High friction expansion of broiler feed prior to pelleting and its effect on broiler performance

by

Dieter Cecil Fleischmann

Submitted in partial fulfilment of the requirements for the degree

MSc (Agric) Animal Nutrition

In the Faculty of Natural & Agricultural Sciences
University of Pretoria
Pretoria
2012

Declaration

I, Dieter Cecil Fleischmann declare that the thesis/dissertation, which I hereby submit for the degree MSc(Agric) Animal Nutrition at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

SIGNATURE: .....

DATE: 13/12/2012

ABSTRACT

High friction expansion of broiler feed prior to pelleting and its effect on broiler performance

Dieter Cecil Fleischmann

High feed costs are part of any broiler rearing enterprise and continuous effort is required to help overcome this problem. The use of a feed expander may be beneficial in improving bird performance and thus increasing the profitability of broiler meat production. Four experiments were conducted to evaluate the performance of birds fed expanded feed in relation to the performance of birds fed non-expanded feed. The effect of feeding birds expanded feed was also tested under heat stress conditions. In this experiment, a significant improvement in cumulative feed conversion ratio (CFCR) was observed for birds fed expanded feed (Chapter 3). Pellet size influenced bird performance as birds fed a 3.2 mm non-expanded feed had a better cumulative FCR than the non-expanded 4.5 mm pellets, and this CFCR did not differ significantly from that in birds fed 3.2 mm expanded pellets (Chapter 4). There is, however, an improvement in the cumulative FCR to two weeks of age in birds fed expanded feed, over that in birds fed non-expanded feed, indicating that expanding of feed improves nutrient availability to the young broiler with a partially developed digestive tract. The effects of expanding feed on the body weight of birds were not consistent between experiments. This might be attributed to expanding temperature, as the feed in Chapters 3 and 4 was expanded at 90°C and not at higher temperatures as in the other chapters. Expanding feed at 90°C may not allow proper starch gelatinisation and alteration of nutrient availability. Expanded feed had better pellet durability than non-expanded feed and there were no significant negative effects on vitamin recovery, enzyme stability and nutrients when feed was expanded at temperatures between 95 and 105°C. Pellet quality increased with an increase in expanding temperature. Expanding of broiler feed led to a significant improvement in lipid digestibility (Chapter 6). Expanding of feed at 105°C is recommended as feed expanded at this temperatures tend to have significantly higher AME_n values for broilers than non-expanded feed.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1
Introduction

To stay competitive in the growing animal feed industry it is necessary to improve the efficiency of feed production at the mill and to implement new technologies to improve animal performance. In the area of feed processing, there is certainly room for improvement in both production efficiency and feed quality. Efficiency of feed production can be described in terms of the amount of feed produced per time unit, usually tonnes/hour, as well as the cost to produce a tonne of feed.

A feed production line in a feed mill consists of different feed processing machines, such as mixers, conditioners, expanders or extruders and a pellet machine. In a traditional production line, feed coming from the mixer usually passes through a conditioner, where steam and moisture are added, before entering the pellet machine. This increases the feed temperature, but not enough to cause proper gelatinisation of starch in the feed as is the case when feed passes through an expander prior to pelleting (Svihus and Gullord, 2002).

The use of an expander in feed production has become more common and the expander is incorporated in the production line between the conditioner and pellet press (Vest, 1996). Expanders have the potential to increase the feed output of a production line, allowing the production of more pelleted feed per unit time (Behnke, 1994). Improved pellet durability when an expander is used to condition feed is not only important at bird feeding level, where it can lead to improved feed conversion, but also during feed production, as it will influence the amount of fines that will have to be reworked and thus influence the efficiency of feed production.

Due to the higher degree of gelatinisation taking place during expansion than during normal steam conditioning, the binding properties of feed particles are improved, which leads to an improved pellet durability of expanded pelleted feed (Svihus & Gullord, 2002). The expander also makes it possible to add more liquids, especially fat, to feed without a decrease in pellet quality, as is the case when normal steam conditioning is used (Peisker, 1994). These added liquids act as lubricants making it easier for the expanded feed to move through a 3.2mm diameter pellet die and reducing the pressure/work load on the pellet machine and the wear and tear on the pellet die.

In numerous studies, it was found that when expanded feed is fed to birds an improvement in bird performance is noticed (Fancher *et al.,* 1996). Expanded feed leads to improved feed conversion ratios, higher feed intakes in some cases and an increase in body weight (Behnke, 1994). The improved pellet durability and pellet quality of expanded feed are two of the main contributors to this

improved bird performance. Reduced fines in the feeder pans allow the bird to eat more feed per unit time and also reduce the activity needed to consume a certain amount of feed, thus making more energy available for production (Calet, 1965; Hamilton & Proudfoot, 1993). This characteristic of expanded feed may be beneficial in scenarios where feed intake is reduced, such as when birds are exposed to heat stress. Under heat stress conditions, birds reduce their feed intake in an attempt to maintain their core body temperature and this leads to lower final body weights (Carmen *et al.*, 1991; Cahaner *et al.*, 1995; Al-Fataftah & Abu-Dieyeh, 2007).

Although the expansion of feed has advantages, there are nutrients, such as vitamins, which are heat sensitive and the use of an expander may have detrimental effects on these nutrients when feed is expanded at too high temperatures (Thomas *et al.*, 1997). There may also be certain nutrient interactions such as the Maillard reaction, which decreases protein availability, especially lysine availability.

The purpose of the experiments was to determine the performance of birds fed expanded feed compared to those fed non-expanded feed and to see if there are advantages in feeding birds expanded feed. Due to the characteristics of expanded feed, it was expected that giving birds expanded pelleted feed under conditions of poor feed intake or feed conversion ratios, an improvement in bird performance would be measured. Birds fed expanded feed under heat stress conditions were expected to perform better than birds fed non-expanded feed. Expanding conditions, especially the temperature at which feed was expanded, may have an effect on bird performance. The temperature at which feed is expanded has an effect on the degree of gelatinisation of starch, thus pellet durability and starch digestibility. Expanding temperature influences the recovery of some heat sensitive nutrients. Different expanding temperatures will thus influence feed properties and it is important to obtain the optimum temperature for pellet durability, gelatinisation and nutrient availability as these will influence bird performance.

Chapter 2

Literature Review

1. Pellet quality

1.1 The pelleting process and benefits of pelleting

The efficiency of the feed pelleting process and the quality of the final pelleted product are determined by measuring the strength and durability of the pelleted feed (Kaliyan & Morey, 2008). Pelleting of feeds that were usually fed in mash form was introduced long ago and resulted in increased broiler performance (Inborr & Bedford, 1993). The pelleting process can be defined as a process where small feed particles are molded into larger particles (agglomeration) during a mechanical process in association with moisture, heat and pressure (Falk, 1985).

Pelleting of feed has become a common feed manufacturing procedure due to the numerous advantages obtained by using this procedure (Wood, 1987; Angulo *et al.*, 1996). There were numerous studies done to determine the advantages of pelleting feed (Calet, 1965; Slinger, 1973; Behnke, 1994; AI Bustany, 1996). It is stated in Behnke (1994) that pelleting of feed usually improves broiler production parameters, including feed conversion due to:

- Decreased feed wastage
- Reduced selective feeding
- Decreased ingredient segregation
- Less time and energy expended for prehension
- Destruction of pathogenic organisms
- Thermal modification of starch and protein
- Improve palatability

The process of pelleting is a pressure-assisted densification procedure (Li & Liu, 2000). During pelleting, the feed material is pressed through open-ended cylindrical holes, known as dies, which are made in the periphery of a ring (Kaliyan & Morey, 2008). There are one to three rotating rolls which pushes the feed into the die's holes from the inside of the ring to the outside. The skin friction between the feed particles and the wall of the die resists the free flow of feed and thus the particles are compressed against each other inside the die to form pellets (Kaliyan & Morey, 2008). Adjustable knives cut the pellets to a predetermined length. The diameter of the pellets produced is determined by the diameter of the die holes used. Pelleting of feed increases the water solubility of starch and protein (Pettersson *et al.*, 1991). Another advantage of pelleting feed is the denaturation of heat-sensitive growth inhibitors, such as trypsin inhibitors in soybean meal (Pettersson *et al.*, 1991).

By producing a good quality pellet with good durability, the percentage fines that are observed at the point of utilisation, which is in the feeders, can be minimised. These fines are caused by mechanical handling during production and transportation of the feed (Kaliyan & Morey, 2008). By improving the durability of pellets, time and money is also saved during production, because when the durability of the pellets increases there are less fines that will require reworking (Johnston *et al.*, 1999). Durability of pellets can be measured in different ways with the most common method being the tumbler method, where durability is measured as the percentage fines after the pelleted feed was tumbled for a certain period of time (Behnke, 1994).

The pelleting of low fibre diets based on wheat or maize usually improves their nutritional value (McIntosh *et al.*, 1962). Long term steam conditioning or the use of an expander can improve pellet quality of maize based diets (Johnston *et al.*, 1999). It was concluded by Lundblad *et al.* (2008) that the addition of water into the mixer prior to steam conditioning improved pelleting efficiency and pellet durability of maize based diets.

1.2 Factors affecting pellet quality

As stated above, pellet quality is related to its strength and durability. Durability is seen as the potential of a pellet to withstand pressure without producing fines. There are numerous factors affecting pellet quality, ranging from feed contents to processing variables.

1.2.1 Feed ingredients

Because of the inherent variability in the physio-chemical properties of the raw materials, the effect of different feed ingredients on the strength and the durability of the pelleted feed may be studied in terms of constituents such as starch, protein, fibre and fat (Kaliyan & Morey, 2008). Wood (1987) stated that the functional properties of the protein and starch present in a feed had a bigger influence on pellet durability and hardness than the method of conditioning.

Starch

During heat treatment, in association with high moisture levels, starch undergoes a process called gelatinisation (Svihus & Gullord, 2002). This process involves structural changes to the starch and results in better quality pellets due to the improved binding properties of the gelatinised starch (Svihus & Gullord, 2002). Pellet quality and durability improve as the extent of starch gelatinisation increases (Heffner & Phost, 1973)

Protein

The source of protein in the diet is very important as protein from maize has a negative effect on pellet quality (Cavalcanti, 2004). Protein which is obtained from protein sources with paste forming ability, such as wheat and soybean meal, has a positive effect on pellet quality and durability (Stevens, 1987; Cavalcanti, 2004). The protein present in the feed will undergo denaturation during pelleting due to the additive effects of heat, moisture and shear on protein. This induces the binding functionality of protein (Wood, 1987; Thomas *et al.*, 1997). In an experiment conducted by Wood (1987), it was concluded that the addition of raw protein to the diet resulted in higher pellet durability and hardness than when denaturated proteins were added.

Lipids

It is widely accepted that the inclusion of fat in feed leads to lower pellet quality due to a decrease in the pellet durability (Stark, 1994; Angulo *et al.*, 1996; Briggs *et al.*, 1999). Fat acts as a lubricant between the feed particles and also between the feed and the die-walls, resulting in lower friction and therefore lower pressure in the die. This causes a final pelleted product with lower durability and more fines during production and in the broiler feeders (Kaliyan & Morey, 2008). Fat also inhibits the binding properties of the water-soluble components in the feed like starch, protein and fibre. This is due to the lipids' hydrophobic nature (Thomas *et al.*, 1997). Cavalcanti (2004) found that fat inclusion levels higher than 6.5% in a maize-soybean based feed are detrimental to pellet durability and thus pellet quality.

Fibre

Fibre has different effects on pellet quality, depending on the type of fibre (Kaliyan & Morey, 2008). Water-soluble fibres increase the viscosity of the feed and have a positive effect on the structural characteristics of the pellets. On the other hand, water-insoluble fibres may get entangled and folded between feed particles resulting in weak spots in the pellet where fragmentation can take place (Rumpf, 1962).

1.2.2 Feed particle size

The particle size of the feed has a large influence on the pellet durability. In most cases the finer/smaller the particles are, the higher the durability of the pellet produced (Reece, 1966). Maize is an exception to this rule, because finer maize particles produce pellets of lower durability than coarser maize particles. Finer feed particles usually produce better quality pellets due to the fact that finer particles accept more moisture and thus become more conditioned than larger particles (Kaliyan & Morey, 2008). The recommended particle size of feed to produce a good quality pellet is 0.6 - 0.8mm.

Too large particles (bigger than 1mm) may cause weak points in the pellet and act as predetermined breakpoints.

1.2.3 Feed moisture content

Water acts as a binding agent and lubricant during the pelleting process (Kaliyan & Morey, 2008). There are several studies indicating that the strength and durability of pellets increase as feed moisture content increases, until an optimum level is reached (Reece, 1966; Smith *et al.,* 1977; Turner, 1995). It is suggested by Obernberger & Thek (2004) that the production of high quality pellets is only possible when the moisture level of the feed is between 8 and 12%. Moisture added in the form of steam also improves pellet quality more than the direct addition of water in the mixer (Thomas *et al.*, 1997). The extent of starch gelatinisation that can occur is directly influenced by the moisture content of the feed (Svihus & Gullord, 2002).

1.2.4 Pre-pelleting treatment

The treatment of feed before pelleting usually involves the increase of feed mash temperature via steam conditioning and sometimes passing of the feed mash through an expander. The temperature of the feed is increased to prevent microbial activity during storage, for the inactivation of anti-nutritional factors and to alter the structural characteristics of feed contents such as starch (Kaliyan & Morey, 2008). Steam conditioning helps to produce durable and hard pellets by the releasing and activation of natural binders and lubricants in the feed, activating of artificial binders, enhancing of starch gelatinisation and causing protein denaturation (Kaliyan & Morey, 2008). The steam quality, defined as the percentage of steam added in the vapor phase, influences pellet durability as high quality steam has more energy to raise the feed temperature (Kaliyan & Morey, 2008). Raw material variations in diets influence the quality of the pellets that can be produced at different steam pressures (Payne, 1978). The retention time of the feed in the conditioner also influences pellet durability as was shown when the pellet durability increased by 5% when retention time was increased from 5 s to 15 s (Briggs *et al.*, 1999).

Feed passing through an expander prior to pelleting results in better pellet durability and thus pellet quality (Behnke, 1994). This is largely due to the structural changes of feed particles and the higher level of gelatinisation achieved during expansion, as all three components, high temperature, high moisture levels and shear, needed for gelatinisation of starch are present during the expansion of feed (Turner, 1995; Svihus & Gullord, 2002). Expansion of maize-based feed prior to pelleting significantly improves the durability of the pellet produced (Behnke, 1994). It is also known that for

raw materials with a natural high pelleting ability, such as wheat, the use of an expander may not be justified due to the increase in energy consumption when feed are expanded (Behnke, 1994).

1.2.5 Binders

Binders are added to the feed to improve the binding properties of the feed particles. They can be added as a liquid or in a solid form. Steam conditioning or pre-heating is essential to provide heat and moisture to activate the inherent binders or added binders (Kaliyan & Morey, 2008). Lignosulfonate, bentonite (clay mineral), sepiolite, modified cellulose binders, starches and some proteins are some of the binders that are frequently used in the manufacturing of animal feeds. It is important to add a binder to feed with a high fat content to improve the pellet quality and reduce the variation in pellet durability (Pfost, 1964; Angulo *et al.*, 1996).

1.2.6 Pellet-mill variables

Pellet quality of similar feed may vary between feed mills due to the use of equipment from different manufacturers resulting in variation in milling, mixing, conditioning, pelleting and cooling processes.

Die dimension

The smaller the die size, the greater the extent of gelatinisation in poultry feed (Heffner & Pfost, 1973). Heffner & Pfost (1973) also stated that the larger the die length to diameter ratio, the higher the durability of the pellets produced will be. Due to the fact that the amount of shear of the feed increases as the die diameter gets smaller or the length/thickness of the die increases, an improvement in the pellet durability may be observed (Kaliyan & Morey, 2008). Feed high in fat may show improved pellet durability when it is pelleted using a larger die length or thicker die (Thomas *et al.*, 1997).

Die speed

The speed of the die is also important because it may cause plugging of some maize-based diets (Stevens, 1987). For the production of small pellets (3-6 mm diameter), a high die speed of around 10 ms^{-1} is suggested and a die speed between 6-7 ms^{-1} for the production of larger pellets (Thomas *et al.*, 1997)

Gap between roller and die

There is an optimum range for the gap width as pellet durability and strength will improve up to a point (2 - 2.5 mm) and it will then decrease as the gap width increases further (4 - 5 mm) (Robohm, 1992; Thomas *et al.*, 1997). This is due to a dense layer of material compressed through the die as a

result of the increase shear at a width of 2 - 2.5 mm and a decrease in stability of the feed on the roller and die because of sideways leaking of mash at a 4 – 5 mm gap width (Kaliyan & Morey, 2008).

1.3 The effect of pellet quality on broiler performance

By supplying the bird with a good quality pelleted feed one can improve bird performance (Behnke, 1994). Due to the increase in bulk density of pelleted feed, the bird can consume more feed per time unit than when it receives mash feed (Calet, 1965; Hamilton & Proudfoot, 1993). This leads to higher nutrient intake by the bird and thus more nutrients for growth which results in heavier body weights (Hamilton & Proudfoot, 1993). If feed with low pellet durability is fed there will be an increase in the percentage of fines in the feeder and the bird will need to spend more time eating to consume a certain amount of feed. By decreasing the feeding time, as well as the activity of the bird to consume a certain amount of feed, the birds' maintenance requirements are reduced as less energy is lost through heat production (Summer & Leesons, 1997). This in turn leads to an improved feed conversion ratio as more energy is available for production.

A better feed conversion ratio in broilers fed pelleted feed may also be attributed to an increase in the extent of gelatinisation during pelleting, which increases the starch digestibility in the bird (Hamilton & Proudfoot, 1993). Good quality pelleted feed supports high growth rates, especially in male broilers, which may increase mortalities due to sudden death syndrome (Proudfoot & Hulan, 1982).

2. Starch gelatinisation

Starch is the major component contributing to the energy of a diet for humans as well as monogastric animals (Gaillard, 1987). Processing of starch by chemical or physical modifications allows starch to play an even larger role in nutrition. Starch is obtained from plants, with maize and wheat being two major sources of starch in the poultry industry. The starch source used in poultry feeds is area-dependant due to the availability of certain sources in different regions (Gaillard, 1987).

Due to the fact that raw/native starch does not disperse in water, most starch used in diets undergoes some sort of heat processing (Ratnayake & Jackson, 2009). Heat treatment results in structural and sometimes molecular changes in the granular and polymeric structures of starch (Ratnayake & Jackson, 2009). The process in which starch granules undergo structural changes is called gelatinisation. Gelatinisation increases the susceptibility for starch degradation in the digestive tract (Svihus and Gullord, 2002). The extent of gelatinisation that occurs will be determined by the properties of the starch. Cereal starches contain some resistant starch that is not digested in the small

intestine. Poor starch digestibility in the small intestine results in poor broiler performance (Svihus and Gullord, 2002).

2.1 Structural characteristics of starch

There are two distinct populations of starch. Amylopectin consists of α- 1,4 glucose chains, with frequent branches due to α-1,6 bonds. The other polymer, amylose, does not have frequent branches. Amylopectin has a higher molecular weight than amylose. Grains usually contain about 200-250 g/kg amylose, but it can be as high as 700g/kg in maize. The ratio of amylose:amylopectin is genetically determined. Starch is accumulated in granules in the endosperm, deposited in layers of amylose and amylopectin. The starch granules consist of alternating semi-crystalline and amorphous layers. The semi-crystalline layers consist of crystalline layers of double helical α-glucans extending from intermitted branches of amylopectin and the amorphous layers of amylopectin branch points (Svihus & Gullord, 2002). Granule size and distribution play an important part in the functional properties of starch and are determined by genetic factors (cultivar) and growing conditions. Granule size varies between 1-50μm (Svihus & Gullord, 2002).

There are a few components associated with the starch granule that may affect digestion of the starch. The most important non-starch component is lipids (Búléon *et al.*, 1998). The lipids are usually associated with amylose in the starch granule and palmitic and linoleic acids are the most common fatty acids with a few phospholipids also occurring in the granule (Búléon *et al.*, 1998). The complexes formed between lipids and starch may reduce starch digestibility by reducing the availability of the starch to the digestive enzymes in the digestive system. The lipid to starch ratio also affects the extent of swelling in the granule due to its hydrophobicity (Vasathan & Bhatty, 1996) and this lowers the extent of gelatinisation that can occur.

Protein also occurs in the starch granule. Surface proteins may affect the availability of starch. A softer endosperm that fractures more easily during milling leads to less starch damage. Protein matrixes may also limit the availability of starch to digestive enzymes (Vasathan & Bhatty, 1996).

Starch that contains high levels of amylose is less digestible than amylopectin starches. Amylopectin starches are better digested, especially after heating and cooling. Amylose being tightly bound into a helix is relatively inaccessible to amylase, whereas the more branched structure of amylopectin is more accessible to enzymes. Amylopectin rich starches have lower gelatinisation temperatures than amylose rich starch and are thus more readily gelatinised (Svihus & Gullord, 2002).

2.2 Gelatinisation

The most common effect of processing of feeds at temperatures above 80°C in the presence of moisture is gelatinisation. Starch digestibility increases due to a loss of the crystalline structure with subsequent increased susceptibility for amylolytic degradation (Holm *et al.*, 1988). The process of gelatinisation is seen as a process that occurs due to swelling (Donald, 2001). Swelling occurs during processing along the amorphous regions, while the crystalline layers do not expand/swell during processing. This causes stress to increase at the interface between amorphous and crystalline regions where bonds exist between amylopectin in the crystalline regions and amylose in the amorphous regions.

The stress increases as the swelling increases up to a point where the crystalline regions are rapidly and irreversibly broken and gelatinisation is initiated. This swelling and cracking of the crystalline region causes amylose in the starch granule to be leached out (Han & Hamaker, 2001). The resulting increase in viscosity is due to swollen granules and gels consisting of solubilised amylose (Hermansson & Kidman, 1995). The increase in viscosity during gelatinisation also has a positive effect on the physical quality of processed feed, such as pellet quality and durability due to an increase in the binding potential between particles (Svihus & Gullord, 2002).

