conversion Ratio</td>
<td>FCR</td>
<td>The efficiency of converting feed mass into body gain</td>
</tr>
</tbody>
</table>
Table 5.2 Means (Standard Errors) of the feeding behaviour and production traits.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Mean (SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meals per day, no. (MLNB)</td>
<td>9.51 (0.06)</td>
</tr>
<tr>
<td>Meal size, g (MLSZ)</td>
<td>73.69 (0.47)</td>
</tr>
<tr>
<td>Total Daily Meal duration, min (MLDR)</td>
<td>62.22 (0.50)</td>
</tr>
<tr>
<td>Time feeding per meal, min (TSFM)</td>
<td>6.07 (0.06)</td>
</tr>
<tr>
<td>Visits per meal, no. (VINB)</td>
<td>1.19 (0.00)</td>
</tr>
<tr>
<td>Avg. Daily Feed Intake, g (ADFI)</td>
<td>661.23 (1.97)</td>
</tr>
<tr>
<td>Time feeding per day, min (TSFD)</td>
<td>54.32 (0.45)</td>
</tr>
<tr>
<td>Body weight at 16 wk, kg (BW16)</td>
<td>14.58 (0.02)</td>
</tr>
<tr>
<td>Body weight at 20 wk, kg (BW20)</td>
<td>22.57 (0.04)</td>
</tr>
<tr>
<td>Avg. Daily Gain, g (ADG)</td>
<td>0.26 (0.00)</td>
</tr>
<tr>
<td>Feed Conversion Ratio (FCR)</td>
<td>2.61 (0.01)</td>
</tr>
</tbody>
</table>
Table 5.3 Heritabilities (Standard Errors) (Diagonal), Phenotypic Correlations (Standard Error) (Above), and Genetic Correlations (Standard Error) (Below) of the feeding behaviour traits.

<table>
<thead>
<tr>
<th>Trait*</th>
<th>MLNB</th>
<th>MLSZ</th>
<th>MLDR</th>
<th>TSFM</th>
<th>VINB</th>
<th>ADFI</th>
<th>TSFD</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLNB</td>
<td>0.44 (0.07)</td>
<td>-0.78 (0.01)</td>
<td>0.41 (0.03)</td>
<td>-0.27 (0.03)</td>
<td>0.34 (0.03)</td>
<td>0.22 (0.03)</td>
<td>0.27 (0.03)</td>
</tr>
<tr>
<td>MLSZ</td>
<td>-0.92 (0.03)</td>
<td>0.55 (0.07)</td>
<td>-0.39 (0.03)</td>
<td>0.18 (0.03)</td>
<td>-0.26 (0.03)</td>
<td>0.32 (0.03)</td>
<td>-0.28 (0.03)</td>
</tr>
<tr>
<td>MLDR</td>
<td>0.30 (0.11)</td>
<td>-0.40 (0.09)</td>
<td>0.58 (0.07)</td>
<td>0.69 (0.02)</td>
<td>0.28 (0.03)</td>
<td>0.07 (0.03)</td>
<td>0.96 (0.00)</td>
</tr>
<tr>
<td>TSFM</td>
<td>-0.31 (0.11)</td>
<td>0.15 (0.11)</td>
<td>0.79 (0.05)</td>
<td>0.60 (0.07)</td>
<td>-0.13 (0.03)</td>
<td>-0.13 (0.03)</td>
<td>0.81 (0.01)</td>
</tr>
<tr>
<td>VINB</td>
<td>0.46 (0.12)</td>
<td>-0.37 (0.12)</td>
<td>0.48 (0.12)</td>
<td>-0.03 (0.14)</td>
<td>0.30 (0.06)</td>
<td>0.18 (0.03)</td>
<td>0.09 (0.03)</td>
</tr>
<tr>
<td>ADFI</td>
<td>-0.25 (0.18)</td>
<td>0.54 (0.12)</td>
<td>-0.18 (0.16)</td>
<td>-0.19 (0.16)</td>
<td>0.39 (0.18)</td>
<td>0.16 (0.05)</td>
<td>0.02 (0.03)</td>
</tr>
<tr>
<td>TSFD</td>
<td>0.16 (0.11)</td>
<td>-0.29 (0.10)</td>
<td>0.98 (0.00)</td>
<td>0.88 (0.03)</td>
<td>0.31 (0.13)</td>
<td>-0.24 (0.16)</td>
<td>0.58 (0.07)</td>
</tr>
</tbody>
</table>

*MLNB= Number of meals per day, MLSZ= Meal Size, MLDR=Total Daily Meal Duration, TSFM=Time Spent Feeding per Meal, FR=Feed Rate, VINB= Number of Visits per Meal, ADFI=Average Daily Feed Intake, TSFD=Time Spent Feeding per Day.
Table 5.4 Phenotypic correlations ($r_p$) (standard error), and genetic correlations ($r_g$) (standard error) between the feeding behaviour traits and the production traits.

<table>
<thead>
<tr>
<th>Traits*</th>
<th>BW16</th>
<th>BW20</th>
<th>ADG</th>
<th>FCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h^2$</td>
<td>0.35 (0.06)</td>
<td>0.35 (0.06)</td>
<td>0.18 (0.05)</td>
<td>0.14 (0.04)</td>
</tr>
<tr>
<td>MLNB</td>
<td>-0.14 (0.03)</td>
<td>-0.05 (0.03)</td>
<td>0.07 (0.03)</td>
<td>0.11 (0.03)</td>
</tr>
<tr>
<td>MLSZ</td>
<td>0.21 (0.03)</td>
<td>0.26 (0.03)</td>
<td>0.17 (0.03)</td>
<td>0.10 (0.03)</td>
</tr>
<tr>
<td>MLDR</td>
<td>0.11 (0.03)</td>
<td>0.04 (0.03)</td>
<td>-0.05 (0.03)</td>
<td>0.10 (0.02)</td>
</tr>
<tr>
<td>$r_p$ TSFM</td>
<td>0.18 (0.03)</td>
<td>0.06 (0.03)</td>
<td>-0.11 (0.03)</td>
<td>0.01 (0.03)</td>
</tr>
<tr>
<td>VINF</td>
<td>0.03 (0.03)</td>
<td>0.02 (0.03)</td>
<td>0.002 (0.03)</td>
<td>0.13 (0.03)</td>
</tr>
<tr>
<td>ADFI</td>
<td>0.19 (0.03)</td>
<td>0.43 (0.02)</td>
<td>0.43 (0.02)</td>
<td>0.38 (0.02)</td>
</tr>
<tr>
<td>TSFD</td>
<td>0.11 (0.03)</td>
<td>0.04 (0.03)</td>
<td>-0.06 (0.03)</td>
<td>0.07 (0.03)</td>
</tr>
<tr>
<td>$r_g$ MLNB</td>
<td>-0.18 (0.13)</td>
<td>-0.30 (0.13)</td>
<td>-0.27 (0.17)</td>
<td>0.15 (0.18)</td>
</tr>
<tr>
<td>MLSZ</td>
<td>0.17 (0.12)</td>
<td>0.38 (0.11)</td>
<td>0.42 (0.14)</td>
<td>-0.02 (0.18)</td>
</tr>
<tr>
<td>MLDR</td>
<td>0.29 (0.11)</td>
<td>0.09 (0.12)</td>
<td>-0.17 (0.15)</td>
<td>0.05 (0.17)</td>
</tr>
<tr>
<td>TSFM</td>
<td>0.37 (0.11)</td>
<td>0.26 (0.12)</td>
<td>-0.02 (0.16)</td>
<td>-0.17 (0.17)</td>
</tr>
<tr>
<td>VINF</td>
<td>0.25 (0.14)</td>
<td>0.19 (0.15)</td>
<td>0.06 (0.19)</td>
<td>0.26 (0.19)</td>
</tr>
<tr>
<td>ADFI</td>
<td>0.39 (0.16)</td>
<td>0.59 (0.13)</td>
<td>0.57 (0.15)</td>
<td>0.30 (0.21)</td>
</tr>
<tr>
<td>TSFD</td>
<td>0.28 (0.12)</td>
<td>0.10 (0.12)</td>
<td>-0.15 (0.15)</td>
<td>-0.04 (0.17)</td>
</tr>
</tbody>
</table>