After the gelatinisation of starch during processing, a process called retrogradation occurs. Retrogradation is the crystallisation of gelatinised starch in an amorphous matrix, which occurs as cooling takes place. During retrogradation the formation and subsequent aggregation of double helices of amylose and amylopectin occur (Svihus and Gullord, 2002). Retrogradation of amylose is of more concern than that of amylopectin, because the retrogradation of amylose occurs faster and results in more starch resistance to enzymatic degradation. With the relatively low moisture content and rapid drying that occurs in extrusion and other processes, extensive retrogradation would not be expected in feed (Ratnayake & Jackson, 2009).

2.3 Effect of feed processing on starch

Common methods of feed processing which may affect starch include grinding, steam flaking, pelleting, extrusion and expander processing. Different processing methods have different effects on the starch properties and thus starch availability (Briggs *et al.*, 1999).

Normal steam conditioning and pelleting of feed do not have a large effect on starch digestibility or physical quality of the feed (Svihus and Gullord, 2002), as only 10-200 g starch/kg is usually

gelatinised. It is known that, as the starch contribution of maize increases, the pellet quality decreases (Briggs *et al.*, 1999). The amount of starch gelatinised during steam conditioning depends on the amount of steam added and the time the feed spends in the conditioner. When feed is expanded prior to pelleting, water is added and the feed may be exposed to temperatures above 100°C along with high pressure. When feed is expanded the extent of gelatinisation is usually between 220-350 g starch/kg, with no effect on the availability of the nutrients (Cramer *et al.*, 2003). Extrusion of feed results in a high degree of gelatinisation of starch due to processing temperatures above 110°C and the high moisture content of the feed as it passes through the extruder. Extrusion of feed is also known to increase the availability of starch (Murray *et al.*, 2001).

During feed processing, processes other than gelatinisation may occur which will influence the starch availability. Processing at high temperatures may cause the denaturation of α-amylase inhibitors and thus increases starch digestibility. In turn, processing, especially extrusion, may increases the amount of amylose-lipid complexes causing reduced digestibility of starch (Jacobs & Delcour, 1998). It is for this reason that a linear relationship between the extent of gelatinisation of starch and availability of the starch cannot be assumed.

Different processing methods result in different effects on the structure of starch and its gelatinisation. Gelatinisation increases the susceptibility of the starch to digestive enzymes and leads to better physical quality of feed due to the improved binding potential between feed components. This results in good quality pellets with increased durability. For gelatinisation to occur, feed must be processed at high temperatures and high moisture content. This is why extrusion of feed results in a high degree of gelatinisation. The structure of the starch granule influences the extent of gelatinisation that can occur in other feed components such as lipids and also has an effect on the swelling capacity of the starch granule layers and thus gelatinisation (Svihus & Gullord, 2002).

2.4 Effect of gelatinisation on broiler performance

According to Moritz *et al.* (2003), grain that was gelatinised to a significant degree resulted in a decrease in feed intake without affecting body weight and thus an improvement in the feed conversion ratio. Allred *et al.* (1957) found that feeding broilers processed maize led to higher body weights and improved bird performance, but work done by Sloan *et al.* (1971) showed that there were not any nutritional advantages for broilers fed processed/ gelatinised maize.

3. Expanders

Todays' broiler industry is production driven and to achieve maximum production continual assessments and improvements need to be made in all aspects of the integrated enterprise, starting at the feed production level. Feed costs account for about 60 - 70% of total broiler production cost (Benke, 1996). Improving the efficiency of feed utilisation of birds will have a beneficial effect on the profitability of broiler production, which makes this an area of interest in feed processing as well. The use of expanders in the manufacturing of poultry feed has increased over the last few years (Vest, 1996). Feed passes through the expander before it enters the pellet mill. The expander has a similar mode of action to the single screw extruder, but the expander uses less energy than the extruder (Thomas *et al.*, 1997).

Some of the advantages of using an expander include (Benke, 1996) :

- Improved pellet quality with increased production capacity of the feed mill
- Ability to add high liquid ratios, like fat, before pelleting (additions as high as 15-25% have been achieved)
- Improved starch hydrolisation of high grain feed
- Reduction or elimination of undesired and harmful microorganisms in feeds due to high temperature and pressure exposure

Fancher *et al.* (1996) also gave the following additional advantages of expanding feed :

- Improved animal performance
- Lower feed moisture content
- Manipulation of feed bulk density
- Longer pellet die life

The expander consists of a barrel which is equipped with stop bolts. Paddles of different geometry are mounted on the expander shaft. The feed product is sheared and kneaded when passing through the machine by means of these paddles and stop bolts. Fancher *et al.* (1996) described the expander as a high temperature, short time conditioner primarily used for the pre-treatment of feed prior to pelleting, resembling a single screw extruder, but differs by discharging the feed over an annular gap outlet instead of forcing it through a fixed die. This is one of the reasons why the expander does not produce a shaped pellet like the extruder (Riaz, 2007).

The pressure exerted on the feed passing through the expander can be changed by closing or opening the annular gap by the use of a hydraulic system (Thomas *et al.*, 1997). Before the feed enters the

expander, it passes through a conditioner where steam is added which increases the temperature of the mash feed as well as the moisture content of the feed (Riaz, 2007). The mash enters the expander at a temperature around 80°C, but it is dependent on the conditions in the steam conditioner (Fancher *et al.*, 1996). The width of the annular gap and the feed flow rate through the expander determine the amount of friction occurring and thus the amount of mechanical energy generated. This mechanical energy is responsible for increasing the temperature of the feed as it passes through the expander (Behnke, 1996).

Expanding temperatures as high as 125°C can be reached, but it is recommended that broiler feed is expanded at temperatures between 100 and 110°C (Fancher *et al.*, 1996). As the feed passes through the annular gap, there is an immediate drop in temperature and pressure. This results in a process called flash evaporation where the steam turns into vapour (Fancher *et al.*, 1996). A decrease in the moisture content of feed also occurs during this process. The amount of stress occurring in the expander can be manipulated by altering the feed mash moisture content, changing the input of mechanical energy and modifying the geometric configuration of the screw parts. The treatment intensity is usually calculated and measured as kWh/ton. Due to the high temperature, increased moisture content of raw materials and pressure during expanding, some chemical and physical changes of the feed ingredients may be expected (Vest, 1996).

When an expander is used along with a short term conditioner it is called pressure conditioning. The conditioner is used for pre-treatment of the feed with steam and liquids such as water or oil (Riaz, 2007). The feed leaves the annular gap as a non-shaped expandate and enters the pellet mill directly or the expandate may pass through a structuriser or crusher before entering the pellet mill to minimise the risk of the pellet mill getting blocked.

3.1 Effect of expanding of feed

3.1.1 Pellet quality

One of the remarked advantages of expanding feed is the improvement in pellet quality (Behnke, 1996). This is a result of starch gelatinisation and the integration of fat into the pellets (Svihus & Gulbro, 2002). When feed is not expanded prior to pelleting, the addition of high levels of fat will lead to decreased pellet quality as measured by the Pellet Durability Index (PDI), because added fat acts as a lubricant as the feed passes through the pellet die (Fancher *et al.*, 1996). Due to the flash evaporation occurring as the feed exits the annular gap during expanding, there is a lot of moisture loss and thus more fat can be added before feed enters the expander as this fat will be integrated (Riaz, 2007).

Expansion of feed also leads to a higher degree of starch gelatinisations, which further improves the binding properties of the feed and thus pellets durability (Coelho, 1994). As gelatinisation of the amylose-lipid complex takes place at around 100°C, the added fat is integrated into the complex and thus the amount of fat that can be integrated depends on the degree of gelatinisation. According to Peisker (1994) this is the reason why more fat may be added to the feed when it is expanded prior to pelleting.

3.1.2 Heat liable nutrients and feed additives

There is concern that some of the heat sensitive nutrients such as vitamins and feed additives may be damage during expansion. Riaz (2007) stated that any heat treatment influences the stability of feed additives, such as enzymes, and that the expansion process does not damage feed additives any more than the traditional pelleting process. Vitamins are indispensable to animals and must be added to the feed to prevent deficiencies. Vitamins as biological active micro-nutrients are generally sensitive to various physical and chemical factors. In the expander the feed is exposed to high temperatures, moisture, friction and other processing stressors such as oxidation, which may alter vitamin stability. Thomas *et al.* (1997) stated that heat labile components such as vitamins and lysine should not be sacrificed for the need of a flexible machine such as the expander and should be taken into account in the design of the machine.

Pipa & Frank (1989) evaluated the vitamin retention when feed was expanded at 120°C. There were no significant effects on vitamin B_1 and E retention, but vitamin A losses varied between feed types and were as high as 20% in some cases. Similar observations were made by Moulois (1991). In contradiction, Schai *et al.* (1991) also tested the effect of expanding broiler feed at 106°C in a commercial feed mill and found no significant effect in vitamin recoveries. It seems that expansion does not adversely affect vitamin recovery, although vitamin A, K_3 and C are more prone to damage by high temperatures, not only during expansion but also during the process of traditional pelleting (Riaz, 2007). There is also no evidence that the expansion of broiler feed has any negative effect on protein and amino acid availability (Riaz, 2007).

3.1.3 Feed safety

Feed quality relating to feed safety is of upmost importance today. Expansion of feed, also known as shear conditioning, may alter the physico-chemical properties of the mash feed and also lead to the improvement of the physical and hygienic quality of diets (Benke & Beyer, 2002). By expanding feed, one can eliminate or reduce effects of some antinutritional factors and also bacteria such as

Salmonella. Antinutritional factors (ANF) are usually substances of certain raw materials, which have a negative influence on feed intake, nutrient digestibility, feed metabolism, and health of the animal.

Common ANFs are protease inhibitors, such as trypsin inhibitor and lectins. These ANFs are completely or partially inactivated when the feed undergoes heat treatment (Plavnik & Wan, 1995). The use of an expander is a safe, efficient and economical method to inactivate ANFs without the addition of any chemicals to the feed (Riaz, 2007). Due to the fact that Salmonella and moulds in the feed could be detrimental to bird health, the use of an expander will also improve the health of the bird as more of the microorganisms are eliminated during expanding than during normal conditioning (Plavnik & Wan, 1995). This is due to the combination of high temperature and high shear force being exerted on the feed.

3.2 The effect of expanding feed on animal performance

3.2.1 The effect of expanded feed on broiler performance

Modern broilers have the genetic potential for rapid growth and they are selected for higher feed intakes. For the birds to grow according to their potential a feed of good pellet quality, high energy content and free from harmful substances like ANFs, bacteria and moulds is needed (Vest, 1996). By expanding feed it is possible to give the birds a high density diet with good pellet quality (Behnke, 1994). The improved pellet quality at higher fat levels is related to starch gelatinisation as this produces a starch matrix that may physically bind the added fat, contributing to better pellet quality, which in turn influences the body weight and feed conversion ratio of the bird (Riaz, 2007).

Feed conversion ratio of birds fed expanded feed is decreased due to better pellet quality, but also due to higher digestibility of expanded feed (Peisker, 1994). This improved digestibility is visible in the increased fat digestibility, which may lead to higher availability of metabolisable energy of the feed, which in turn will increase growth rate and decrease feed conversion of the bird (Peisker, 1994).

Results from an experiment conducted by Smith *et al.* (1995) showed that expanded pellets had a significantly higher pellet quality as measured by the Pellet Durability Index than non-expanded pellets. Expanded pellets also had lower moisture content than non-expanded pellets. When these two feeds were fed to broilers, the birds which received the expanded pelleted feed had a significantly higher body weight than those which received the non-expanded pellets. A repetition of this experiment gave similar results, but this time broilers fed expanded pelleted feed also had a better feed conversion ratio than the birds fed non-expanded pelleted feed. Similarly, broilers that received

expanded feed had a significantly better feed conversion ratio and growth rate than birds fed non-expanded feed in an experiment conducted by Fancher *et al.* (1996).

3.2.2 Effect of expanded feed on layer performance

Due to the fact that layers are bred for egg production and not for feed intake and growth rate, a layer feed has some unique and important characteristics. Although egg production is genetically limited, the layer must still be provided with good quality feed to sustain maximum production, without leading to obese birds. Calcium plays an important role in egg shell formation and a high level of limestone is added to layer diets. Limestone is not very palatable and birds may eat selectively whenever possible (Riaz, 2007). By expanding layer feed the limestone is bound into the starch matrix, reducing the possibility of selective feeding.

Expanding also reduces the bulk density of the feed which allows the bird to consume higher volumes of feed without becoming obese (Thomas *et al.*, 1997). The lower density of expanded feed results in the bird spending more time eating and thus occupying the birds and reducing cannibalism. Salmonella is a problem in poultry and by expanding layer feed the risk of Salmonella is reduced, due to the exposure of the feed to high temperatures. In a trial conducted by Lucht (1997) in which layers were fed crumbled expandate and normal mash, the number of eggs/hen produced was higher for expandate fed layers than normal mash fed layers. An increase in total egg weight was also observed. The expandate fed layers had a lower daily feed intake with a better FCR.

4. Heat stress in broilers

Heat stress is a common problem in broiler production systems across the world (Cahaner *et al.*, 1995), including the northern and eastern parts of South Africa. Heat stress may be experienced during the summer season and a high mortality rate can occur during a sudden heat wave when temperatures rise above 30°C. Broilers may undergo acute or chronic heat stress, which is determined by the duration of the exposure to high temperatures as well as the ambient temperature (Al-Fataftah & Abu-Dieyeh, 2007). Broilers undergo acute heat stress when they are exposed to very high temperatures for a short period, such as during a heat wave lasting a few days. One of the signs of acute heat stress is a sharp increase in mortality rate. A good example is where the mortality rate was over 40% during a heat wave in the Jordan Valley in 1985, which lasted three days (Al-Fataftah, & Abu-Dieyeh, 2007).

When broilers are exposed to elevated temperatures for a long period they might suffer from chronic heat stress. Chronic heat stress usually results in a decrease in overall bird performance (Carmen *et al.*, 1991; Cahaner *et al.*, 1995; Al-Fataftah & Abu-Dieyeh, 2007). This reduced performance is largely due to reduced feed intake, growth rate, feed conversion ratio, increased mortality and lower slaughter weights (Hurby *et al.*, 1995). Due to the improvement in the genetic potential for growth, modern broilers are becoming more prone to heat stress (Cahaner *et al.*, 1995). In a trial conducted by Al-Fataftah & Abu-Dieyeh (2007) it was concluded, with the help of a heat tolerance test, that birds reared at a higher ambient temperature from the beginning are more tolerant to heat stress than broilers reared at lower temperatures, due to the birds' ability to adapt to these elevated temperatures (Al-Fataftah & Abu-Dieyeh, 2007). This adaption ability is defined as acclimatisation. Acclimatisation is acquired because of a change in their panting ability (Deaton, 1984; Al-Fatafth & Abu-Dieyeh, 2007). Chickens do not have sweat glands and are therefore very prone to heat stress.

Heat shock proteins (Hsps) play an important role in the folding/unfolding and translocation of proteins, as well as assembly/disassembly of protein complexes (Zugel & Kaufmann, 1999). They are classified in families according to their size. The high expression of heat shock proteins, especially the Hsps 60 family, usually occurs as a result of the broiler's thermoresistance (Mahmoud *et al.*, 2003). The expression of these proteins helps with the survival of cells, especially the myocardial cells, under stress conditions like when birds are suffering from heat stress (Yan *et al.*, 2008). In heat stressed broilers, the plasma creatinine kinase (CK) levels increase and this is an indication of skeletal muscle damage which is mediated by alteration of the cell membrane (Mitchell & Sandercock, 1995).

The two main variables leading to heat stress are ambient temperature and relative humidity as these two variables determine the birds' ability to lose heat to their surroundings (Teeter & Belay, 1996). Along with these two variables, other factors which also influence the birds' susceptibility to heat stress are the age of the bird, size, previous high temperature exposure and its genetic make-up (Teeter & Belay, 1996). Death during heat stress is usually caused by heat exhaustion (Gary *et al.*, 2003). Heat stress is rarely a problem in broilers under 4 weeks of age (Teeter & Belay, 1996).

4.1 Temperature regulation during heat stress

If broilers are exposed to high temperatures which might lead to heat stress, they try to increase the physiological processes leading to heat dissipation and also lower those which lead to heat production (Gary *et al.*, 2003). When the bird is kept within its thermoneutral zone the main pathway of heat loss is non-evaporative cooling as this pathway is the most energetically efficient way of heat loss (Wiernusz & Teeter, 1996). Non-evaporative cooling is dependent on a big differential between the

environmental temperature and the birds' body temperature. As environmental temperature rises the differential between the birds' body temperature and the environmental temperature narrows and the importance of non-evaporative cooling declines, causing evaporative cooling to become more important (Teeter & Belay, 1996). Evaporative cooling is associated with an increase in respiration rate and becomes more pronounced as the bird starts moving to the upper limit of its thermoneutral zone. Panting of broilers causes an increase in muscle activity and thus increases energy requirements during heat stress (Gary *et al.*, 2003). Panting normally starts at temperatures above 30°C. This increased respiration rate may alter the acid – base balance of the bird as a lot of carbon dioxide is being exhaled (Teeter & Belay, 1996; Gary *et al.*, 2003). This loss of carbon dioxide leads to blood alkalosis and also alters the electrolyte balance of the bird as potassium and other minerals are also depleted (Gary *et al.*, 2003). Relative humidity influences the amount of heat that can be lost to the environment as it is an indication of the degree of saturation of the air at a certain ambient temperature.

One of the main causes of heat production is the activity associated with feeding and the digestion of the consumed feed and this leads to the typical decrease in feed intake seen in heat stress broilers (Vest, 1996).

4.2 Protein and energy

Diets high in protein usually have a more detrimental effect on broiler performance during heat stress conditions, due to a higher heat increment associated with its digestion (Mushraf & Latshaw, 1999). During heat stress it is not the amount of protein in the diet, but the quality which is important as birds fed lower crude protein diets with supplemental lysine and methionine showed better performance than birds fed high crude protein diets (Bregendahl *et al.*, 2002). Low protein and high energy diets resulted in higher final body weight and also improved growth rate (Kamram *et al.*, 2004). Broilers have a reduced energy requirement when ambient temperatures are close to their thermoneutral zone, due to a reduction in the energy needed to maintain the birds' body temperature (Daghirr, 1983). The level of energy and protein in a diet given to broilers subjected to heat stress may also alter the carcass composition (Zaman *et al.*, 2005).

4.3 Minimising heat stress

The effects of heat stress can be reduced by certain dietary adaptations and management practices. Although there have been many proposed solutions for heat stress, there is still no cure for heat and attempts can only be made to minimise its effects. The comfort zone for broilers decreases from 35°C

at hatching to around 24°C at 4 weeks of age. Heavier and faster growing broilers are more susceptibility to heat stress as they mature, due to the fact that bird surface area, which is required for heat dissipation by conduction and convection, increases only three fourths as fast as body weight (Teeter & Belay, 1996). During periods of heat stress, management practices focus both on maintaining bird performance and reducing the number of mortalities.

Feed form

The activity associated with feed consumption and the digestion/metabolism of the feed are some of the main contributors to heat production by the bird and therefore a decrease in feed intake during heat stress may be observed. The impact of a decreased feed intake on broiler performance can be reduced by allowing the bird to consume more feed in the shortest time. This will decrease the feeding activity and thus heat produced (Calet, 1965). In an experiment conducted by Howlider & Rose (1992), bird weight gain was greater for broilers fed a 13 MJ/kg pelleted feed compared to a 15 MJ/kg mash feed. Birds fed pelleted feed also had a higher feed intake than birds fed mash feed (Howlider & Rose, 1992).

Feeding broilers good quality pelleted feed during heat stress reduced the time spent feeding to consume a certain amount of feed (Galobart & Moran, 2005). Pellets with high durability will reduce the amount of fines in the feeder, which has the same negative effect on broiler performance as feeding mash (Behnke, 1994). Good quality pellets also reduce feed wastage, which will improve feed conversion ratio. It also reduces the microbial threat and competitive activities between birds, which increase the metabolisable energy available for production (Benhke, 1994).

Housing

There are a few basic housing requirements which can reduce the effects of heat stress. Firstly, the house must have an east-west orientation with sufficient roof overhang to prevent direct sunlight from entering the house. Proper ventilation is important as this influences the relative humidity and the house temperature, thus influencing the amount of moisture that can be absorbed into the air and the evaporative cooling ability of the bird (Teeter & Belay, 1996).

Stocking density

By maintaining an adequate stocking density the effects of heat stress can also be reduced (Benhke, 1994). At a low stocking density the bird is exposed to more airflow and there is also less total heat production in the house which rises the ambient temperature (Benhke, 1994; Turkyilmaz, 2006).

Timed feeding

The heat increment of feed, associated with heat generated by the action of digestion, leads to an increase in the birds' body temperature. By feeding the birds early in the morning or at night when ambient temperatures are lower, the impact of heat increment on body temperature can be reduced (Teeter & Belay, 1996).

Acclimatisation

The fact that birds exposed to elevated temperatures at an earlier age will have lower susceptibility to heat stress later in their lives has led to the use of bird acclimatisation as a heat stress management practice (May *et al.*, 1989). Breeding chickens for heat stress resistance is one of the more cost-effective approaches to mitigating the stress (Galobart & Moran, 2005). The degree of feathering will influence a breeds' susceptibility to heat stress as heavy feathering will reduce the birds' potential to lose heat to the environment (Cahaner *et al.,* 1995).

Water intake

Water to feed intake ratio is around 2:1 for broilers at a temperature of 24°C, but this can increase up to 5:1 at temperatures approaching 35°C. The increase in water intake decreases the viscosity of the digesta causing a loss of mineral ions and poor litter quality, with build-up of house ammonia (Gary *et al.*, 2003). The amount of water a bird will consume is influenced by the birds' blood osmotic pressure. Through the addition of salts to the water the bird's water consumption can be increased which helps to lower its body temperature. This method is only effective if the drinking water is cool (Teeter & Smith, 1987). The increase in cool water intake usually leads to an improved growth rate in heat stressed broilers (Teeter & Belay 1996).

Diet composition

The most common addition to a diet fed to heat stressed broilers is fat as fat is a concentrated energy source and has a low heat increment, which helps the broiler to consume enough energy without a significant rise in its body temperature (Dale & Fuller, 1979). By also improving the quality of the protein, which has a better amino acid composition, the bird can achieve a higher protein accretion with less feed consumed. The addition of vitamin C may also help to counteract heat stress, but the response to its addition is very variable. Economic advantages are also possible by the addition of virginiamycin at 20mg/kg feed during heat stress as a result of a decrease in mortality rates (Teeter & Belay, 1996).