*MLNB= Number of meals per day, MLSZ= Meal Size, MLDR=Total Daily Meal Duration, TSFM=Time Spent Feeding per Meal, FR=Feed Rate, VINF= Number of Visits per Meal, ADFI=Average Daily Feed Intake, TSFD=Time Spent Feeding per Day, BW16= Body weight at 16 weeks of age, BW20= Body weight at 20 weeks of age, ADG= Average Daily Gain, FCR=Feed conversion Ratio
Chapter 6  General Discussion

Automated feed intake systems have made it easier to collect data on individual birds in group-housed environments. These environments are more representative of breeder and commercial barns and therefore, feeding behaviour data from these systems are more accurately illustrated. However, a limitation of this research is that the feeding stations used to collect the data is not what is commonly found within commercial barns. Although a primary purpose is determining feed efficiency with these automated feed intake systems, the feeding behaviour data collected throughout the process can have multiple applications. A detailed look at multiple short-term feeding behaviours has previously not been studied in turkeys, and scarcely studied in other agricultural species. For this reason, the main focus of this thesis was to define feeding behaviours in turkeys and calculate initial genetic parameters.

6.1 Defining Feeding behaviours in a sire and dam line

The first goal of this thesis was to accurately calculate meal criterion. This was achieved through quantitative measures, similarly described in previous studies (DeVries et al., 2003; Howie et al., 2009a). The point of intersect between the square root of the relative frequency of the intra-visit duration and inter-visit duration was calculated for each line. This point of intersect is then known as the meal criterion and subsequently used in defining feeding behaviours. Although this quantitative method of calculating meal criterion is better than arbitrarily choosing a value, adding in the probability of the start of a new meal would, from a biological relevance stand-point, strengthen the meal criterion calculation. In Chapter 4, feeding behaviour traits were defined and calculated. The importance of clearly defining a meal becomes apparent when examining different feeding behaviours. An example would be the difference between time spent feeding per meal, which is directly linked to duration, and the proportion of time spent feeding per meal. Meals, themselves, are most often defined by the meal criterion, although this may be affected by multiple variables. Examples of these variables include non-feeding events and a bird changing from one feeder to another. For this reason, being clear in the definition of a meal and feeding behaviours is critical in order to allow for comparisons to be made to other studies.
Some differences were found in the meal characteristics between the sire and dam lines. The meal criterion was different, with the sire line meal criterion being 13.93 min and the dam line meal criterion being 7.11 min. Turkeys in the sire line consumed twice the amount of feed per meal in twice the amount of time compared to the dam line. The sire line also had more visits per meal and consequently fewer meals per day. This could be attributed to the difference in trait selection emphasis between both lines. In general, the feeding behaviours were similar to what was previously reported in the literature (Howie et al., 2010; Willems, 2015). The proportion of the time spent feeding per meal compared to the overall meal duration for both sire and dam lines were roughly the same (94% and 95%, respectively) and were found to be higher than the proportion previously found 82%. This would imply that in the present study, turkeys had shorter non-feeding periods during meals compared to the previous study. The turkeys in the previous study however, had a faster feeding rate and more visits per meal compared to those in the current study. These differences may reflect differences in barn management and larger bird-to-feeder ratio (13:1) compared to both lines in the current study (10:1 for the sire line and 9:1 for the dam line). The lower bird-to-feeder ratio in the current study may decrease levels of competition for feed, resulting in differences in short-term feeding behaviours. Differences between the current study and the previous may also be directly attributable to the differences in age and weight of the birds at the start of the trials.

6.2 Feeder preferences

As expected, turkeys consumed less than 0.002% and – 0.02% of their feed during the dark period (for the sire and dam lines, respectively), and displayed a peak in feeding behaviour within the first hour or two of the day, and a second peak two hours prior to the dark period. This is similar to a semi-diurnal pattern previously described in laying hens. For this reason, all feeder preference analysis was conducted with behaviours exhibited throughout the light period of the day.