Chapter 3

The susceptibility of broilers to heat stress when fed expanded or non-expanded feeds

Abstract

Two open sided broiler houses were each stocked with 1920 Hubbard broiler chicks and 1920 Ross 308 broiler chicks; each of the breeds randomly allocated to 16 pens in each house. Rearing conditions for the two houses were identical, except that the birds in one of the houses were subjected to induced heat stress from Day 22 to Day 35. The negative effects of heat stress on broiler production were investigated and whether the feeding of expanded pelleted feed to heat-stressed birds had any advantages over feeding them non-expanded feed. Birds that were subjected to heat stress had significantly lower body weights and lower feed intakes, but the feed conversion ratio was not significantly affected. The feeding of expanded pelleted feed to birds under heat stress did not affect final body weights, but improved the cumulative feed conversion ratio significantly, compared to birds on non-expanded feed, in both experimental houses (1.58 and 1.62, for birds fed expanded and non-expanded feed, respectively).

Introduction

It is widely accepted that heat stress is a major cause of poor production and thus profit losses in the broiler industry. Modern fast-growing broilers are more susceptible to heat stress due to a higher metabolic rate to support their faster growth rates (Cahaner *et al.,* 1995). Animals typically react to heat stress by eating less feed in an attempt to control the rise in deep body temperature caused by the digestion processes (Hurby *et al.*, 1995). The higher the ambient temperature and relative humidity, the more difficult it becomes for the bird to lose heat to the environment. The bird also increases its respiratory rate and water intake to try and maintain its core temperature (Gary *et al.*, 2003). The increase in water intake decreases the viscosity of the digesta causing a loss of mineral ions, poor litter quality and a build-up of house ammonia.

Breeding chickens for heat stress resistance is one of the more cost-effective approaches to mitigating heat stress, or by rearing broilers at higher ambient temperatures, which leads to acclimatisation and thus lower susceptibility to heat stress as broilers get older (Deaton, 1984). There are a few practical solutions that can be implemented to reduce the effect of heat stress such as proper housing, rearing broilers at lower stocking densities, increasing water consumption, feeding high density diets and by the use of timed feeding (Teeter & Belay, 1996).

Feed form has a significant influence on the heat production of birds due to its association with feeding activity and digestion of feed. Feeding birds good quality pellets may lead to an improvement in feed conversion ratio as the bird will spend less time consuming a certain amount of feed, thus reducing heat production and energy wastage (Howlider & Rose, 1992). The feeding of good quality pellets may help to reduce the effect of heat stress on final body weight as less heat is produced as a result of a decrease in the feeding activity of the birds (Behnke, 1994).

Expanding of feed prior to pelleting improves pellet quality and may help the bird to maintain growth under heat stress conditions. Expanded pelleted feed has increased pellet durability and is thus more resistant to mechanical damage during transporting and feeding. This results in less fines in the feeder, which have the same negative effects on bird performance as feeding mash.

The aim of this trial was to compare the performance of broilers both under heat stress and non-heat stress conditions to establish their susceptibility to heat stress. The effects of feeding expanded pelleted feed to birds under heat stress and non-heat stress conditions were also investigated to determine if there are any advantages in feeding birds expanded feed.

Materials and methods

Housing

The trial was conducted at the test facilities at Daybreak Farms, Sundra from Tuesday 7 April 2009 to Wednesday 13 May 2009. Two open sided broiler houses, named A and B, were used. Temperatures in the houses were controlled with a boiler. The duration of the trial was five weeks (35 days).

The temperature profile followed from 2 days pre-placement to Day 35 in House B is given in Appendix B. The same temperature profile was followed in House A up to Day 21. From Day 22, the temperature in House A was held constant at 32°C between 09:00 and 16:00 and reduced to 25°C from 16:00 to 09:00 until the end of the trial at Day 35. Minimum and maximum temperatures, as measured with six min/max thermometers per house, together with the reading on the monitor of the boiler, were recorded on a daily basis. Two temperature loggers per house were also used to record temperatures.

The actual temperatures logged in House A during the experiment are given in Table 3.11.

Birds

Two thousand and eighty (2080) day-old Ross 308 chicks as well as two thousand and eighty (2080) day-old Hubbard chicks (Midway Hatcheries) were placed in House A on Tuesday 7 April. For House B, the same amount of chicks from each breed were placed on Wednesday 8 April, thus in total four thousand one hundred and sixty (4160) Ross 308 and four thousand one hundred and sixty (4160) Hubbard day-old chicks were placed. One hundred and thirty (130) chicks were randomly allocated to each of the 32 pens per house on Day 0. Birds per pen were reduced to 120 birds on Day 7 (any mortalities during the first week were taken into account, and then poorer quality birds were removed from the pen to a total of 120 birds). Stocking density at Day 7 was 20 birds/m^2. After Day 7, no more culls took place, unless the bird was morbidly sick or injured.

Feed

The following dietary treatments were tested in this trial:

Feed Treatment A - Expanded (90°C) standard broiler feed
Feed Treatment B - Non-expanded standard broiler feed

These treatments applied to all four feeding phases: pre-starter, starter, grower and finisher phases. Birds were fed according to days on feed (10, 8, 10 and 7 days, respectively). Pre-starter feed was weighed back and discarded on Day 10 in both houses; and the starter feed weighed back and discarded on Day 18. The grower was weighed back and discarded on Day 28 while the finisher feed was weighed in on Day 28 and weighed back on Day 35 when the trial ended.

The feeding schedule is shown in Table 3.1. The raw material and nutrient specifications for both treatments were the same and are given in Appendix A.

Table 3.1 The feeding schedule (feed allocations and days on feed)

Feed	Feeding period (days)	Feed allocation (g/bird)	Feed allocation/pen (kg)
Pre-starter	10	277	36
Starter	8	500	60
Grower	10	1300	156
Finisher	7	1300	156

For Treatment A the pre-starter feed was in the form of crumbles and the starter, grower and finisher feeds were in the form of 3.2 mm pellets. The pre-starter feed for Treatment B was also in the form of crumbles while the starter, grower and finisher feeds were in the form of 4.5 mm pellets.

Feed samples

Feed samples of 5 kg for each phase of each treatment (expanded and non-expanded feed) were collected. Grab samples were collected from all the bags of the same phase feed of each treatment to ensure a representative sample.

Feed analyses

The feed samples were analysed at Nutrilab, Department of Animal and Wildlife Science, University of Pretoria for the following:

Crude protein, fat, ash, fibre, moisture content and for Ca, P, Na and K.
Methods used for feed analyses :

Crude Protein	-	Mackro-Kjeldahl	(Leco FP-428)
Fat	-	Ether extract method	
Fibre	-	Wijkstrohm method	
Moisture	-	AOAC Official Method 7.003	
Ca, P, Na and K		AOAC Official Method 935.13	

The results of the laboratory analyses are given in Table 3.2.

Table 3.2 Analysed nutrient values (%) of the feed (DM basis)

Sample	DM	Ash	Crude Protein	Crude Fibre	Fat	Ca	P	K	Na
Expanded Pre-starter	88.57	6.10	22.42	5.20	6.10	1.25	0.70	1.04	0.22
Non-expanded Pre-starter	89.72	6.17	21.96	5.07	8.93	1.36	0.71	0.99	0.29
Expanded Starter	90.69	5.37	21.94	4.80	7.13	0.98	0.66	0.98	0.23
Non-expanded Starter	90.74	5.64	22.47	5.08	9.20	1.06	0.68	0.96	0.24
Expanded Grower	88.93	5.01	19.30	4.48	8.25	0.85	0.62	0.98	0.26
Non-expanded Grower	88.51	5.20	19.29	5.42	9.11	1.07	0.60	0.88	0.24
Expanded Finisher	89.53	4.48	18.35	4.93	7.66	0.79	0.54	0.83	0.23
Non-expanded Finisher	89.19	4.49	18.36	6.00	8.63	0.84	0.51	0.84	0.21

Statistical Design

A randomised block design was used in this trial. There were two fixed factors in this trial (feed treatment and breed). However, the effect of breed is beyond the scope of this dissertation and so, although breed has been included in the statistical analysis for purposes of accuracy, the discussion below is confined to the effect of feed treatment on broilers. There were thus 4 four treatments (2 feed treatments x 2 breeds), with 8 replicates per treatment in each house. Both the houses were

divided into four blocks, with eight pens per block (Pens 1 to 8; 9 to 16; 17 to 24; 25 to 32). Two replicates per treatment were randomly allocated to each block.

Data were statistically analysed as a randomized block design with the GLM model (Statistical Analysis System, 2011) for the average effects over time. Repeated Measures Analysis of Variance with the GLM model was used for repeated week or period measures. Means and standard deviation of mean were calculated and significance of difference ($P < 0.05$) between means was determined by Fischers test (Samuels, 1989).

The linear model used is described by the following equation:

$Y = \mu + T + B + e$

Where Y = variable studied during the period

μ = overall mean of the population

T = effect of the i treatment

B = effect of the j block

e = error associated with each Y

Response variables analysed during the experiment were body weight, weekly body weight gains, weekly feed intake, cumulative feed intake, weekly feed conversion ratio, cumulative feed conversion ratio, performance efficiency factor, weekly mortality and cumulative mortality. The feed conversion ratios were mortality corrected and initial body weights were subtracted from the body weights used in the calculation of feed conversion ratios. These variables were calculated from the following measurements: bird counts, initial body weight, weekly body weights, feed weighed in and feed weighed out and mortality records.

Production Efficiency Factor (PEF) was calculated as:
PEF = ((100- cumulative mortality %)*Body weight*100) / (CFCR*days) / 1000

Experimental procedure

Birds were placed into the pens as described above, after they have been weighed to determine their initial weight. Birds were weighed each week thereafter. The feed was weighed weekly to determine the weekly feed intake of the birds. Feed was also weighed on Day 10 and 18, when the pre-starter and grower were discarded, respectively. Mortalities were collected each morning and indicated on the data sheets. Birds were fed *ad libitum*.

Results

The results of this trial are discussed in terms of the main effects (feed expansion; house (heat stress)) and the interaction of house (heat stress) x feed expansion.

Body weights from placement to the end of the trial are given in Table 3.3. Body weights of birds in House A were significantly higher than those of birds in House B up to Day 28, although initial body weights of birds in House A were significantly lower. However, there were no significant differences in final body weight (Day 35) between the two houses. Birds fed non-expanded feed had significantly higher body weights than birds fed expanded feed from Day 7 to Day 28, but at the end of the trial there was no significant difference in Day 35 body weight between feed treatments.

In terms of the house x feed interaction, in House A there was no difference between body weights on expanded and non-expanded feeds, but in House B, birds fed the non-expanded feed had significantly higher body weights than birds on expanded feed at Days 7, 21 and 28 (Table 3.3).

Table 3.3 Mean body weight (g) of broiler chickens fed expanded and non-expanded feeds, and kept above the thermoneutral zone from 22 to 35 days of age in House A or within the thermoneutral zone in House B (means ± standard deviation)

	Body weight (g)‡					
	0 d	7 d	14 d	21 d	28 d	35 d
House						
A	45.0^{a} (±1.65)	177^{a} (±5.09)	420^{a} (±19.85)	822^{a} (±42.32)	1328^{a} (±64.01)	1892^{a} (±99.49)
B	45.5^{b} (±2.93)	171^{b} (±6.07)	392^{b} (±18.66)	784^{b} (±36.51)	1294^{b} (±63.15)	1905^{a} (±86.68)
Feed						
Expanded	45.3^{a} (±2.41)	173^{a} (±7.09)	403^{a} (±24.85)	795^{a} (±45.95)	1304^{a} (±68.65)	1899^{a} (±92.41)
Non-expanded	45.2^{a} (±2.37)	175^{b} (±5.43)	409^{b} (±22.88)	810^{b} (±40.39)	1318^{b} (±62.17)	1897^{a} (±94.66)
House x feed interaction						
House A x Expanded	45.0^{a} (±1.46)	176^{a} (±5.74)	417^{a} (±21.44)	815^{a} (±45.73)	1324^{a} (±68.90)	1901^{a} (±98.61)
House A x Non-expanded	45.0^{a} (±1.86)	177^{a} (±4.52)	423^{a} (±18.38)	829^{a} (±38.95)	1332^{a} (±60.76)	1883^{a} (±102.85)
House B x Expanded	45.5^{b} (±3.12)	169^{b} (±6.62)	389^{b} (±19.30)	776^{c} (±38.06)	1284^{b} (±64.38)	1899^{a} (±89.02)
House B x Non-expanded	45.5^{b} (2.83)	172^{c} (±5.26)	395^{b} (±18.04)	792^{d} (±34.09)	1304^{c} (±62.39)	1911^{a} (±86.71)
F-prob						
House	0.001	0.000	0.000	0.000	0.000	0.264
Feed	0.607	0.0256	0.059	0.000	0.007	0.853
House x feed	0.954	0.170	0.894	0.581	0.204	0.217
Block (House)	0.004	0.001	0.135	0.007	0.066	0.074
Variation accounted for, %	95.6	80.0	78.8	94.2	93.1	79.4

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

Body weight gains from Day 7 to Day 35 are given in Table 3.4. Body weight gains were significantly higher in House A during the first 3 weeks of the trial, when the birds were in their

thermoneutral zone in both houses. From Day 22, when heat stress was induced in House A, the body weight gains in House B became significantly higher than in House A. During Weeks 1 and 3, birds fed non-expanded feed had significant higher weight gains than birds fed expanded feed. For the remainder of the trial, there were no significant differences in gains between birds on expanded and non-expanded feed.

In terms of the interaction of house x feed, there were no significant differences between gains in birds fed expanded and non-expanded feed in House A from Day 7 to Day 35. In House B, birds fed expanded feed had significantly lower weight gains during Weeks 1 and 3 than those fed non-expanded feed. During Week 2, gains on both feed treatments in House A differed significantly from those in House B but, at Day 21, only the birds fed expanded feed in House B had significantly lower weight gains than birds on either feed treatment in House A. At the end of the trial, birds on both the feed treatments in House B had significantly higher weight gains than birds on the treatments in House A (Table 3.4).

Table 3.4 Mean body weight gain (g/ bird day) broiler chickens fed expanded and non-expanded feeds, and kept above the thermoneutral zone from 22 to 35 days of age in House A or within the thermoneutral zone in House B (means ± standard deviation)

	Body weight gain (g/ bird day) ‡				
	7 d	14 d	21 d	28 d	35 d
House					
A	16.5^{a} (±0.75)	34.8^{a} (±2.56)	57.4^{a} (±3.51)	72.3^{a} (±3.73)	80.6^{a} (±9.31)
B	15.7^{b} (±1.05)	31.6^{b} (±2.22)	56.0^{b} (±3.85)	72.9^{a} (±4.04)	87.3^{b} (±4.08)
Feed					
Expanded	15.9^{a} (±1.09)	32.9^{a} (±2.83)	56.1^{a} (±4.11)	72.7^{a} (±3.67)	85.0^{a} (±6.57)
Non-expanded	16.2^{b} (±0.88)	33.5^{a} (±2.67)	57.3^{b} (±3.67)	72.5^{a} (±4.11)	82.9^{a} (±8.99)
House x feed interaction					
House A x Expanded	16.4^{a} (±0.84)	34.4^{a} (±2.41)	56.8^{a} (±3.81)	72.8^{a} (±3.49)	82.3^{a} (±7.45)
House A x Non-expanded	16.5^{a} (±0.66)	35.1^{a} (±2.11)	57.9^{a} (±3.21)	71.9^{a} (±4.03)	78.9^{a} (±10.82)
House B x Expanded	15.5^{b} (±1.13)	31.3^{b} (±2.36)	55.3^{b} (±4.39)	72.7^{a} (±3.96)	87.8^{b} (±4.20)
House B x Non-expanded	15.8^{c} (±0.98)	31.8^{b} (±2.12)	56.8^{a} (±3.21)	73.1^{a} (±4.23)	86.8^{b} (±4.02)
F-prob					
House	0.000	0.000	0.005	0.264	0.000
Feed	0.018	0.164	0.006	0.689	0.165
House x feed	0.165	0.814	0.697	0.203	0.442
Block (House)	0.001	0.675	0.524	0.790	0.041
Variation accounted for, %	87.8	70.5	81.8	78.3	48.8

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

Cumulative feed intakes (CFI) for Day 7 to Day 35 are given in Table 3.5. Birds in House A had significantly higher cumulative feed intakes than those in House B, except on Day 35. This was to be expected because of the induced heat stress in House A. Birds fed expanded feed had significantly higher cumulative feed intakes than birds fed non-expanded feed for the first two weeks of the trial, but, from Day 28, birds fed non-expanded feed had significantly higher cumulative feed intakes.

Within House A, birds fed expanded feed had a significantly higher CFI on Day 14 but, at Day 21 and Day 28 there was no significant difference in CFI between birds on expanded and non-expanded feed. The CFI of birds fed expanded feed on Day 35 was significantly lower than the birds fed non-expanded feed. Within House B, the birds fed expanded feed had a significantly higher CFI than those fed non-expanded feed for the first 2 weeks of the trial but, for the last 2 weeks of the trial, the birds fed the expanded feed had significantly lower CFI. Birds fed the non-expanded feed in House B ended the trial with the highest CFI (Table 3.5).

Table 3.5 Mean cumulative feed intake (g/bird) of broiler chickens fed expanded and non-expanded feeds, and kept above the thermoneutral zone from 22 to 35 days of age in House A or within the thermoneutral zone in House B (means ± standard deviation)

	Cumulative feed intake (g/bird) ‡				
	7 d	14 d	21 d	28 d	35 d
House					
A	149^{a} (±4.21)	457^{a} (±19.17)	1066^{a} (±48.52)	1928^{a} (±89.78)	2947^{a} (±158.97)
B	144^{b} (±5.03)	438^{b} (±17.65)	1013^{b} (±48.34)	1891^{b} (±92.07)	2999^{b} (±139.35)
Feed					
Expanded	148^{a} (±5.00)	450^{a} (±21.13)	1041^{a} (±59.64)	1880^{a} (±96.70)	2932^{a} (±149.77)
Non-expanded	145^{b} (±4.82)	444^{b} (±20.15)	1037^{a} (±51.09)	1940^{b} (±77.89)	3014^{b} (±141.92)
House x feed interaction					
House A x Expanded	149^{a} (±4.44)	460^{a} (±20.31)	1068^{a} (±49.77)	1914^{a} (±89.66)	2924^{a} (±159.73)
House A x Non-expanded	148^{ab} (±3.89)	454^{b} (±18.10)	1064^{a} (±48.75)	1943^{a} (±90.51)	2970^{b} (±159.89)
House B x Expanded	146^{b} (±5.13)	440^{c} (±17.55)	1014^{b} (±57.60)	1846^{b} (±93.61)	2940^{ab} (±143.89)
House B x Non-expanded	142^{c} (±4.11)	435^{d} (±17.88)	1011^{b} (±38.80)	1937^{a} (±65.78)	3058^{c} (±109.15)
F-prob					
House	0.000	0.000	0.000	0.004	0.002
Feed	0.001	0.002	0.513	0.000	0.000
House x feed	0.200	0.888	0.950	0.016	0.027
Block (House)	0.074	0.050	0.617	0.653	0.018
Variation accounted for, %	62.5	90.4	83.4	76.34	85.8

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

Weekly feed intakes (FI) for Day 7 to Day 35 are given in Table 3.6. When feed intake is looked at in terms of weekly, rather than cumulative feed intakes, the effect of the high environmental temperature in House A from Day 22 can be seen. Birds in House A had significantly higher feed intakes than those in House B for the first 3 weeks of the trial, but from Week 4, weekly feed intakes in birds in House A began to reduce and, through Week 5, were significantly lower than in House B.

There was no significant difference in feed intake between birds fed expanded and non-expanded feed during Weeks 2 and 3 but, from Week 4, birds fed expanded feed had significantly lower feed intakes than birds fed non-expanded feed (Table 3.6).

Within House A, there was a significant difference in weekly feed intakes between birds fed expanded and non-expanded feed during Week 4, with birds on expanded feed having a lower weekly intake. Within House B, birds fed expanded feed had significantly lower feed intakes during Week 4 and 5 than those fed non-expanded feed.

Table 3.6 Mean weekly feed intake (g/bird day) of broiler chickens fed expanded and non-expanded feeds, and kept above the thermoneutral zone from 22 to 35 days of age in House A or within the thermoneutral zone in House B (means ± standard deviation)

	Weekly feed intake (g/bird day) ‡				
	7 d	14 d	21 d	28 d	35 d
House					
A	18.6^{a} (±0.53)	44.0^{a} (±2.38)	87.1^{a} (±4.62)	123.2^{a} (±8.11)	145.5^{a} (±11.60)
B	18.0^{b} (±0.63)	41.9^{b} (±2.21)	82.2^{b} (±4.74)	125.5^{a} (±8.87)	158.3^{b} (±8.02)
Feed					
Expanded	18.5^{a} (±0.62)	43.2^{a} (±2.73)	84.5^{a} (±6.72)	119.8^{a} (±6.72)	150.3^{a} (±11.48)
Non-expanded	18.1^{b} (±0.60)	42.8^{a} (±2.30)	84.7^{a} (±7.70)	128.9^{b} (±7.70)	153.5^{b} (±12.08)
House x feed interaction					
House A x Expanded	18.7^{a} (±0.55)	44.3^{a} (±2.60)	87.0^{a} (±4.67)	120.8^{a} (±7.34)	144.2^{a} (±11.11)
House A x Non-expanded	18.5^{ab} (±0.49)	43.7^{a} (±2.17)	87.2^{a} (±4.72)	125.5^{b} (±8.40)	146.8^{a} (±12.30)
House B x Expanded	18.3^{b} (±0.64)	42.0^{b} (±2.40)	82.0^{b} (±5.94)	118.7^{a} (±6.09)	156.3^{b} (±8.43)
House B x Non-expanded	17.8^{c} (±0.51)	41.8^{b} (±2.07)	82.4^{b} (±3.33)	132.3^{c} (±5.25)	160.3^{c} (±7.34)
F-prob					
House	0.000	0.000	0.000	0.126	0.000
Feed	0.001	0.128	0.749	0.000	0.006
House x feed	0.200	0.447	0.979	0.005	0.552
Block (House)	0.074	0.041	0.659	0.841	0.001
Variation accounted for, %	62.5	86.5	74.2	60.1	88.4

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

Mean cumulative feed conversion ratios (g feed/g gain) for Day 7 to Day 35 are given in Table 3.7. Birds in House A had significantly better cumulative feed conversion ratios (CFCR) at the end of the first and second weeks than the birds in House B but, after Week 2, there were no significant differences in CFCR between the houses. Birds fed expanded feed had significantly higher CFCRs than birds fed non-expanded feed up to Day 21 but, during Week 4 and 5, birds fed expanded feed had significantly better CFCRs (Table 3.7).

In terms of the interaction of house x feed, House A birds fed expanded feed ended the trial with a significantly better CFCR than those fed non-expanded feed, but the birds fed non-expanded feed had a better CFCR during Week 2 and 3. In House B, birds fed expanded feed had significantly poorer CFCRs than those fed non-expanded feed up to Week 3 but, from Week 4, this response reversed, with birds that received expanded feed having a significantly better CFCR (Table 3.7).

Table 3.7 Mean cumulative feed conversion ratio (g feed/g gain) of broiler chickens fed expanded and non-expanded feeds, and kept above the thermoneutral zone from 22 to 35 days of age in House A or within the thermoneutral zone in House B (means ± standard deviation)

	Cumulative feed conversion ratio (g feed/g gain) ‡				
	7 d	14 d	21 d	28 d	35 d
House					
A	1.13^{a} (±0.04)	1.22^{a} (±0.03)	1.37^{a} (±0.03)	1.50^{a} (±0.05)	1.60^{a} (±0.06)
B	1.16^{b} (±0.07)	1.27^{b} (±0.05)	1.37^{a} (±0.04)	1.52^{a} (±0.05)	1.61^{a} (±0.04)
Feed					
Expanded	1.16^{a} (±0.07)	1.26^{a} (±0.05)	1.39^{a} (±0.04)	1.49^{a} (±0.04)	1.58^{a} (±0.04)
Non-expanded	1.12^{b} (±0.04)	1.22^{b} (±0.04)	1.36^{b} (±0.03)	1.53^{b} (±0.05)	1.63^{b} (±0.05)
House x feed interaction					
House A x Expanded	1.14^{a} (±0.05)	1.24^{a} (±0.03)	1.39^{a} (±0.04)	1.50^{a} (±0.04)	1.58^{a} (±0.05)
House A x Non-expanded	1.12^{a} (±0.03)	1.20^{b} (±0.02)	1.36^{b} (±0.03)	1.51^{a} (±0.05)	1.62^{bc} (±0.07)
House B x Expanded	1.19^{b} (±0.08)	1.29^{c} (±0.06)	1.39^{a} (±0.04)	1.49^{a} (± 0.04)	1.59^{ab} (±0.03)
House B x Non-expanded	1.12^{a} (±0.04)	1.25^{a} (±0.04)	1.35^{b} (±0.03)	1.54^{b} (±0.05)	1.64^{c} (±0.04)
F-prob					
House	0.004	0.000	0.802	0.307	0.179
Feed	0.000	0.000	0.000	0.005	0.000
House x feed	0.023	0.781	0.730	0.094	0.587
Block (House)	0.020	0.463	0.503	0.948	0.795
Variation accounted for, %	71.7	49.1	46.1	36.7	33.0

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

Mean weekly feed conversion ratios (g feed/g gain) for Day 7 to Day 35 are given in Table 3.8. For the first two weeks, birds in House A had significantly better weekly FCR than birds in House B but, on Day 21, birds in House B had significantly better FCR with no significant differences between houses in Week 4 and 5. Birds fed expanded feed had significantly higher weekly FCR for the first two weeks but, for the last two weeks of the trial, birds fed expanded feed had significantly better FCR than those fed non-expanded feed.

Within House A, there were only significant differences in weekly FCR during Weeks 4 and 5, with birds fed expanded feed having a better FCR than those fed non-expanded feed. For the first two weeks of the trial in House B, the birds on the non-expanded feed had a significantly better FCR than those fed expanded feed. During Week 4 in House B, the birds fed the expanded feed had a significantly lower FCR than the birds fed the non-expanded feed and, during the last week of the trial, the birds fed expanded feed tended ($p< 0.1$) to have a significantly lower FCR than birds fed non-expanded feed (Table 3.8).

Table 3.8 Mean weekly feed conversion ratio (g feed/g gain) of broiler chickens fed expanded and non-expanded feeds, and kept above the thermoneutral zone from 22 to 35 days of age in House A or within the thermoneutral zone in House B (means ± standard deviation)

	Feed conversion ratio (g feed/ g gain) ‡				
	7 d	14 d	21 d	28 d	35 d
House					
A	1.13^{a} (±0.04)	1.27^{a} (±0.04)	1.52^{a} (±0.05)	1.71^{a} (±0.11)	1.83^{a} (±0.27)
B	1.16^{b} (±0.07)	1.33^{b} (±0.08)	1.47^{b} (±0.07)	1.72^{a} (±0.12)	1.81^{a} (±0.07)
Feed					
Expanded	1.16^{a} (±0.07)	1.32^{a} (±0.08)	1.51^{a} (±0.08)	1.65^{a} (±0.07)	1.77^{a} (±0.11)
Non-expanded	1.12^{b} (±0.04)	1.29^{b} (±0.06)	1.48^{a} (±0.06)	1.78^{b} (±0.11)	1.87^{b} (±0.25)
House x feed interaction					
House A x Expanded	1.14^{a} (±0.05)	1.29^{a} (±0.03)	1.53^{a} (±0.05)	1.66^{a} (±0.08)	1.76^{a} (±0.14)
House A x Non-expanded	1.12^{a} (±0.03)	1.25^{a} (±0.02)	1.51^{ab} (±0.05)	1.75^{b} (±0.13)	1.90^{b} (±0.35)
House B x Expanded	1.19^{b} (±0.08)	1.35^{b} (±0.09)	1.49^{bc} (±0.09)	1.63^{a} (±0.06)	1.78^{ab} (±0.06)
House B x Non-expanded	1.12^{a} (±0.04)	1.32^{b} (±0.07)	1.45^{c} (±0.05)	1.81^{b} (±0.09)	1.85^{ab} (±0.06)
F-prob					
House	0.004	0.000	0.002	0.443	0.772
Feed	0.000	0.027	0.057	0.000	0.041
House x feed	0.023	0.664	0.789	0.063	0.472
Block (House)	0.019	0.901	0.928	0.962	0.880
Variation accounted for, %	71.7	36.6	32.9	46.1	21.4

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

Mean cumulative mortality (% of birds placed at day 7) of birds for Day 7 to Day 35 is given in Table 3.9. Cumulative mortality was significantly higher for birds in House A at both Day 28 and Day 35, after heat stress was induced at Day 22 (Table 3.25). No significant differences in cumulative mortality between birds on expanded and non-expanded feed were observed. Cumulative mortality rates were significantly higher on both feed treatments (expanded and non-expanded) in House A than on both feed treatments in House B (Table 3.9).

Table 3.9 Mean cumulative mortality (% of birds placed at Day 7) of broiler chickens fed expanded and non-expanded feeds, and kept above the thermoneutral zone from 22 to 35 days of age in House A or within the thermoneutral zone in House B (means ± standard deviation)

	Cumulative mortality (%) ‡				
	7 d	14 d	21 d	28 d	35 d
House					
A	0.60^{a} (±0.67)	0.78^{a} (±1.07)	1.37^{a} (±1.23)	2.61^{a} (±1.72)	4.97^{a} (±2.40)
B	0.58^{a} (±0.65)	0.68^{a} (±0.75)	0.98^{a} (±0.99)	1.53^{b} (±1.44)	2.02^{b} (±1.57)
Feed					
Expanded	0.53^{a} (±0.67)	0.73^{a} (±0.81)	0.93^{a} (±0.99)	2.11^{a} (±1.53)	3.45^{a} (±2.22)
Non-expanded	0.65^{a} (±0.65)	0.73^{a} (±1.04)	1.43^{a} (±1.22)	2.03^{a} (±1.80)	2.54^{a} (±2.82)
House x feed interaction					
House A x Expanded	0.39^{a} (±0.56)	0.63^{a} (±0.78)	0.83^{a} (±0.75)	2.34^{a} (±1.33)	4.58^{a} (±2.17)
House A x Non-expanded	0.82^{b} (±0.72)	1.41^{b} (±1.21)	1.88^{b} (±1.41)	3.07^{a} (±2.01)	5.73^{a} (±2.54)
House B x Expanded	0.68^{ab} (±0.75)	0.83^{a} (±0.86)	1.20^{ab} (±1.17)	2.14^{ab} (±1.75)	2.55^{b} (±1.81)
House B x Non-expanded	0.48^{ab} (±0.55)	0.52^{a} (±0.60)	0.94^{a} (±0.80)	1.20^{b} (±0.86)	1.72^{b} (±1.20)
F-prob					
House	0.891	0.114	0.271	0.007	0.000
Feed	0.445	0.270	0.135	0.780	0.719
House x feed	0.043	0.012	0.015	0.029	0.026
Block (House)	0.179	0.158	0.494	0.363	0.117
Variation accounted for, %	31.8	35.5	33.0	36.7	62.7

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

Mean weekly mortality (% of birds placed at day 7) for Day 7 to Day 35 is given in Table 3.10, along with the production efficiency factor (PEF; Day 35). There was a significant difference between the two houses in weekly mortality rates from Day 22 onwards, due to the heat stress introduced in House A from this date. Birds fed expanded feed had a significantly higher mortality rate than birds on non-expanded feed in the week to Day 28 (Table 3.10).

Birds in House B had a significantly higher PEF at 35 days of age than birds in House A. There were no significant differences in PEF at 35 days between birds fed expanded and non-expanded feed. Within both House A and House B, there were no significant differences in PEF between birds fed expanded and non-expanded feeds.

Table 3.10 Mean weekly mortality (% of birds placed at Day 7) and Production Efficiency Factor (PEF; Day 35) of broiler chickens fed expanded and non-expanded feeds, and kept above the thermoneutral zone from 22 to 35 days of age in House A or within the thermoneutral zone in House B (means ± standard deviation)

	Weekly mortality (%) ‡					
	7 d	14 d	21 d	28 d	35 d	PEF 35 d
House						
A	0.60^{a} (±0.67)	0.36^{a} (±0.56)	0.34^{a} (±0.47)	1.35^{a} (±1.09)	2.45^{a} (±1.86)	322^{a} (±27.5)
B	0.58^{a} (±0.65)	0.05^{b} (±0.00)	0.39^{a} (±0.52)	0.60^{b} (±0.77)	0.47^{b} (±0.67)	331^{b} (±21.8)
Feed						
Expanded	0.53^{a} (±0.67)	0.16^{a} (±0.33)	0.29^{a} (±0.50)	1.22^{a} (±1.05)	1.33^{a} (±1.60)	328^{a} (±22.6)
Non-expanded	0.65^{a} (±0.65)	0.26^{a} (±0.54)	0.44^{a} (±0.47)	0.73^{b} (±0.91)	1.59^{a} (±1.82)	325^{a} (±26.5)
House x feed interaction						
House A x Expanded	0.39^{a} (±0.56)	0.21^{a} (±0.37)	0.21^{a} (±0.37)	1.51^{a} (±1.15)	2.24^{a} (±1.79)	322^{a} (±25.2)
House A x Non-expanded	0.82^{b} (±0.72)	0.52^{b} (±0.60)	0.47^{a} (±0.52)	1.07^{a} (±1.05)	2.66^{a} (±1.95)	323^{a} (±28.5)
House B x Expanded	0.68^{ab} (±0.75)	0.10^{a} (±0.00)	0.36^{a} (±0.61)	0.94^{a} (±0.91)	0.42^{b} (±0.53)	334^{b} (±20.4)
House B x Non-expanded	0.48^{ab} (±0.55)	0.00^{a} (±0.00)	0.42^{a} (±0.43)	0.26^{b} (±0.40)	0.52^{b} (±0.80)	328^{ab} (±23.4)
F-prob						
House	0.891	0.003	0.644	0.001	0.000	0.048
Feed	0.445	0.307	0.167	0.032	0.440	0.023
House x feed	0.043	0.044	0.354	0.420	0.642	0.312
Block (House)	0.179	0.168	0.107	0.226	0.315	0.460
Variation accounted for, %	31.8	34.7	34.2	37.9	51.2	62.0

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

Table 3.11 Actual temperatures as measured in House A

Day	Temperature						
	Average	Median	Minimum	Maximum	Day-time	Night-time	Average
0	27.17	28.70	15.30	35.30	24.52	32.18	27.07
1	32.28	32.40	29.70	34.40	32.49	32.08	32.35
2	32.45	32.10	30.40	38.70	32.72	32.16	32.53
3	32.23	32.00	30.90	35.10	32.42	32.03	32.29
4	32.80	32.90	30.80	34.90	32.71	32.94	32.79
5	32.41	32.60	30.40	34.20	32.20	32.54	32.32
6	32.19	32.40	27.30	34.40	32.69	31.75	32.38
7	31.95	31.75	27.90	37.80	32.90	30.95	32.25
8	31.13	30.70	29.60	34.30	31.03	31.18	31.08
9	31.25	30.80	28.20	34.20	32.05	30.49	31.53
10	30.53	29.95	27.40	42.50	31.85	29.20	30.97
11	29.35	29.25	26.20	33.30	30.37	28.34	29.69
12	28.72	28.70	26.80	31.60	29.21	28.26	28.90
13	28.79	28.85	25.60	32.90	29.85	27.62	29.11
14	28.19	27.50	24.90	32.80	29.54	26.74	28.61
15	28.48	28.45	26.80	30.50	28.92	28.10	28.65
16	29.00	28.90	27.20	34.10	29.66	28.22	29.18
17	27.46	27.40	24.80	30.30	28.11	26.96	27.73
18	27.02	27.00	24.60	29.20	27.50	26.67	27.22
19	28.52	28.50	26.10	30.90	28.85	28.33	28.68
20	28.25	28.05	26.10	31.30	28.98	27.47	28.47
21	29.35	28.75	25.60	40.20	31.34	27.38	30.02
22	27.74	27.60	25.80	31.40	28.14	27.32	27.87
23	29.23	28.50	25.40	35.40	31.60	26.95	30.05
24	28.32	27.80	23.20	33.20	30.13	26.53	28.93
25	28.76	28.35	25.60	33.30	30.17	27.36	29.23
26	28.58	28.25	23.60	33.80	30.29	26.80	29.13
27	29.38	29.25	24.70	34.80	31.20	27.63	30.01
28	29.97	29.25	24.80	35.40	32.15	27.74	30.68
29	29.21	29.15	25.10	34.00	29.94	28.46	29.45
30	29.99	29.60	26.40	33.80	30.93	28.99	30.28
31	29.49	29.15	25.20	33.30	30.32	28.61	29.75
32	30.55	30.00	26.30	36.40	32.16	28.97	31.10
33	30.76	29.75	27.30	36.40	32.32	29.17	31.27
34	30.44	29.60	27.40	35.40	32.07	28.82	30.99
35	30.12	29.90	27.10	35.10	31.40	28.82	30.54

Discussion

Birds in House A had significantly higher body weights than those in House B up to Week 4, but the trial ended with no significant difference in body weight between birds in House A and those in House B (Table 3.3). This was due to the induced heat stress in House A from Day 22. Reduced body weight is one of the effects of heat stress on broilers (Al-Fataftah & Abu-Dieyeh, 2007). Although there were no differences in final body weight between the two houses, birds in House B had significantly higher growth rates (87.3 g/bird day) during the final week of the trial, showing the effect of the induced heat stress in House A (80.6 g/bird day). It was thought that there might be a difference in final body weight when birds were fed expanded feed under heat stress conditions. This was not the case in this trial, as body weights in birds fed expanded or non-expanded feed did not differ significantly in House A at 35 days of age (1901 g and 1883 g, respectively). The results of this trial showed that heat stress affects growth rates, but the feeding of expanded feed to broilers under heat stress conditions did not improve final body weights (Table 3.3).

The reason for the initial better performance of the non-expanded feed might have been as a result of the higher levels of fat in the feed as detected by the laboratory feed analyses in Table 3.2, although the same formulation was used for both treatments.

Feed intake was lower in House A than in House B during Week 5 as was expected after the induction of heat stress in House A (Tables 3.5 and 3.6). Birds decrease their feed intake during heat stress in an attempt to maintain lower body temperatures. Birds fed expanded feed had higher feed intakes during the first two weeks of the trial than the birds fed non-expanded feed as shown in Tables 3.5 and 3.6. However, for the last two weeks of the trial, birds fed expanded feed had significantly lower feed intakes than those fed non-expanded feed. This gives the impression that expanded feed stimulates feed intake in the early stages and improves feed conversion rates from Week 4.

In Week 4, the FCR of birds fed expanded feed was 1.65, compared to an FCR of 1.78 in birds fed non-expanded feed; and, in Week 5, the FCR of birds fed expanded feed was 1.77, compared to an FCR of 1.88 in birds fed non-expanded feed. This expansion-related improvement in FCR in the last week of the trial was particularly noticeable in birds fed the expanded feed under heat stress conditions in House A.

Improved FCR of birds fed expanded feed may be due to the better pellet quality associated with expanded feed. Good quality pellets reduce the feeding activity and heat production of birds (Behnke, 1994; Howlider & Rose, 1992) because of a reduction in the amount of fines in the feed.
Heat stress may affect FCR negatively, but this was not seen in this trial as body weights and feed intake were proportionally lower in House A than in House B and the cumulative FCR at 35 days was 1.60 and 1.61, respectively for House A and House B.

The weekly and cumulative mortality rates were significantly higher in House A than in House B from Day 22 as was expected with the induced heat stress in House A (Tables 3.9 and 3.10). Within House A, there was no significant difference in cumulative mortality rate at Day 35 between birds fed expanded and non-expanded feed, which indicates no effect of feed treatment on mortality rate.

Conclusion

Heat stress has significant effects on growth rates and feed intakes, as both these variables decreased under heat stress conditions. The feed conversion ratio of birds in House A did not differ significantly from the birds in House B as the decrease in growth recorded resulted from lower feed intakes. The induced heat stress conditions increased the mortality rate of broiler birds.

Feeding expanded feed to broilers led to an increased feed intake during the first two weeks of the trial and, after Week 3, birds fed expanded feed had a significantly better FCR than the birds fed non-expanded feed. Final body weights in birds under heat stress seem to be unaffected by the feeding of expanded feed to broilers.

Chapter 4

Investigation of the effect of feed expansion and pellet size on broiler performance

Abstract

The effects of feed expansion and pellet size on broiler performance, particularly feed conversion rate were investigated. Ross 308 broilers were fed either non-expanded 3.2 mm or 4.5 mm pellets, or 3.2 mm expanded pellets. A fourth treatment (Treatment D) offered the birds expanded feed until Day 18, followed by non-expanded feed to the end of the trial. The birds fed expanded 3.2 mm pellets had significantly better cumulative FCR and higher growth rates than the birds fed the non-expanded 3.2 mm pellet treatment during the first two weeks of the trial, indicating that the expanding of feed prior to pelleting has advantages for young broilers. From Week 3, birds on these two treatments did not perform significantly different from each other, but FCRs were significantly better than for the broilers fed the non-expanded 4.5 mm pellets and Treatment D. Feeding birds expanded feed thus improved FCR and body weights of birds for the first 3 weeks of the trial, with pellet size also having a significant influence as the 3.2 mm and the 4.5 mm non-expanded treatments differed significantly in cumulative FCR and feed intake at Day 21. Feeding birds bigger pellets increased their feed intake and thus increased cumulative FCR at Day 35. Expansion of feed resulted in no improvement in broiler performance from Week 3.

Introduction

The use of expanders in feed processing has overcome a lot of production challenges from the past (Vest, 1996). A marked increase in pellet quality, measured according to the Pellet Durability Index, is one of the advantages of using expanders (Behnke, 1996). The increase in pellet quality of expanded feed (measured as the percentage pellets retained on a sieve of known mesh gauge) and the increase in pellet durability (measured by the use of a tumbler) has led to reduced fines in the feeder pans and improved FCR, due to less feed wastage and less energy expenditure during eating (Svihus & Gullord, 2002). The ability of the expander to handle feed with higher moisture levels makes it possible to increase the fat content of the mash diet, without reducing pellet quality (Vest 1996).

Feed can be expanded at different temperatures either by increasing or decreasing the conditioning temperature or by decreasing the annular gap width, through which the feed passes, which results in an increase in shear pressure causing the temperature of the mash to rise (Thomas *et al.,* 1997). Expanding of feed has the following advantages : (1) improves pellet quality (2) increases pellet mill output (3) allows for higher levels of liquids (especially fat) to be added to the feed prior to pelleting

and (4) lowers the microbial level of the feed (Behnke, 1996). Broiler performance is usually increased when they are fed expanded feed, especially their feed conversion ratio (Smith *et al.,* 1995). In an experiment conducted by Fancher *et al.* (1996), it was concluded that birds fed expanded feed had a better FCR and higher growth rate than birds fed non-expanded feed. Gelatinisation of starch during expansion of feed prior to pelleting may lead to improved digestibility of starch in the digestive tract. This may improve broiler performance further, along with improved pellet quality of expanded pellets (Svihus & Gullord, 2002)

The aim of this trial was to determine whether pellet quality and size affect performance in broilers and also to determine if the expansion of feed affects performance.

There were four feed treatments in this trial and all four treatments had the same raw material composition and nutrient specifications within each feeding phase (pre-starter, starter, grower and finisher). Treatment A was the control, non-expanded feed, 4.5 mm pellets; Treatment B, non-expanded feed, 3.2 mm pellets; Treatment C, expanded feed, 3.2 mm pellets; Treatment D, expanded pre-starter, crumbles ; expanded starter, 3.2 mm pellets ; non-expanded grower and finisher, 4.5 mm pellets.

Treatment C was expected to support better performance than the other treatments. Any differences in performance of broilers fed Treatment B and C in relation to Treatment A would indicate if the mode of action of expanded feed on broiler performance was a pellet quality and size effect, an effect due to the expansion of the feed, or both. Treatment D was included to determine whether the feeding of good quality crumbles and starter pellets early in the production cycle would help the bird to perform better on the non-expanded feed later in the cycle.

Materials and methods

Housing

The trial was conducted at the test facilities at Daybreak Farms, Sundra from Tuesday 26 May 2009 to Tuesday 30 June 2009. An open sided broiler house was used, in which temperature was controlled by a boiler. The duration of the trial was five weeks (35 days).