Based on the FI group results for the sire line, the average feed consumed by turkeys in the High and Average FI groups was generally closer to the expected average feed intake. The feed consumed by the Low FI birds however, was widely variable across all feeders and may be
representative of birds who are subject to displacement. This variability in feed consumed between feeders by the Low FI birds was also apparent in the dam line.

Results specific to feed consumed at different occupancy hours revealed that the sire line showed great variability, with no definitive pattern, in the average feed consumed across all four occupancy hours whereas, the dam line showed a clear pattern in feed consumption. Within the dam line there appeared to be an aversion for specific groups of feeders. This clear feed consumption pattern in the dam line could imply that this line may have a higher level of competition compared to the sire line.

We did see similarities in the feeders where less feed is being consumed between the two lines by all three FI groups as well as clear aversions for specific groups of feeders at all four occupancy hours in the dam line. In addition, when looking at feeder preferences across the whole flock throughout the study, clear aversions to specific feeders or groups of feeders were observed. The first feeder in the row, the corner of the “L” shape feeder placement, and, in the sire line, the last feeder in the row were least preferred. We can hypothesize that there may have been environmental factors, such as lighting, or high worker traffic, that caused all-around aversion of these feeders. Further investigation would be needed to determine the cause of the aversion in order to rectify it and re-establish an equal distribution of birds to feeder.

6.3 Heritabilities

Heritability estimates varied among the feeding behaviour and production traits studied in this thesis. Feeding behaviour heritability values were generally higher compared to the values found for production traits. Within feeding behaviours, heritability estimates were either within the same range or higher than previously reported in the literature. Heritability estimates of feeding behaviours were hypothesized to be low to moderate in range; however, the heritabilities of some of these behaviours, such as time spent feeding per meal, total daily meal duration, and meal size, were found to be high. For the production traits, it was hypothesized that heritability measurements would fall within a low to moderate range, and that was found in this study for both body weights, as well as for ADG and FCR. The differences observed in the heritability estimates could be attributed to the method of calculating meal criterion, differences in species, or even the trait definitions. For example, in this thesis, total daily meal duration encompasses both feeding and non-feeding events into the time whereas previous studies simply calculated
total daily meal duration as time spent at the feeder. Looking specifically at the heritabilities of feed conversion ratio compared to previous literature, the value found in this study was lower than in broilers (Howie et al., 2011), and slightly lower but within the same range as previously found in turkeys (Willems, 2015). An additional study, using turkeys, resulted in similar heritabilities for feed conversion ratio, body weight around 15-19 weeks of age, and average daily gain (Case et al., 2012).

6.4 Phenotypic and Genetic Correlations

As hypothesised, most of the feeding behaviours were moderate to highly correlated to one another. Some of these traits showed positive correlations whereas others showed a negative correlation. The high negative genetic correlations between some of the traits would imply that selection for any of these traits could have an opposing directional effect on the other. This is not to say that the negative correlations are unfavourable, however, precautions should be taken if incorporating any of these traits into a breeding program selection index.

Although, most correlations were within range as previously reported in the literature, some differences were observed. The present study had more moderate phenotypic and genetic correlations compared to the low correlations of the broiler study (Howie et al., 2011). These observations were most likely due to differing management practices, nutritional components of the feed, differences in species, and the methodology for calculating meal criterion.

Upon observing the correlations between feeding behaviours, we see some differences between some of the phenotypic correlations and their genetic correlation counterparts. In all instances, the phenotypic correlations were positive while their genetic correlations were negative. When observing the large standard errors of the genetic correlations, it is more likely that the genetic correlations are closer to zero rather than negative. The residual variances of these traits were observed and the differences in the signs on the correlations could also be due to the high residual variance component of the phenotypic variance for the traits involved. A large residual variance could be due to multiple components such as variations in management or the environment, in addition to the variation in the social components of the birds themselves. Animals may alter their short-term feeding behaviours in order to achieve their required daily intake. As turkeys are highly social animals and in small groups have well-established hierarchies, the social effect on the hierarchy could lead to these changes in short-term feeding
behaviour, thus increasing the residual variance component. In larger groups however, the hierarchical system breaks down and aggressive dominant behaviour is conducted based on cost/benefit strategy assessments (D’Eath and Keeling, 2003). Additional research should be conducted with a larger data set in order to potentially minimize the standard error and therefore calculate a more accurate correlation.