The temperature profile followed from 2 days pre-placement to Day 35 was the normal, prescribed Ross rearing temperature profile for winter. Minimum and maximum temperature, as measured with six min/max thermometers per house, together with the reading on the monitor of the boiler, were recorded each day on a data sheet. Two temperature loggers per house were used to ensure proper temperature regulation.

Birds

Four thousand three hundred and twenty (4320) day old chicks (Ross 308) were randomly placed in each of the 32 pens, at a stocking density of 135 birds/pen, on Day 0. Birds per pen were reduced to 126 birds on Day 7 (any mortality during the first week was first taken into account and then poorer quality birds were removed from the pen). Stocking density at Day 7 was 21 birds/m^2. After Day 7, no more culling took place, unless the bird was morbidly sick or injured.

Feed

The following feed treatments were tested in this trial:

Treatment A - Non-expanded standard broiler feed; pre-starter and starter crumbles, grower and finisher pellets 4.5 mm

Treatment B - Non-expanded standard broiler feed; pre-starter crumbles, starter, grower and finisher pellets 3.2 mm

Treatment C - Expanded standard broiler feed (90°C); pre-starter crumbles, starter, grower and finisher pellets 3.2 mm

Treatment D - Expanded standard broiler feed; pre-starter crumbles and starter pellet 3.2mm Non-expanded standard broiler feed; grower and finisher pellets 4.5 mm

Birds were fed the different phases according to days on feed (10, 8, 10 and 7 days, respectively). Pre-starter feed was weighed back and discarded on Day 10 and the starter weighed back and discarded on Day 18. The grower feed was weighed back and discarded on Day 28 while the finisher feed was weighed in on Day 28 and weighed back on Day 35 when the trial ended.

Feed samples

Feed samples of 5 kg of each phase of each of the four treatments were collected. These samples comprised grab samples from all the bags of the same phase feed of each treatment. The feeding schedule is shown in Table 4.1. The feed specifications of the pre-starter, starter, grower and finisher feeds used in the trial are shown in Appendix A.

Table 4.1 The feeding schedule (feed allocations and days on feed)

Feed	Feeding period (days)	Feed allocation (g/bird)	Feed allocation/pen (kg)
Prestarter	10	326	40.9
Starter	8	600	72.0
Grower	10	1385	166.2
Finisher	7	1120	133.4

Feed analyses

The feed samples were analysed for the following (Nutrilab, Department of Animal and Wildlife Science, University of Pretoria):

Crude protein, fat, ash, fibre, moisture content and for Ca, P, Na and K.

Methods used for feed analyses :

Crude Protein	-	Mackro-Kjeldahl (Leco FP-428)
Fat	-	Ether extract method
Fibre	-	Wijkstrohm method
Moisture	-	AOAC Official Method 7.003
Ca, P, Na and K		AOAC Official Method 935.13

The result of the laboratory analyses are given in Table 4.2.

Table 4.2 Analysed nutrient values (%) of the feed (DM Basis)

Sample	DM	Ash	Protein	Fibre	Fat	Ca	P	K	Na
Non-expanded 4.5 mm Pre-starter	89.707	6.30	22.57	4.79	5.79	1.27	0.77	0.95	0.26
Non-expanded 4.5 mm Starter	89.988	4.95	20.14	4.79	7.55	0.93	0.61	0.87	0.24
Non-expanded 4.5 mm Grower	89.286	4.77	19.77	4.82	8.42	0.87	0.55	0.88	0.26
Non-expanded 4.5 mm Finisher	88.775	5.12	19.98	5.46	7.38	0.92	0.65	0.96	0.24
Non-expanded 3.2 mm Pre-starter	88.466	6.43	23.48	4.22	8.52	1.18	0.81	0.98	0.28
Non-expanded 3.2 mm Starter	89.017	6.07	22.35	5.11	7.59	1.07	0.81	1.02	0.29
Non-expanded 3.2 mm Grower	90.072	5.26	19.69	3.94	8.16	0.88	0.64	0.92	0.24
Non-expanded 3.2 mm Finisher	89.035	4.97	19.72	3.71	9.14	0.79	0.62	0.87	0.22
Expanded 3.2 mm Pre-starter	89.160	6.33	23.62	3.87	7.00	1.13	0.81	0.97	0.29
Expanded 3.2 mm Starter	90.124	5.71	21.87	4.17	7.47	1.04	0.69	1.02	0.34
Expanded 3.2 mm Grower	89.438	5.22	19.54	4.48	8.95	0.93	0.61	0.93	0.25
Expanded 3.2 mm Finisher	88.851	4.95	19.21	3.99	9.80	0.81	0.62	0.94	0.22
Treatment D Pre-starter	89.301	6.21	23.09	5.73	6.53	1.15	0.79	1.04	0.27
Treatment D Starter	89.724	5.77	21.77	5.08	8.01	1.03	0.70	1.00	0.27
Treatment D Grower	89.234	5.15	20.56	5.44	8.24	0.89	0.57	0.99	0.25
Treatment D Finisher	87.978	5.14	19.83	5.06	8.33	0.90	0.64	0.83	0.22

Statistical design

A randomised block design was used in this trial. There were four blocks in the broiler house with eight pens per block (Pens 1 to 8; 9 to 16; 17 to 24; 25 to 32). There was one fixed factor in this trial (feed treatment). There were thus 4 (four) treatments, with 8 (eight) replicates per treatment in the house; 2 replicates per block).

Data were statistically analysed as a randomized block design with the GLM model (Statistical Analysis System, 2011) for the average effects over time. Repeated Measures Analysis of Variance with the GLM model was used for repeated week or period measures. Means and standard error of mean (SEM) were calculated and significance of difference ($P < 0.05$) between means was determined by Fischers test (Samuels, 1989).

The linear model used is described by the following equation:

$Y = \mu + T + B + e$

Where Y = variable studied during the period

μ = overall mean of the population

T = effect of the i treatment

B = effect of the j block

e = error associated with each Y

Response variables analysed were body weight, weekly body weight gains, weekly feed intake, cumulative feed intake, weekly feed conversion ratio, cumulative feed conversion ratio, performance 2efficiency factor, weekly mortality and cumulative mortality. These variables could be calculated, respectively, from the following measurements: bird counts, initial body weight, weekly body weights, feed weighed in and feed weighed out (weekly and at Day 10 (end of pre-starter phase) and Day 18 (end of starter phase), mortality records. The feed conversion ratios were mortality corrected.

Production Efficiency Factor (PEF) was calculated as:

PEF = ((100- Cumulative mortality %)*Body weight*100) / (CFCR*days) / 1000

Experimental procedure

Birds were randomly divided to the pens as described above, after they have been weighed to determine initial weight. Birds were weighed each week thereafter. The feed were also weighed weekly to determine the weekly feed intake of the birds. Feed were also weighed on Day 10 and 18, when the pre-starter and grower were discarded, respectively. Mortalities were collected each morning and indicated on the data sheets. Birds had unrestricted access to feed and water.

Results

In the discussion below, it should be remembered that Treatment D received expanded pre-starter crumbles and 3.2 mm starter pellets; followed by *non-expanded* 4.5 mm grower and finisher pellets.

Body weights from placement to the end of the trial are given in Table 4.3. Birds fed non-expanded 4.5 mm pellets (Treatment A) were the heaviest on Day 7; their body weights differing significantly from all the treatments except the expanded 3.2 mm treatment (Treatment C). On Day 14, the birds receiving the non-expanded 3.2 mm feed (Treatment B) were significantly lighter than birds on the other treatments. At Day 28 and Day 35, body weights were not significantly different between birds on the 4.5 mm non-expanded feed (Treatment A) and birds on Treatment D (Table 4.3). The 35 day weights show no significant difference in body weights between the 3.2 mm expanded and 3.2 mm non-expanded feed treatments (Treatments B and C); but the birds fed the expanded 3.2 mm feed (Treatment C) had a significantly lower final body weight than birds on the 4.5 mm non-expanded feed (Treatment A) and Treatment D (Table 4.3).

Table 4.3 Mean body weight (g) of Ross broiler chickens fed expanded and non-expanded feeds (means ± standard deviation)

	Body weight (g) ‡					
	0 d	7 d	14 d	21 d	28 d	35 d
Feed						
A Non-expanded 4.5 mm	44.6^{a} (±0.58)	168^{a} (±1.39)	405^{a} (±5.83)	815^{a} (±7.91)	1412^{ac} (±11.39)	1901^{a} (±25.03)
B Non-expanded 3.2 mm	44.4^{a} (±0.85)	161^{b} (±5.55)	393^{b} (±9.09)	815^{a} (±11.40)	1394^{b} (±13.93)	1893^{ab} (±7.83)
C Expanded 3.2 mm	44.4^{a} (±0.39)	166^{ac} (±5.34)	406^{a} (±8.60)	829^{b} (±12.39)	1407^{ab} (±14.84)	1880^{b} (±27.77)
D Treatment D	44.3^{a} (±0.77)	164^{bc} (±3.480	404^{a} (±6.13)	831^{b} [11.71)	1424^{c} (±16.96)	1908^{a} (±32.32)
F-prob						
SEM	±0.229	±1.419	±2.502	±3.315	±4.847	±7.702
Feed	0.838	0.007	0.005	0.001	0.002	0.071
Block	0.189	0.100	0.103	0.012	0.14	0.019
Variation accounted for, %	0.19	47.29	48.31	59.13	49.95	44.27

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

Body weight gains of birds (g/bird day) from Day 7 to Day 35 are given in Table 4.4 and illustrated in Figure 4.1. For the first two weeks, birds fed expanded 3.2 mm crumbles and pellets (Treatment C) had significantly higher daily gains than the birds fed the non-expanded 3.2 mm crumbles and pellets (Treatment B), which had a significantly lower gain than all the treatments at Day 14. In the week to Day 21, birds receiving non-expanded 4.5 mm pellets (Treatment A) had significantly poorer daily

gains than birds fed all other treatments. In the same week, birds fed Treatment D grew significantly faster than birds on both the non-expanded feed treatments (Treatments B and C; Table 4.4).

In the week to Day 28, birds receiving non-expanded 4.5 mm pellets (Treatment A) or Treatment D had significantly higher daily gains than birds fed either the expanded or non-expanded 3.2 mm pellets (Treatments B and C). This was the grower phase, and both Treatment A and Treatment D used 4.5 mm pellets during this phase. In the same week, birds fed Treatment D grew significantly faster than birds on both the non-expanded feed treatments (Treatments B and C; Table 4.4). In the last week of the trial, birds fed the non-expanded 3.2 mm pellets (Treatment B) grew fastest, but not significantly faster than the birds on Treatments A or D. Birds fed the expanded 3.2 mm pellets (Treatment C) grew at the slowest rate, but not significantly more slowly than birds on Treatments A or D.

Body weight gains of all the treatments were lower in Week 5 than in Week 4 (Table 4.4) and the feed conversion ratios were also much worse as indicated below in Table 4.8. This may be due to improper control of the boiler, which resulted in fluctuating temperatures and therefore stressed the chickens. Disease stress may also play apart with birds suffering from ascites, which may cause growth rates to decrease. Birds were reared at high stocking densities, which could have a significant influence on bird performance as they get bigger.

Table 4.4 Mean body weight gain (g/bird day) of Ross broiler chickens fed expanded and non-expanded feeds (means ± standard deviation)

	Body weight gain (g/bird day) ‡				
	7 d	14 d	21 d	28 d	35 d
Feed					
A Non-expanded 4.5 mm	15.4^{a} (±0.22)	33.9^{a} (±0.72)	58.5^{a} (±0.92)	85.3^{a} (±1.42)	69.9^{ab} (±3.79)
B Non-expanded 3.2 mm	14.5^{b} (±0.72)	33.2^{b} (±0.62)	60.2^{b} (±1.08)	82.8^{b} (±2.27)	71.2^{a} (±1.20)
C Expanded 3.2 mm	15.2^{a} (±0.67)	34.2^{a} (±0.70)	60.5^{bc} (±0.73)	82.7^{b} (±2.65)	67.4^{b} (±2.91)
D Treatment D	14.9^{ab} (±0.44)	34.2^{a} (±0.62)	61.2^{c} (±0.95)	84.6^{a} (±1.55)	69.3^{ab} (±4.80)
F-prob					
SEM	±0.184	±0.232	±0.281	±0.599	±1.147
Feed	0.011	0.018	0.000	0.010	0.149
Block	0.116	0.253	0.012	0.008	0.124
Variation accounted for, %	44.59	39.79	72.55	53.71	32.72

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

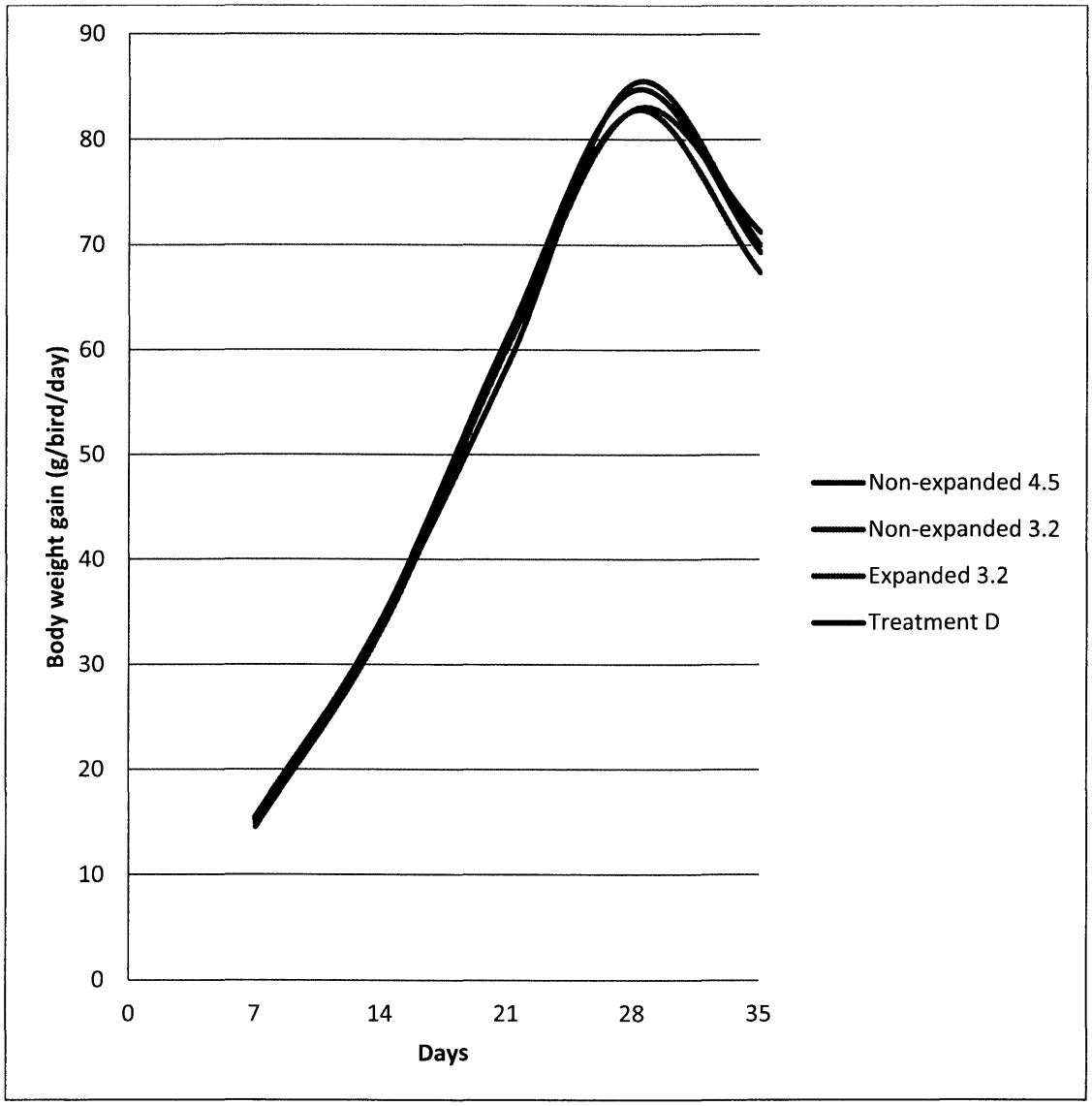

Figure 4.1 Mean body weight gain of birds fed expanded and non-expanded feed

Mean cumulative feed intakes (g/bird day) from Day 7 to Day 35 are given in Table 4.5 and illustrated in Figure 4.2. During the first week, the birds on the expanded 3.2 mm crumbles (Treatment C) had a significantly lower cumulative feed intake (CFI) than birds on the other treatments. From Week 3, the birds fed the expanded 3.2 mm (Treatment C) and the non-expanded 3.2 mm pellets (Treatment B) had significantly lower cumulative feed intakes than the birds fed the non-expanded 4.5 mm pellets (Treatment A) or birds on Treatment D; this trend started at Week 2. Birds fed expanded 3.2 mm pellets (Treatment C) had the lowest cumulative feed intake at Day 35, but it was not significantly lower than the feed intake of the birds that were fed the non-expanded 3.2 mm pellets (Treatment B). Both these treatments had significantly lower CFI at 35 days of age than the other two treatments (Treatments A and D; Table 4.5).

Table 4.5 Mean cumulative feed intake (g/bird) of Ross broiler chickens fed expanded and non-expanded feeds (means ± standard deviation)

	Cumulative feed intake (g/bird) ‡				
	7 d	14 d	21 d	28 d	35 d
Feed					
A Non-expanded 4.5 mm	138^{a} (±4.40)	451^{a} (±5.29)	1096^{a} (±17.66)	2083^{a} (±34.88)	3109^{a} (±43.04)
B Non-expanded 3.2 mm	136^{a} (±4.50)	440^{b} (±10.48)	1045^{b} (±24.50)	1990^{b} (±30.29)	3014^{b} (±33.06)
C Expanded 3.2 mm	134^{b} (±4.78)	441^{b} (±9.91)	1049^{b} (±15.87)	1989^{b} (±17.26)	2984^{b} (±24.29)
D Treatment D	134^{a} (±2.82)	444^{ab} (±6.20)	1095^{a} (±16.61)	2124^{c} (±29.01)	3158^{c} (±39.21)
F-prob					
SEM	±1.549	±2.917	±6.231	±10.292	±12.8
Feed	0.150	0.058	0.000	0.000	0.000
Block	0.898	0.378	0.084	0.571	0.571
Variation accounted for, %	20.34	32.03	73.07	84.15	83.01

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

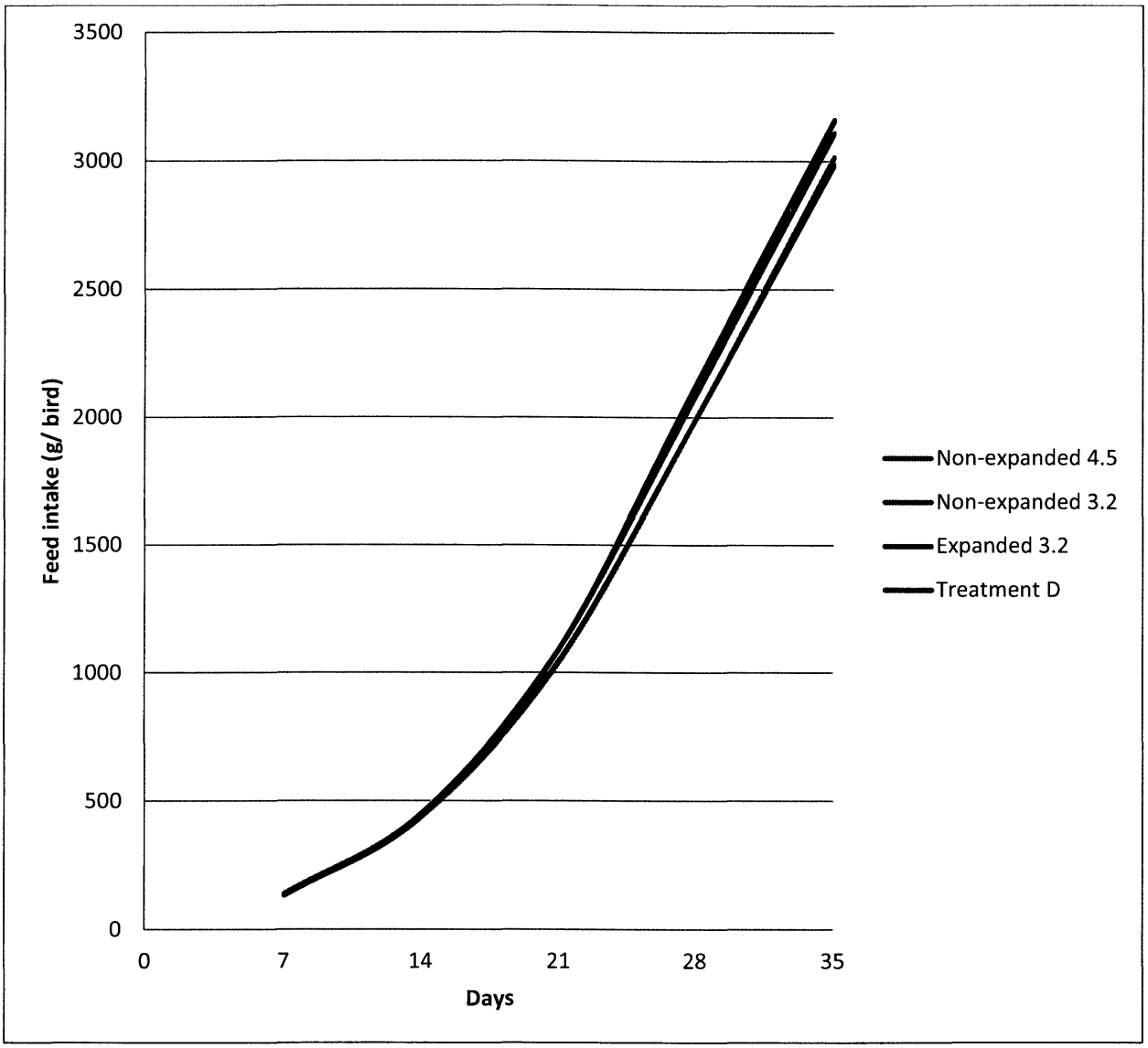

Figure 4.2 Mean cumulative feed intake of birds fed expanded and non-expanded feed

Weekly feed intakes of birds (g/bird day) from Day 7 to Day 35 are given in Table 4.6. Weekly feed intake followed a similar pattern to cumulative feed intake, with the birds fed the two 3.2 mm feed treatments (Treatments B and C) having significantly lower intakes during Week 3 and 4 (end of starter/grower phase) than birds on Treatments A and D (both 4.5 mm pellets from Day 18). During Week 5, feed intake on the expanded 3.2 mm pellets fed birds (Treatment C) was significantly lower than in birds on the other treatments. There were no other significant differences in feed intakes between treatment pairs at Day 35.

Table 4.6 Mean weekly feed intake (g/bird day) of Ross broiler chickens fed expanded and non-expanded feeds (means ± standard deviation)

	Weekly feed intake (g/bird day) ‡				
	7 d	14 d	21 d	28 d	35 d
Feed					
A Non-expanded 4.5mm	17.3^{a} (±0.55)	44.7^{a} (±0.63)	92.1^{a} (±2.09)	141.2^{a} (±3.93)	146.4^{a} (±3.10)
B Non-expanded 3.2mm	17.0^{ab} (±0.56)	43.5^{b} (±0.97)	86.4^{b} (±2.50)	134.9^{b} (±1.87)	146.4^{a} (±2.24)
C Expanded 3.2mm	16.7^{b} (±0.60)	44.0^{a} (±1.01)	86.9^{b} (±1.48)	134.3^{b} (±1.87)	142.2^{b} (±2.53)
D Treatment D	16.8^{ab} (±0.35)	44.2^{a} (±0.70)	93.1^{a} (±1.87)	146.9^{c} (±2.09)	147.8^{a} (±4.16)
F-prob					
SEM	±0.196	±0.274	±0.665	±0.862	±1.107
Feed	0.157	0.039	0.000	0.000	0.008
Block	0.886	0.058	0.095	0.112	0.512
Variation accounted for, %	20.15	42.17	78.1	85.5	40.43

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

Cumulative feed conversion ratio (CFCR) of birds from Day 7 to Day 35 is given in Table 4.7. For the first two weeks, birds on the expanded 3.2 mm treatment (Treatment C) had a significant lower CFCR than birds from the non-expanded 3.2 mm treatment (Treatment B) but, from Week 3, birds on the two treatments performed the same, with significantly lower CFCR than the other two treatments (Treatments A and D). On Day 35, Treatment D had a significantly higher cumulative FCR than the non-expanded 4.5 mm treatment (Treatment A; Table 4.7).

Table 4.7 Mean cumulative FCR (g feed/g gain) of Ross broiler chickens fed expanded and non-expanded feeds

	CFCR (g feed/g gain)) ‡				
	7 d	14 d	21 d	28 d	35 d
Feed					
A Non-expanded 4.5 mm	1.12^{ac} (±0.03)	1.25^{ac} (±0.02)	1.42^{a} (±0.03)	1.52^{a} (±0.03)	1.67^{a} (±0.03)
B Non-expanded 3.2 mm	1.17^{b} (±0.03)	1.27^{a} (±0.02)	1.36^{b} (±0.02)	1.47^{b} (±0.02)	1.63^{b} (±0.02)
C Expanded 3.2 mm	1.10^{a} (±0.04)	1.22^{b} (±0.02)	1.34^{b} (±0.01)	1.46^{b} (±0.02)	1.63^{b} (±0.02)
D Treatment D	1.13^{c} (±0.03)	1.24^{bc} (±0.02)	1.39^{c} (±0.01)	1.54^{a} (±0.02)	1.70^{c} (±0.03)
F-Prob					
SEM	±0.009	±0.006	±0.007	±0.008	±0.007
Feed	0.000	0.000	0.000	0.000	0.000
Block	0.003	0.193	0.497	0.973	0.088
Variation accounted for, %	67.7	56.3	76.9	75.0	72.7

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

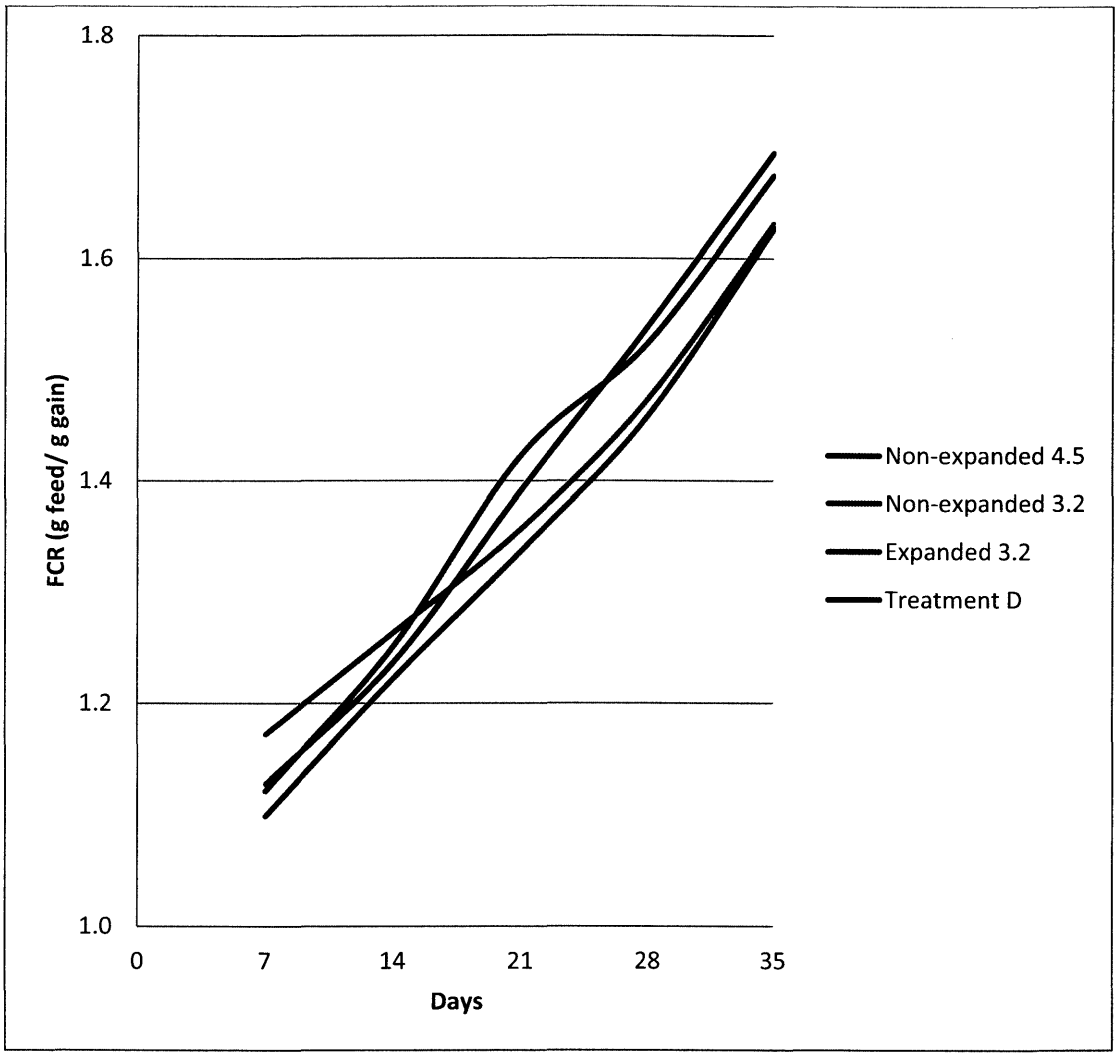

Figure 4.3 Mean cumulative FCR of birds fed expanded and non-expanded feed

Weekly feed conversion ratios from Day 7 to Day 35 are given in Table 4.8. As mentioned above, FCR in general was significantly poorer during the last week of the trial than during Week 4 (Table 4.8). Up to Week 3, birds fed expanded 3.2 mm feed (Treatment C) and non-expanded 3.2 mm feed (Treatment B) performed the best but, during Week 5, only birds on the non-expanded 3.2 mm treatment (Treatment C) still had a significantly lower FCR than birds on the three other treatments.

Table 4.8 Mean weekly FCR (g feed/g gain) of Ross broiler chickens fed expanded and non-expanded feeds (means ± standard deviation)

	Weekly FCR (g feed/g gain) ‡				
	7 d	14 d	21 d	28 d	35 d
Feed					
A Non-expanded 4.5mm	1.12^{ac} (±0.03)	1.33^{a} (±0.02)	1.56^{a} (±0.05)	1.66^{a} (±0.03)	2.09^{ab} (±0.08)
B Non-expanded 3.2mm	1.17^{b} (±0.03)	1.31^{ab} (±0.02)	1.43^{b} (±0.03)	1.63^{a} (±0.04)	2.06^{b} (±0.04)
C Expanded 3.2mm	1.10^{a} (±0.04)	1.29^{b} (±0.02)	1.44^{b} (±0.02)	1.63^{a} (±0.04)	2.11^{ab} (±0.08)
D Treatment D	1.13^{c} (±0.03)	1.29^{b} (±0.02)	1.52^{a} (±0.02)	1.74^{b} (±0.03)	2.14^{a} (±0.11)
F-prob					
SEM	±0.009	±0.009	±0.014	±0.133	±0.026
Feed	0.000	0.017	0.000	0.000	0.155
Block	0.003	0.952	0.480	0.510	0.013
Variation accounted for, %	67.7	33.7	70.3	65.2	42.89

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

Cumulative mortality from Day 7 to Day 35 is given in Table 4.9, along with performance efficiency factor (PEF 35 d). There were no significant differences in cumulative mortality between treatments during the trial. Performance efficiency factor values were significantly lower in birds on Treatments A and D than in birds on Treatment B. Birds on Treatment C had PEF values at 35 days not significantly different from those on any other treatment (Table 4.9).

Table 4.9 Mean cumulative mortality (% of birds placed at 7 days of age) and production efficiency factor of Ross broiler chickens fed expanded and non-expanded feeds (means ± standard deviation)

	Mean cumulative mortality % and PEF (Day 35) ‡					
	7 d	14 d	21 d	28 d	35 d	PEF 35 d
Feed						
A Non-expanded 4.5mm	0.26^{a} (±0.383)	0.4^{a} (±0.422)	0.8^{a} (±0.425)	1.0^{a} (±0.704)	2.0^{a} (±0.847)	318^{a} (±9.6)
B Non-expanded 3.2mm	0.00^{a} (±0.000)	0.3^{a} (±0.409)	0.7^{a} (±0.509)	0.8^{a} (±0.601)	1.4^{a} (±0.822)	327^{b} (±4.0)
C Expanded 3.2mm	0.18^{a} (±0.343)	0.3^{a} (±0.409)	0.7^{a} (±0.509)	0.9^{a} (±0.787)	1.5^{a} (±1.667)	325^{ab} (±9.9)
D Treatment D	0.09^{a} (±0.262)	0.2^{a} (±0.562)	0.3^{a} (±0.562)	0.4^{a} (±0.600)	1.4^{a} (±1.101)	318^{a} (±10.9)
F-prob						
SEM	±0.097	±0.170	±0.183	±0.238	±0.399	±2.96
Feed	0.283	0.876	0.115	0.325	0.674	0.068
Block	0.502	0.872	0.624	0.325	0.195	0.063
Variation accounted for, %	20.5	5.3	25.0	22.6	20.94	39.6

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

Discussion

Early body weights up to Day 21 for both the birds fed expanded 3.2 mm feed (Treatment C) and Treatment D were significantly higher than the birds fed the two non-expanded treatments, Treatment A (4.5 mm pellets) and Treatment B (3.2 mm pellets). Weights were 815, 815, 829 and 831, respectively, for Treatment A, B, C and D. There is thus a definite advantage in early body weight in feeding birds expanded feed, as Treatment C and D were expanded 3.2mm pellets and Treatment B was non-expanded 3.2 mm pellets (Behnke, 1994). This improvement in body weights of birds fed the expanded treatments was obtained without a significant increase in feed intake for the first two weeks with Treatment B, C and D having cumulative feed intakes of 440, 441 and 444 g/bird.

Expanded feed led to a significantly better FCR when fed to birds during the first two weeks of the trial, as was the case in a study done by Fancher *et al.* (1996). This effect can be as a result of an improvement in nutrient digestibility of expanded feed for young broilers with partially developed digestive tracts, even at an expanding temperature of 90°C; especially starch digestibility as stated in Hamilton & Proudfoot (1993).

In Table 4.3, the final body weight of the birds fed Treatment C and Treatment B did not differ significantly, but the birds fed Treatment C had a significantly lower final body weight than the birds fed Treatment A (1880 g and 1893 g, respectively). These observations differ from experiments conducted by Smith *et al.* (1995), in which birds fed expanded feed had increased feed intakes and higher body weights. Expanding of feed at 90°C may not be sufficient for proper starch gelatinisation and thus improvement in nutrient availability to the older bird. This may explain the lower final body weight of birds fed the expanded feed throughout the trial.

The birds on Treatment A and Treatment D received 4.5 mm non-expanded pellets from Day 18, which was the period in which the two 3.2 mm pelleted feeds started to have lower body weight gains (Table 4.4). This indicates that pellet size had an influence on body weight at later stages, with the birds fed the 4.5 mm pellets (Treatment A and D) having higher Day 28 and 35 body weights. Therefore, pellet size seemed to have no significant influence on early body weights but, from Week 3, feeding birds 4.5 mm pellets produced higher body weights. This was as a result of significantly higher cumulative feed intakes in the birds fed Treatment A and D at Day 28 and 35. It can be concluded that birds fed 4.5 mm pellets will have a higher feed intake than those fed 3.2 mm pellets from 3 weeks of age.

The significantly lower cumulative feed intakes of Treatment B and C at the end of the trial were also associated with significantly lower body weights. Lower feed intake is desirable in broiler production,

but only when body weight is maintained, which was not the case in this trial. Both the 3.2 mm treatments had better cumulative FCRs than the Treatments A and D, but it was not substantial enough to maintain the same body weights as Treatment A and D, although the FCR was significantly better. Cumulative FCRs for birds at the end of the trial were 1.67, 1.63, 1.63 and 1.70, respectively for Treatment A, B, C and D.

There is a definite advantage, in terms of feed conversion ratio, when birds were fed 3.2 mm pellets rather than 4.5 mm pellets from week 2. The performance of birds receiving Treatment D was indicative of the better FCR of birds fed expanded feed until Day 18, and higher feed intakes with poorer FCRs when fed bigger pellets (4.5mm) from Day 19.

In this trial pellet size influenced feed intake significantly, with the birds fed the 4.5mm pellets having higher cumulative feed intakes than those fed the 3.2 mm pellets. However, pellet size also influenced cumulative FCR, with the birds fed the 3.2 mm pellets having a significantly better cumulative FCR on Day 35 than those fed the 4.5 mm pellets. The expansion of feed prior to pelleting improved FCRs of birds significantly for the first two weeks of production and led to significantly higher body weights at Week 3, thus showing advantages over non-expanded feed for young broilers.

The expanded 3.2 mm treatment had the highest PEF, differing significantly from the Treatment D and the non-expanded 4.5 mm treatment, but not from the non-expanded 3.2 mm treatment. This indicates that Treatment C will result in the best performance when fed to broilers under commercial conditions.

Conclusion

The expanding of feed clearly improved early broiler performance (up to 21 days of age), with birds fed the 3.2 mm expanded treatment having better FCR and growth rates than the birds fed the non-expanded 3.2 mm pellets. This showed that nutrient alteration by processes, such as gelatinisation of starch during the expansion of feed, could be beneficial to young birds with an immature digestive system, by improving nutrient digestibility. Pellet size significantly affected broiler performance, with birds that were fed the smaller 3.2 mm pellets having lower feed intakes than those fed the 4.5 mm pellets from Week 3; and subsequently lower body weights. Body weight, however, did not decrease proportionally to the decrease in feed intake, resulting in a better final cumulative FCR for birds which received the 3.2 mm pelleted treatments compared to those on the 4.5 mm pelleted feed.

For the first three weeks it is recommended to feed expanded feed to birds as it improved FCR without any significant effects on body weight. If heavier birds at Day 35 are desired, it will be best to

feed 4.5 mm pellets from Day 18 as Treatment D, which received 4.5 mm non-expanded pellets from Day 18 and expanded feed up to Day 18, ended the trial with the highest body weight. For more economical growth, it will be the best to keep feeding 3.2 mm expanded pellets as it will result in an improvement in FCR and thus decrease the cost to produce a kg of broiler meat.

Chapter 5

Expanding temperature and its effect on broiler performance

Abstract

In this trial, birds received feed that was not expanded or feed that was expanded at 95, 105 or 115 °C, to determine the effect of expanding temperature of feed on bird performance. All the expanded feed treatments resulted in significantly higher final body weights than the non-expanded treatment. The final body weights were 1739, 1810, 1791 and 1793 g, for the non-expanded, 95°C, 105°C and 115°C expanded treatments, respectively. The high temperature expanded treatments performed significantly better than the non-expanded treatment for the first two weeks of the trial. Birds on the 95°C and 105°C expanded 3.2 mm treatments ended the trial with cumulative feed conversion ratios of 1.60 and 1.61 respectively, which were significantly lower than the CFCRs of 1.65 for the 115°C expanded 3.2 mm treatment and the 1.68 for the non-expanded treatment. Expanding of feed at 105 °C and higher might have negatively affected nutrient availability in the feed. The performance of broilers that received these feeds declined as the trial progressed, especially in terms of higher FCRs stemming from lower weight gains. Expanding feed at temperatures between 95 and 105°C resulted in constant bird performance for the duration of the trial, without significant effects on vitamin and enzyme recovery.

Introduction

Starch gelatinisation occurs when maize is subjected to high temperature, high pressure and high moisture processing before entering the pellet machine (Svihus & Gullord, 2002). The degree of gelatinisation is influenced by processing temperature (Murray *et al.,* 2001). The gelatinisation of starch results in improved binding properties of the feed particles, which improves pellet quality (Han & Hamaker, 2001) and may also improve starch digestion in the digestive tract (Peisker, 1994). Furthermore, the high temperatures used during expansion may improve broiler performance because of the destruction of some anti-nutritional factors such as protein inhibitors and potentially harmful pathogens (Plavnik & Wan, 1995).

On the downside, high temperature feed processing procedures such as expansion, may lead to the destruction of heat sensitive nutrients such as enzymes and vitamins (Riaz, 2007). The aim of this trial was to determine the optimum expanding temperature for broiler feeds. The effects of feeding expanded or non-expanded feed to broilers were also evaluated. The effect of expanding feeds at different temperatures on broiler performance and the influence of temperature on vitamin and enzyme recovery were determined. It was expected that, as the expanding temperature increases, the

pellet quality would also increase, as a result of a higher degree of starch gelatinisation taking place at higher processing temperatures.

There were four different feed treatments in the trial. The same feed specification and raw materials were used for all three of the treatments, within each of the three feeding phases (starter, grower and finisher). Feed treatments therefore only differed in the way the feed was processed. The three phase-feeds of Treatment A were not expanded prior to pelleting, whereas the three-phase feeds of Treatments B, C and D were expanded at 95, 105 and 115°C, respectively.

Materials and methods

Housing

The trial was conducted at the test facilities at Daybreak Farms, Sundra from 21 October 2009 to 25 November 2009. An open sided broiler house was used. The duration of the trial was five weeks (35 days).

A standard temperature profile was followed from 2 days pre-placement to Day 35 (Appendix B). Minimum and maximum temperature, as measured with six min/max thermometers, together with the reading of the monitor on the boiler, was recorded daily. Two temperature loggers were also used to ensure good temperature regulation.

Birds

Four thousand and thirty two (4032) day old chicks (Ross 803) were randomly divided into 32 pens on Day 0 at a stocking density of 21 birds/m^2 (126 birds per pen).

Feed

One standard basal feed for each of three feeding phases (starter, grower and finisher) was formulated for this trial as shown in Appendix A; the only difference between treatments were thus the processing method of the feed, as described below

Treatment A - Non-expanded standard broiler feed; starter crumbles, grower and finisher pellets 4.5 mm
Treatment B - Expanded standard broiler feed (95°C); starter crumbles, grower and finisher pellets 3.2 mm

Treatment C - Expanded standard broiler feed (105°C); starter crumbles, grower and finisher pellets 3.2 mm
Treatment D - Expanded standard broiler feed (115°C); starter crumbles, grower and finisher pellets 3.2 mm

These treatments applied to all 3 feeding phases, with the starter being fed as crumbles. Birds were fed according to days on feed (18, 10 and 7 days, respectively). Starter feed was weighed back and discarded on Day 18 and the grower feed weighed back and discarded on Day 28. The finisher was weighed back and discarded on Day 35 when the trial ended.

The feeding schedule is given in Table 5.1.

Feed samples

Representative feed samples of 2 kg each were collected from all phases of all four treatments. These samples comprised of grab samples that were collected from each bag of the same phase per treatment.

Table 5.1 The feeding schedule (feed allocations and days on feed)

Feed	**Feeding period (days)**	**Feed allocation (g/bird)**	**Feed allocation/pen (kg)**
Starter	18	850	107.1
Grower	10	1285	162
Finisher	7	1050	132.3

Feed analyses

The feed samples were analysed for the following at Nutrilab, Department of Animal and Wildlife Science, University of Pretoria:
Crude protein, fat, ash, fibre, moisture content and for Ca, P, Na and K.
Methods used for feed analyses :

Crude Protein - Mackro-Kjeldahl method (Leco FP-428)
Fat - Ether extract method
Fibre - Wijkstrohm method
Moisture - AOAC Official Method 7.003
Ca, P, Na and K AOAC Official Method 935.13
Gross Energy - Bomb Colrimeter method

Grower and finisher samples of all four the treatments were analysed for phytase and avizyme (Danisco, USA), while grower samples of all the treatments were analysed for vit A and B_1 levels at DSM Nutrition, Isando.