For the most part genetic correlations between feeding behaviours and body weight were low which is in agreement with what was previously found in broilers. The genetic correlations between the feeding behaviours and feed conversion ratio ranged from low to moderate and for the most part were equal or higher to the correlations in the previous study. The phenotypic correlations in the present study however were lower than what was previously reported in turkeys (Willems, 2015). Although, both studies used turkeys, the standard errors were smaller in the present study compared to the previous study. Some genetic correlations were found to be high between certain feeding behaviours and the production trait average daily gain. Finding higher genetic correlations between feeding behaviours and production traits would imply that selection for feed efficiency would lead to changes in feeding behaviours. As feed efficiency is a trait of economic importance, it would be beneficial to keep feeding behaviour traits in mind as selection criteria in order to maximize selection response. Using the results found in this study I would suggest three of the feeding behaviours to incorporate into the selection index if none other. These traits are number of meals per day, meal size, and number of visits per meal. In both cases, number of meals per day and meal size have high heritabilities and moderate genetic correlations with ADG, which is a trait of interest when calculating feed efficiency. In the case of number of visits per meal, the heritability is only moderate, same as the genetic correlation, however this correlation is directly with FCR. Since feed efficiency is a very important economic trait within the turkey industry, I believe incorporating feeding behaviour traits that are heritable and correlated to feed efficiency traits would be beneficial to the selection process.

Some reasons for the discrepancies in the correlations between previous studies and the current one could be due to the aforementioned differences in barn management practices, diet, and the calculation of meal criterion. In addition, the weights collected between the broiler study and the present one were done at different stages of their growth curves and would therefore impact the correlations to feeding traits. Selection on feeding behaviours in turkeys would results in a greater effect on the production traits compared to broilers.
6.5 Overall Conclusions

This initial descriptive and genetic analysis of feeding behaviours and their relationship with certain production traits lays the framework for further research. Although using similar methods of calculating meal criterion as a previous study would result in a better comparison of the results, choosing a method that is appropriate for the data set is optimal. In any case, quantitatively calculating meal criterion is suggested over arbitrarily choosing this value. Defining clear feeding behaviours is key in providing the reader with the appropriate information in order to draw their own conclusions from the results for future research.

The feeder preferences observed in this study could suggest that lower feed intake birds may be more subordinate, and forced to visit a wider range of feeders in order to fulfill their meal size requirements. Additional research should be conducted observing feeding behaviours in turkeys of known social standings within a group. These findings can aid the poultry industry in determining clear feeding behaviour patterns among birds of different social standings as well as giving insight on the best way to organize feeder stations to maximize performance and mitigate aggressive behaviour that lead to economic and welfare losses.

The range of heritability estimates for feeding behaviours would imply that the incorporation of these traits into a selection index would result in genetic change over time. The incorporation of feed efficiency into breeding programs is of importance to the turkey industry. As the presence of moderate to high genetic correlations between some of the feeding behaviours and production traits, including feeding efficiency, is apparent, selection for feed efficiency would have an effect on certain feeding behaviours. It is therefore advised to determine the correlation between these traits prior to their incorporation into a selection program and monitor these traits for any change over time.

The work done in this thesis provides the starting point for future research in this field within the turkey industry. Future work may include a more in depth look at specific feeding behaviour patterns between birds of differing social rankings in order to determine if there is a set pattern associated with dominance. Genetic relationships can be analysed to determine within family dominance and feeding behaviour patterns. This in turn can aid in the selection process to
try and mitigate aggressive behaviour and associated economic and welfare losses. The genetic correlations between feeding behaviours and production traits can be more closely examined to determine optimum trait use within the selection program.
Chapter 7  Literature Cited