Table 5.2 Analysed nutrient values (%) of the feed (DM basis)

Sample	DM	Ash	Crude Protein	Crude Fibre	Fat	Gross Energy	Ca	P	K	Na
Treatment-A Starter	90.38	5.25	21.04	4.21	4.90	16.49	0.904	0.527	0.834	0.215
Treatment-A Grower	89.00	4.70	18.98	4.54	6.35	16.61	0.748	0.470	0.719	0.174
Treatment-A Finisher	89.01	4.26	19.47	4.35	5.28	16.46	0.667	0.460	0.737	0.176
Treatment-B Starter	90.30	4.82	20.45	4.67	4.47	16.62	0.832	0.587	0.738	0.176
Treatment-B Grower	89.79	4.33	20.12	4.24	6.50	16.93	0.640	0.481	0.778	0.176
Treatment-B Finisher	90.57	3.95	19.81	4.31	7.51	17.10	0.616	0.429	0.738	0.167
Treatment-C Starter	90.47	5.09	20.90	4.55	4.83	16.53	0.826	0.553	0.836	0.200
Treatment-C Grower	89.89	4.66	19.94	4.15	6.81	16.81	0.702	0.501	0.772	0.200
Treatment-C Finisher	89.64	4.22	19.23	4.00	6.60	16.88	0.612	0.439	0.751	0.162
Treatment-D Starter	90.00	4.65	20.78	4.35	5.40	16.47	0.600	0.563	0.893	0.219
Treatment-D Grower	89.31	4.30	18.63	4.99	6.50	16.66	0.627	0.453	0.755	0.146
Treatment-D Finisher	89.56	4.08	17.94	4.76	7.41	16.90	0.541	0.422	0.725	0.160

Pellet quality

The 2 kg representative samples were reduced to appropriate sizes by using a sample divider. The feed was tested for both crumble and pellet quality.

Crumble quality was determined by weighing 500 g of the sample and sieving it through a 2.36 mm sieve and a 1.00 mm sieve simultaneously. The percentage crumbles retained on each sieve was calculated and the percentage of fines (<1.00mm) determined.

The evaluation of pellet quality was done by measuring the percentage of pellets of the 500 g sample that were retained on a sieve of known mesh gauge (2.36 mm for the 3.2 mm pellets and 3.55 for the 4.5 mm pellets), for all the feed treatments.

Pellet durability

The pellet durability was determined by using a tumbler. An amount of 200 g of the sieve sample (without fines) was weighed and put in the tumbler with five 20 mm nuts in the tumbler. The sample was tumbled for 2 min and then sieved through a 2.36 mm sieve. The pellets retained on the sieve were weighed and the durability expressed as a percentage by dividing the weight of the retained pellets by the original 200g sample.

Statistical design

There was one fixed factor in this trial (Treatment). The test house, which has 32 pens, was divided into four (4) blocks, with 8 pens per block. Block 1 was from pen 1-8; Block 2 from pen 9-16; Block 3 from pen 17-24 and Block 4 from 25-32. There were 4 (four) treatments, with two (2) replicates per treatment in all the blocks and thus a total of 8 replicates per treatment.

Data were statistically analysed as a randomized block design with the GLM model (Statistical Analysis System, 2011) for the average effects over time. Repeated Measures Analysis of Variance with the GLM model was used for repeated week or period measures. Means and standard error of mean (SEM) were calculated and significance of difference ($P < 0.05$) between means was determined by Fischers test (Samuels, 1989).

The linear model used is described by the following equation:

$Y = \mu + T + B + e$

Where Y = variable studied during the period

μ = overall mean of the population

T = effect of the i treatment

B = effect of the j block

e = error associated with each Y

Response variables analysed were body weight (BW), weekly growth rates (GR), weekly feed intake (WFI), cumulative feed intake (CFI), weekly feed conversion ratio (WFCR), cumulative feed conversion ratio (FCR), performance efficiency factor (PEF), weekly mortality and cumulative mortality. These were calculated, respectively, from the following measurements: bird counts, initial body weight, weekly body weights, feed weighed in and feed weighed out (weekly and at 18 days,which was the end of the starter phase) and mortality records.

Production Efficiency Factor (PEF) was calculated as:

((100- Cumulative mortality %)*Body weight*100) / (CFCR*days) / 1000

Experimental procedure

Birds were randomly placed into the pens as described above, after they were weighed to determine initial body weights. Birds were weighed each week thereafter. The feed was weighed weekly to determine the weekly feed intake of the birds. Feed was also weighed on Day 18, at the end of the starter phase, to determine the starter and grower intakes. Mortalities were collected each morning and indicated on the data sheets. Birds had unrestricted access to feed and water.

Results

Body weights of the birds from placement to the end of the trial are given in Table 5.3 and illustrated in Figure 5.1. Birds that received the 115°C expanded feed were the heaviest up to the end of Week 2 (14 days), with body weights that differed significantly from all other treatments at Day 14 and from the birds fed non-expanded 4.5 mm feed at Day 7 (Table 5.3). From 21 days of age, the birds fed the 105°C expanded feed performed the best, having significantly higher body weights than all the other treatments at Day 21 and 28; followed by the other two expanded treatments (95 °C and 115°C) which also differed significantly from the non-expanded feed treatment. The 95°C expanded treatment ended the trial with the highest body weight, but all three of the expanded treatments had significantly higher body weights than the non-expanded treatment.

Table 5.3 Mean body weight (g) of Ross broiler chickens fed expanded and non-expanded feeds (means ± standard deviation)

	Body weight (g) ‡					
	0 d	7 d	14 d	21 d	28 d	35 d
Feed						
A Non-expanded 4.5mm	41.1^{a} (±0.43)	145^{a} (±4.85)	347^{a} (±7.98)	740^{a} (±12.55)	1210^{a} (±12.21)	1739^{a} (±17.81)
B Expanded 3.2 mm 95°C	40.9^{a} (±0.46)	147^{ab} (±4.82)	353^{ab} (±9.63)	750^{ac} (±16.45)	1259^{b} (±14.47)	1810^{b} (±18.52)
C Expanded 3.2 mm 105°C	40.9^{a} (±0.41)	148^{ab} (±4.31)	356^{b} (±8.99)	767^{b} (±11.12)	1274^{b} (±23.36)	1791^{b} (±23.89)
D Expanded 3.2 mm 115°C	41.2^{a} (±0.56)	150^{b} (±3.84)	358^{c} (±6.21)	754^{c} (±10.90)	1241^{c} (±16.38)	1793^{b} (±23.42)
F-prob						
SEM	±0.157	±1.516	±2.856	±4.730	±5.928	±7.139
Feed	0.534	0.116	0.055	0.004	0.001	0.001
Block	0.126	0.162	0.232	0.747	0.112	0.192
Covariate (BW 0)	-					
Variation accounted for, %	25.45	32.65	34.73	42.17	73.92	70.17

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

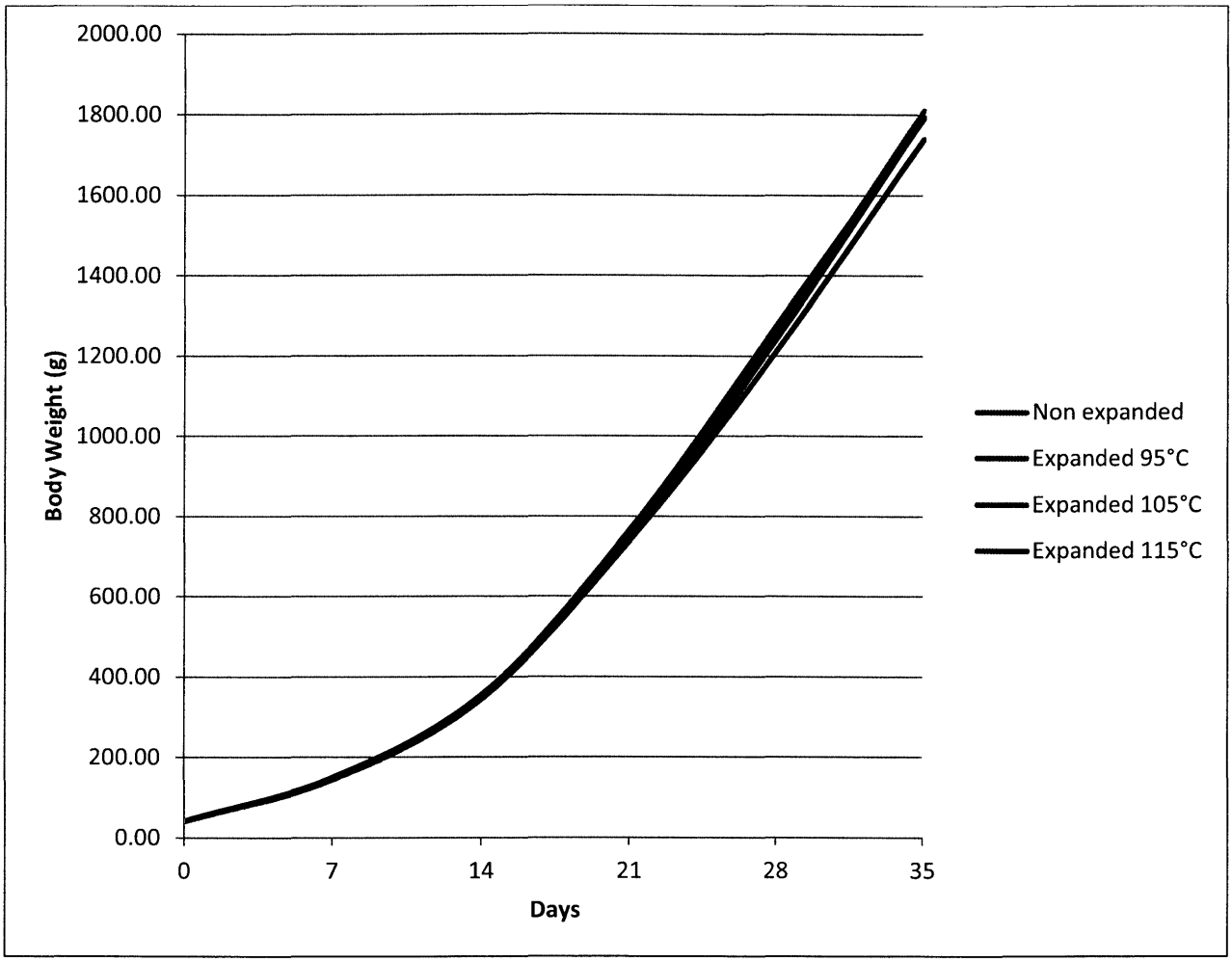

Figure 5.1 Mean body weights of birds fed expanded and non-expanded feed

Body weight gains of the birds from Day 7 to Day 35 of the trial are given in Table 5.4 and illustrated in Figure 5.2. During the first week of the trial, gains were similar on all of the expanded feed treatments. Only the 115°C expanded treatment had a significantly higher weight gain than the non-expanded treatment. During Week 2, birds fed the expanded treatments again performed similarly, but both the 105°C and 115°C expanded treatments had significantly higher body weight gains than the non-expanded treatment. At 21 days, the 105°C expanded treatment supported a significantly higher weight gain than all the other treatments, with no significant difference in weight gain between the other treatment pairs. From Week 4, the birds on the 95°C expanded and 105°C expanded treatments had significantly higher body weight gains, but birds fed the expanded 105°C treatment had the poorest weight gain during Week 5. This is surprising as the other two expanded treatments (95°C and 115°C) supported significantly higher gains than the non-expanded treatment (Table 5.4).

Table 5.4 Mean body weight gain (g/bird/day) of Ross broiler chickens fed expanded and non-expanded feeds (means ± standard deviation)

	Body weight gain(g) ‡				
	7 d	14 d	21 d	28 d	35 d
Feed					
A Non-expanded 4.5mm	13.0^{a} (±0.65)	28.8^{a} (±0.72)	56.2^{a} (±0.73)	67.2^{a} (±2.15)	75.6^{a} (±2.35)
B Expanded 3.2 mm 95°C	13.2^{ab} (±0.59)	29.6^{ab} (±1.01)	56.6^{a} (±1.87)	72.7^{b} (±1.29)	78.7^{b} (±3.06)
C Expanded 3.2 mm 105°C	13.3^{ab} (±0.53)	29.8^{b} (±0.74)	58.8^{b} (±0.99)	72.5^{b} (±2.01)	73.9^{a} (±2.36)
D Expanded 3.2 mm 115°C	13.6^{b} (±0.52)	29.7^{b} (±0.43)	56.6^{a} (±1.17)	69.6^{c} (±1.80)	78.8^{b} (±2.33)
F-prob					
SEM	±0.192	±0.271	±0.457	±0.531	±0.939
Feed	0.149	0.080	0.003	0.001	0.002
Block	0.121	0.506	0.693	0.004	0.844
Variation accounted for, %	32.82	28.54	44.82	78.25	45.75

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

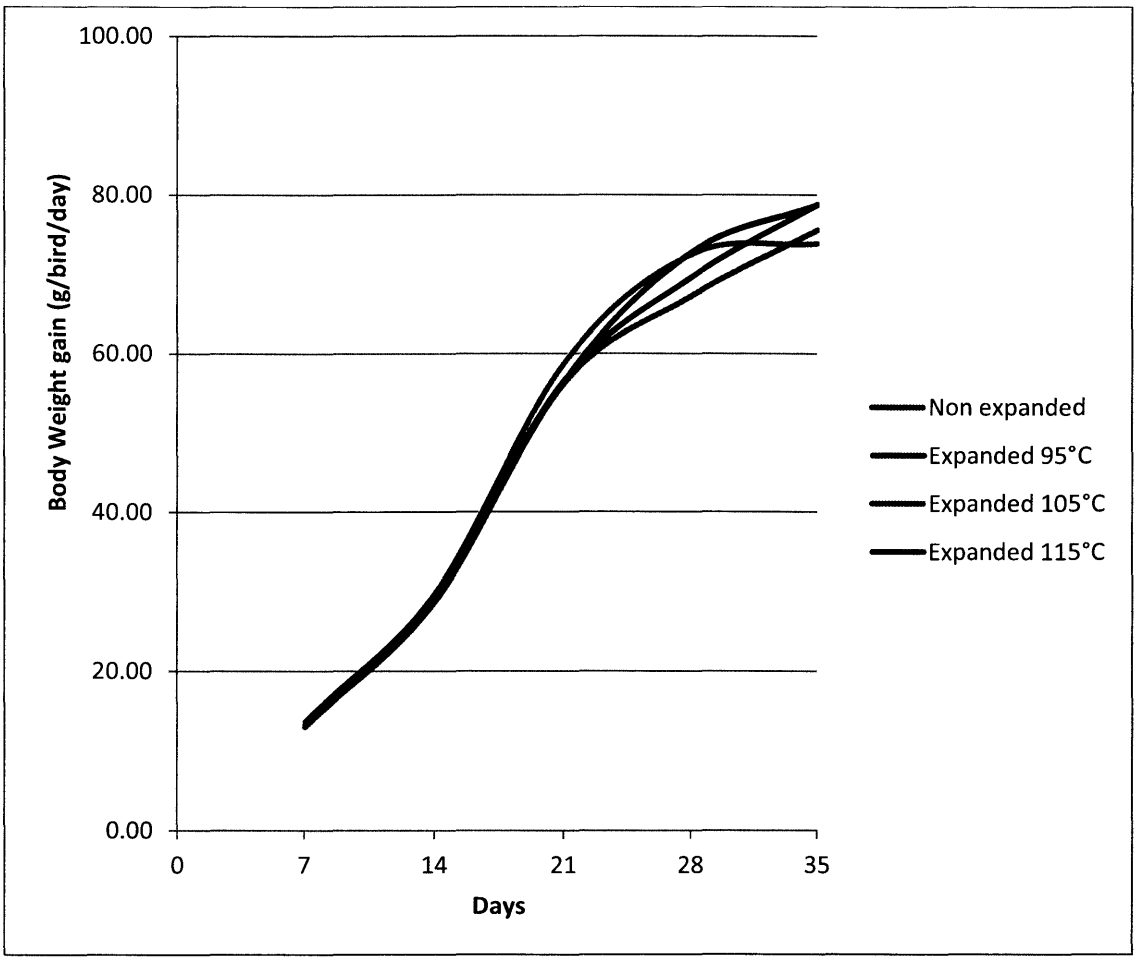

Figure 5.2 Mean body weight gains of birds fed expanded and non-expanded feed

Cumulative feed intakes (CFI) of the birds from Day 7 to Day 35 of the trial are given in Table 5.5 and illustrated in Figure 5.3. The birds on the expanded 115°C treatment had the highest cumulative intake for the duration of the trial and differed significantly from all the other treatments from Week 3, as shown in Table 5.5. Cumulative feed intake on the 95°C and 105°C expanded treatments did not differ significantly from the non-expanded treatment at any stage in the trial. The birds fed the expanded 115°C feed had a significantly higher cumulative feed intake than the birds on the other two expanded treatments at Day 35. Birds might be increasing feed intake as a measure to meet their requirements, as some nutrients may have been destroyed at this high expanding temperature.

Table 5.5 Mean cumulative feed intake (g/bird) of Ross broiler chickens fed expanded and non-expanded feeds (means ± standard deviation)

	Cumulative feed intake (g) ‡				
	7 d	14 d	21 d	28 d	35 d
Feed					
A Non-expanded 4.5 mm	132.6^{a} (±4.66)	422.9^{a} (±14.36)	990.4^{a} (±20.81)	1833^{a} (±23.20)	2856^{ab} (±40.92)
B Expanded 3.2 mm 95°C	135.3^{a} (±6.21)	430.6^{ab} (±9.06)	999.8^{a} (±22.43)	1845^{a} (±28.86)	2825^{a} (±40.69)
C Expanded 3.2 mm 105°C	136.1^{ab} (±4.16)	428.6^{a} (±11.55)	1007^{a} (±13.90)	1846^{a} (±20.08)	2825^{a} (±13.58)
D Expanded 3.2 mm 115°C	139.4^{b} (±5.40)	437.5^{b} (±8.37)	1030^{b} (±9.62)	1873^{b} (±14.93)	2881^{b} (±34.13)
F-prob					
SEM	±1.258	±3.048	±5.719	±7.271	±12.259
Feed	0.007	0.020	0.004	0.005	0.008
Block	0.001	0.001	0.077	0.068	0.534
Variation accounted for, %	66.28	56.97	57.44	49.65	40.38

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

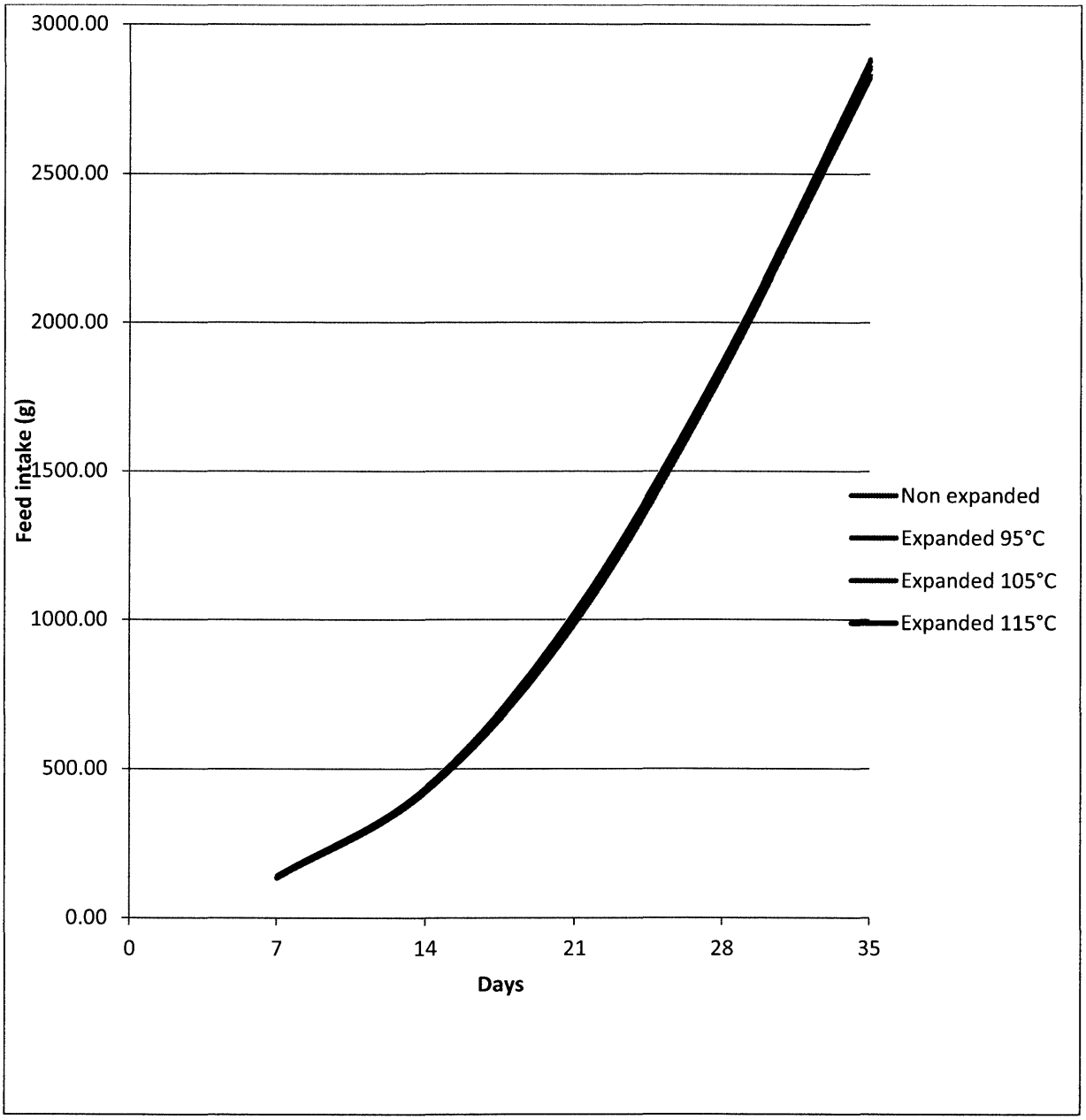

Figure 5.3 Mean cumulative feed intake of birds fed expanded and non-expanded feed

Weekly feed intakes (FI) of the birds from Day 7 to Day 35 of the trial are given in Table 5.6. Weekly FI during the first week was the highest for the birds fed the expanded 115°C feed, which differed significantly from the other treatments, except the expanded 105°C treatment (Table 5.6). All the expanded treatments had similar intakes during Week 2, with the birds on the 115°C expanded treatment having a significantly higher intake than the non-expanded treatment birds. During Week 4, there was no significant difference in weekly feed intake between the treatments. During Week 5, birds fed the 105°C and 95°C expanded treatments had significantly lower feed intakes than those fed the 115°C expanded and the non-expanded treatments.

Table 5.6 Mean weekly feed intake (g/bird day) of Ross broiler chickens fed expanded and non-expanded feeds (means ± standard deviation)

	Weekly feed intake (g/bird day) ‡				
	7 d	14 d	21 d	28 d	35 d
Feed					
A Non-expanded 4.5 mm	16.6^{a} (±0.58)	41.5^{a} (±1.42)	81.1^{a} (±1.20)	120.3^{a} (±1.21)	146.3^{a} (±3.85)
B Expanded 3.2 mm 95°C	16.9^{a} (±0.78)	42.2^{ab} (±0.71)	81.2^{a} (±2.05)	120.8^{a} (±2.42)	140.1^{b} (±4.65)
C Expanded 3.2 mm 105°C	16.9^{ab} (±0.52)	41.8^{ab} (±1.28)	82.6^{b} (±0.83)	120.0^{a} (±1.65)	139.8^{b} (±2.77)
D Expanded 3.2 mm 115°C	17.4^{b} (±0.67)	42.8^{b} (±0.60)	84.6^{c} (±0.52)	120.5^{a} (±1.47)	144.0^{a} (±3.18)
F-prob					
SEM	±0.157	±0.341	±0.472	±0.611	±1.360
Feed	0.007	0.142	0.000	0.787	0.006
Block	0.001	0.042	0.829	0.298	0.863
Variation accounted for, %	66.72	38.26	59.76	16.51	39.95

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

Cumulative feed conversion ratios (CFCR) of the birds from Day 7 to Day 35 of the trial are given in Table 5.7 and illustrated in Figure 5.4. During the first 3 weeks, there were no significant differences in the CFCR between treatments, except for the birds on the 105°C and 115°C expanded treatments, which had a significantly higher CFCR than the other treatments on Day 21. At the end of Week 4, the expanded 115°C and non-expanded treatments had the poorest CFCR, differing significantly from the 95°C and 105°C expanded treatments. Birds fed the expanded 105°C feed had a significantly better CFCR than the other treatments. The CFCR for birds on the 95°C and 105°C expanded treatments on Day 35 were significantly better than the expanded 115°C and non-expanded treatments. Birds fed the non-expanded treatment had a significant poorer CFCR than the expanded 115°C treatment (Table 5.7).

Table 5.7 Mean cumulative feed conversion ratio (FCR; g feed/ g gain) of Ross broiler fed expanded and non-expanded feeds (means ± standard deviation)

	FCR (g feed/g gain)) ‡				
	7 d	14 d	21 d	28 d	35 d
Feed					
A Non-expanded 4.5 mm	1.28^{a} (±0.03)	1.38^{a} (±0.02)	1.42^{a} (±0.01)	1.56^{a} (±0.03)	1.68^{a} (±0.02)
B Expanded 3.2 mm 95°C	1.28^{a} (±0.08)	1.37^{a} (±0.03)	1.41^{a} (±0.02)	1.51^{b} (±0.02)	1.60^{b} (±0.02)
C Expanded 3.2 mm 105°C	1.28^{a} (±0.05)	1.36^{a} (±0.03)	1.39^{b} (±0.02)	1.49^{c} (±0.02)	1.61^{b} (±0.02)
D Expanded 3.2 mm 115°C	1.28^{a} (±0.05)	1.38^{a} (±0.04)	1.44^{c} (±0.02)	1.56^{a} (±0.02)	1.65^{c} (±0.01)
F-prob					
SEM	±0.017	±0.009	±0.006	±0.006	±0.005
Feed	0.997	0.345	0.000	0.000	0.000
Block	0.123	0.353	0.141	0.001	0.051
Variation accounted for, %	20.41	21.61	65.74	82.45	85.21

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

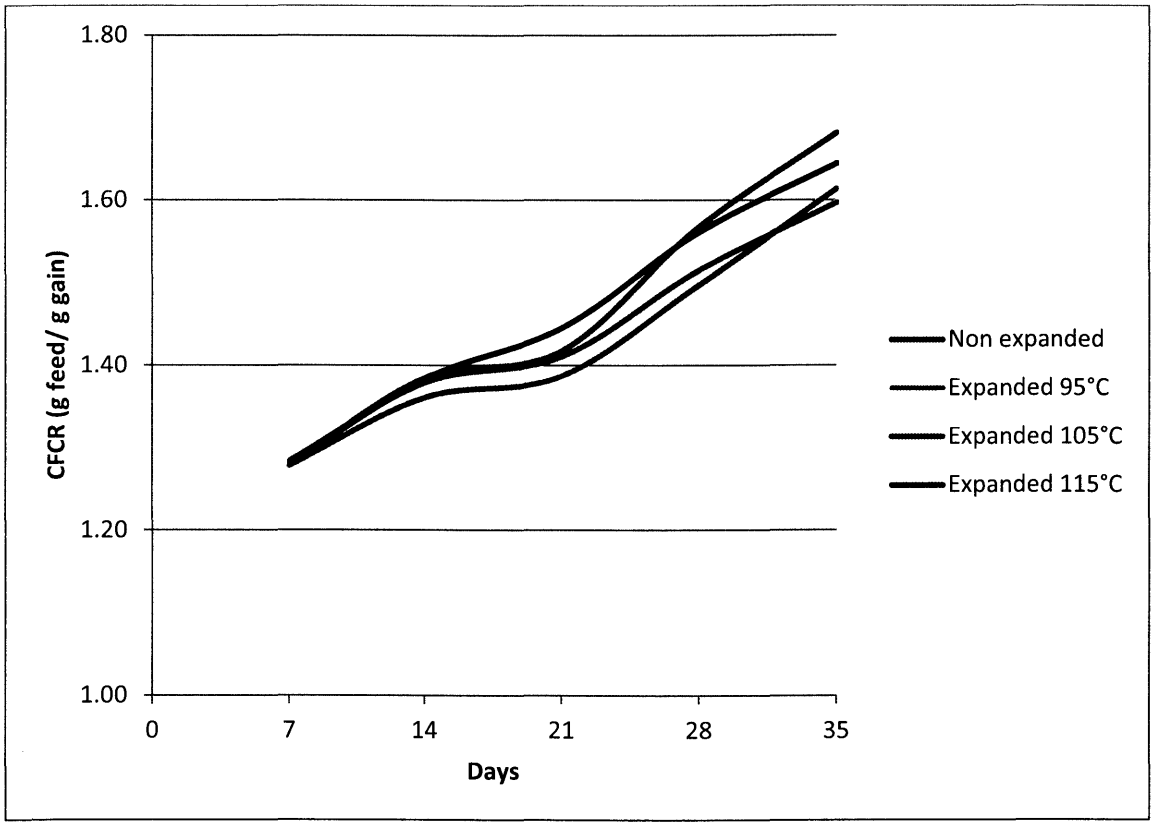

Figure 5.4 Mean cumulative FCR of birds fed expanded and non-expanded feed

Weekly feed conversion ratios (CFCR) of the birds from Day 7 to Day 35 of the trial are given in Table 5.8. There were no differences in weekly FCR between the treatments for the first 2 weeks of the trial. During Week 3, birds on the 115°C expanded treatment had significantly poorer FCR than

birds on all the other treatments; and the birds fed the expanded 105°C feed had a significantly better FCR than the other treatments.

During Week 4, the birds on the 95°C and 105°C expanded treatments had significantly better weekly FCR than the birds on the non-expanded and 115°C expanded treatments, which also differed significantly from each other (the non-expanded being the poorer of the two). Birds on the 95°C expanded treatment had a significantly better FCR (1.78) than all the other treatments during Week 5, with the expanded 105°C and the non-expanded treatments having the poorest weekly FCR (1.89 and 1.93, respectively); differing significantly from each other and the 115°C expanded treatment (1.83).

Table 5.8 Mean weekly FCR (g feed/ g gain) of Ross broiler chickens fed expanded and non-expanded feeds (means ± standard deviation)

	Weekly FCR (g feed / g gain) ‡				
	7 d	14 d	21 d	28 d	35 d
Feed					
A Non-expanded 4.5mm	1.28^{a} (±0.03)	1.44^{a} (±0.04)	1.44^{a} (±0.01)	1.79^{a} (±0.067)	1.93^{a} (±0.02)
B Expanded 3.2 mm 95°C	1.28^{a} (±0.08)	1.43^{a} (±0.04)	1.43^{a} (±0.04)	1.66^{b} (±0.02)	1.78^{b} (±0.03)
C Expanded 3.2 mm 105°C	1.28^{a} (±0.05)	1.40^{a} (±0.03)	1.41^{b} (±0.02)	1.66^{b} (±0.03)	1.89^{c} (±0.04)
D Expanded 3.2 mm 115°C	1.28^{a} (±0.05)	1.44^{a} (±0.03)	1.49^{c} (±0.03)	1.73^{c} (±0.04)	1.83^{d} (±0.03)
F-prob					
SEM	±0.017	±0.013	±0.009	±0.011	±0.011
Feed	0.997	0.221	0.000	0.000	0.000
Block	0.123	0.209	0.109	0.000	0.230
Variation accounted for, %	20.41	27.71	69.31	83.06	82.60

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

Cumulative mortality of birds from Day 7 to Day 35, and the production efficiency factor (PEF) of birds on Day 35 of the trial are given in Table 5.9. There were some significant differences in cumulative mortality at the end of Week 2 and 3 when the birds on the 95°C and 105°C expanded treatments had significantly higher mortality % than the other treatments (Table 5.9).

Performance efficiency factor (PEF) at Day 35 showed the birds on the 95°C expanded treatment having the highest PEF with all the treatments differing significantly from each other. Birds fed the non-expanded feed had the lowest PEF (Table 5.9).

Table 5.9 Mean cumulative mortality (% of birds placed at 7 days of age) and PEF (Day 35), of Ross broiler chickens fed expanded and non-expanded feeds (means ± standard deviation)

	Mean cumulative mortality % ‡					
	7 d	14 d	21 d	28 d	35 d	PEF 35 d
Feed						
A Non-expanded 4.5mm	0.3^{a} (±0.591)	0.5^{a} (±0.590)	0.6^{a} (±0.561)	1.2^{a} (±0.736)	3.5^{a} (±1.403)	285^{a} (±7.5)
B Expanded 3.2mm 95°C	0.7^{a} (±0.509)	0.9^{a} (±0.510)	1.2^{b} (±0.736)	1.7^{a} (±1.075)	3.1^{a} (±1.076)	314^{b} (±5.8)
C Expanded 3.2mm 105°C	0.8^{a} (±0.849)	1.4^{b} (±0.925)	1.5^{b} (±0.894)	1.9^{a} (±0.842)	4.1^{a} (±2.098)	304^{c} (±11.5)
D Expanded 3.2mm 115°C	0.2^{a} (±0.366)	0.3^{ac} (±0.409)	0.6^{a} (±0.561)	1.0^{a} (±0.705)	3.1^{a} (±1.371)	301^{d} (±7.2)
F-prob						
SEM	±0.215	±0.233	±0.247	±0.315	±0.540	±2.633
Feed	0.161	0.014	0.036	0.178	0.534	0.000
Block	0.407	0.662	0.314	0.824	0.364	0.040
Variation accounted for, %	25.64	36.85	35.42	19.94	18.23	74.05

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

Pellet quality results for the different feed treatments are given in Table 5.10. Expanding of feed at 115°C resulted in the best crumble quality for the starter feeds. The best pellet quality for the finisher feed was also achieved by expanding feed at 115°C. However, the 95°C expanded feed showed the best pellet quality for the grower phase feeds. This may be due to the different raw materials in each phase which will influence the degree of gelatinisation that will occur and thus pellet quality.

Table 5.10 Pellet quality of treatments

Treatment	**Phase**	**Sample**	**Pellet % >3.55mm**		**Pellet % >2.36mm**		**Pellet % 2.36<1.00mm**		**Pellet % <1.00mm**	
		g	G	%	g	%	G	%	G	%
Treatment A 4.5mm pellets Non-expanded	Starter	500.2			114	22.8	246.9	49.4	139.5	27.9
	Grower	500.4	281.6	56.3						
	Finisher	500.5	426.5	85.2						
Treatment B 3.2mm pellets Expanded 95°C	Starter	500.3			82.1	16.4	265.3	53.0	151.9	30.4
	Grower	500.5			480.8	96.1				
	Finisher	500.6			437.9	87.5				
Treatment C 3.2mm pellets Expanded 105°C	Starter	500.2			89.2	17.8	270.6	54.1	143.9	28.8
	Grower	500.1			441.7	88.3				
	Finisher	500.1			459.9	92.0				
Treatment D 3.2mm pellets Expanded 115°C	Starter	500.5			193.3	38.6	205.4	41.0	100.5	20.1
	Grower	500.3			468.8	93.7				
	Finisher	500.3			471.4	94.2				

Pellet durability results for the different feed treatments are given in Table 5.11. The non-expanded feed treatment had the lowest durability and the durability of the expanded treatments increased as the expanding temperature increased (Table 5.11).

Table 5.11 Pellet durability of treatments

Treatment	Phase	Sample	Pellet	Durability %
Treatment A 4.5mm pellets Non-expanded	Starter			
	Grower	200	142.2	71.1
	Finisher	200.4	143.9	71.8
Treatment B 3.2mm pellets Expanded 95°C	Starter			
	Grower	200.2	170.7	85.3
	Finisher	200.2	168.7	84.3
Treatment C 3.2mm pellets Expanded 105°C	Starter			
	Grower	200.1	172.5	86.2
	Finisher	200.3	173.8	86.8
Treatment D 3.2mm pellets Expanded 115°C	Starter			
	Grower	200.1	178.1	89.0
	Finisher	200.2	176.9	88.4

Phytase and amylase analyses of the grower and finisher feeds are given in Table 5.12. The phytase activity levels for all treatments were well below the expected value. Because the non-expanded treatment phytase activity level was also low, it might have been that the phytase was not added at the required levels in the mixer and not due to damaging during the expanding of the feed. On the other hand, it might mean that the lower temperature (85°C), which the non-expanded feed was subjected to during pelleting, is already high enough to cause substantial damage to the phytase enzyme.

The amylase results were all above the expected levels, thus showing no signs of damage occurring during the expanding of feed.

Table 5.12 Phytase and amylase analyses of the grower and finisher feeds

Treatment	Expected (FTU)	Grower (FTU)	Finisher (FTU)
Phytase			
Non expanded	500	277	310
Expanded 95	500	297	Not analysed
Expanded 105	500	293	166
Expanded 115	500	314	270
Amylase			
Non expanded	1200	2192	1917
Expanded 95	1200	1572	Not analysed
Expanded 105	1200	1450	1929
Expanded 115	1200	1932	2028

Analysed Vitamin A and B_1 levels of the grower feeds are given in Table 5.13. For vitamin A, all the declared levels in the feed were met, except in Treatment C (105°C), which level was marginally lower than the declared level. The vitamin B_1 levels of the 95°C and 105°C expanded treatments were almost at the declared levels, while the vitamin B_1 levels for the 115°C expanded treatment was much lower, indicating that there might be some destruction of vitamin B_1 when expanding feed at a temperature of 115°C.

Table 5.13 Vitamin A and B_1 levels of the grower feeds

Treatment	Analyze For	Declared Level	Results
T-A Non expanded Grower	Vit. A	13 000 IU/kg	13 913 iu/kg
	Vit B_1	3 mg/kg	2.24 mg/kg
T-B Expanded 95 Grower	Vit. A	13 000 IU/kg	13 730 iu/kg
	Vit B_1	3 mg/kg	2.94 mg/kg
T-C Expanded 105 Grower	Vit. A	13 000 IU/kg	12 839 iu/kg
	Vit B_1	3 mg/kg	2.98mg/kg
T-D Expanded 115 Grower	Vit. A	13 000 IU/kg	14 043 iu/kg
	Vit B_1	3 mg/kg	2.03 mg/kg

Discussion

Birds receiving the 115°C expanded treatment were significantly heavier (357.6 g) than the other treatments up to Day 14. The birds fed the non-expanded 4.5 mm feed had the lowest body weight at Day 14 (346.5 g). During Week 3, the 105°C expanded treatment had the highest body weight gain of 58.8 g/bird day, which resulted in it having a significantly higher body weight at Day 21 than all the other treatments. At the end of the trial, all the expanded feed treatments ended with significantly higher final body weights than the birds fed the non-expanded 4.5 mm feed and did not differ significantly from each other. The final body weights were 1739, 1810, 1791 and 1793 g, respectively for the non-expanded, 95°C, 105°C and 115°C expanded treatments.

From the results it was clear that feeding birds expanded feed led to improved broiler performance. (Behnke, 1994; Peisker, 1994 & Riaz, 2007). This trial produced the same outcome as that in the trial conducted by Smith *et al.* (1995), where birds fed expanded feed had significantly higher body weights than birds fed non-expanded feed.

It would appear that, with the 105°C and 115°C expanded 3.2 mm treatments, there were times during the trial when there was a decrease in the performances of the birds fed these feeds. The birds fed the 115°C expanded treatment had significantly lower weight gains than the other two expanded treatments during Week 4 (Table 5.4). Weight gain for birds fed the 105°C expanded 3.2 mm treatment was significantly lower than the other two expanded treatments during Week 5, with weight

gains of 78.7, 73.9 and 78.8 g/bird day, respectively for 95, 105 and 115°C expanded 3.2 mm treatments. Expanding temperature thus had an effect on broiler growth rates; with results indicating that expanding of feed at temperatures above 105°C have some negative effects on broiler performance.

Anti-nutritional factors are destroyed by high temperature expansion which improves bird performance, but high temperature expansion may cause negative reaction between nutrients, such as the Maillard reaction, to occur or the destruction of nutrients (Vest, 1996; Plavnik & Wan, 1995).

In Table 5.5, the higher feed intake for birds fed the 115°C expanded 3.2 mm treatment explains the significantly higher weight gain for these birds in the early part of the trial. However, although feed intakes on the 115°C expanded 3.2 mm treatment were significantly higher through the whole trial period, this treatment did not support significantly higher weight gains during the later weeks of the trial. This led to a poorer cumulative FCR for this treatment. This might be attributed to a decrease in nutrient availability when feed are expanded at very high temperatures as stated in Thomas *et al.* (1997).

The significantly poorer CFCR of 1.44 for the birds fed the 115°C expanded 3.2 mm treatment during Week 3 is shown in Table 5.7. Birds on the 95°C and 105°C expanded 3.2 mm treatments ended the trial with CFCRs of 1.60 and 1.61 respectively, which were significantly lower than the CFCRs of 1.65 for the 115°C expanded 3.2 mm treatment and the 1.68 for the non-expanded treatment. The above mentioned results are also indicative that there are some negative effects when broiler feed are exposed to very high processing temperatures. Vitamin stability seems to be affected by high temperature expansion as Vitamin A stability were affected by high temperature expanding in two trials done by Pipa & Frank (1989) and Moulois (1991). In these two trials there were no significant effect on Vitamin A, but feed analyses in this trial showed that Vitamin B_1 availability might have been negatively affected when feed was expanded at 115°C.

The pellet quality and durability results (Table 5.10) showed an increase in pellet % and durability as the expanding temperature increased. Improved pellet quality is one of the remarked advantages of expanded feed (Behnke, 1994). The non-expanded grower had a very poor pellet percentage. Phyzyme 1000 TPT were included in the feeds and this form (powder) of the phytase enzyme is known to be very heat sensitive. Phosphorous could therefore have been a limiting nutrient for birds that received the feeds expanded at the higher temperatures and this would have driven higher feed intakes to meet requirements. The grower and finisher samples were analysed for phytase activity to determine the influence of high temperature expansion of feed and the results showed (Table 5.11) that the correct levels of phytase were not present in the feed. The lower than required phytase activity

levels can be explained by either incorrect inclusion of the enzyme during mixing or that damage to the enzymes occurred even at normal pelleting temperatures of 85°C.

The amylase results indicated that no significant damage occured to amylase during the expanding process as all the declared levels were met. The grower phase feeds of all the treatments were analysed for vitamins A and B_1 (Table 5.13). These results were the same as those of Schai *et al.* (1991) which showed that no major damage occurred to vitamins during expanding, although expanding feed at 115°C seemed to have had some negative effects on the recovery of vitamin B_1, with analysed levels being 2.03 mg/kg instead of the expected level of 3 mg/kg.

Conclusion

Expanding of feed prior to pelleting had some definite advantages over feed that was not expanded. These advantages included improved FCR, higher body weights and an overall better performance in broilers that were fed expanded feed. The expanded pelleted feed had a higher pellet quality as determined by the percentage of pellets retained on a sieve of known mesh gauge and pellet durability. Pellet quality increased as the expanding temperature increased. Expanding of feed had no obvious effects on vitamin recovery, although high temperatures might have had negative effects on vitamin B_1.

Results indicated that expanding at temperatures over 105°C may be detrimental to bird performance due to nutrient alteration, as both the 115°C expanded treatment and the 105°C expanded treatment showed decreased bird performance as the trial progressed. The decrease in Vitamin B_1 levels and nutrient availability increased birds feed intakes when fed feed which were expanded at temperatures exceeding 105°C, probably to meet their requirements. The effect of high temperature expansion was observed in poorer FCR for the 105 and 115°C expanded treatments, during Weeks 4 and 5. The cause of the decreased bird performance when birds were fed feed that was expanded above 105°C needs to be further investigated.

Chapter 6

Nitrogen corrected apparent metabolisable energy (AME_n) and lipid digestibility for broiler feed expanded at different temperatures

Abstract

The effect of the temperatures at which feed is expanded on metabolisable energy for broilers and lipid digestibility was evaluated. Eighty 19 day old Ross 788 broilers were placed in layer cages and adapted for 3 days. Feed intake of each bird was determined and total excreta were collected. The expanding of feed at temperatures of 95, 105 and 115°C had no significant influence on the apparent metabolisable energy for broilers. Expanding feed at temperatures of 95 and 105°C showed a slight but not significantly higher AME_n when fed to broilers, compared to non-expanded feed. Lipid digestibility of the expanded feeds was significantly better than the non-expanded treatment.

Introduction

Expanding of feed may lead to an increase in AME_n when fed to broilers, due to the improved pellet quality, improved starch digestion and improved lipid digestion (Peisker, 1994). Improved starch digestion occurs in the digestive tract as a result of the gelatinisation of starch during the expansion process. During gelatinisation of starch, the crystalline structure is lost and this increases the starch susceptibility to amylolytic degradation in the digestive tract (Holm *et al.,* 1988).

The aim of this trial was to investigate whether there were any differences in the nitrogen corrected apparent metabolisable energy (AME_n) of broiler feed expanded at 95, 105 or 115°C. There are debates whether the expansion of feed has significant effects on the digestibility of feed, especially the improvement of starch and lipid digestion and thus the improvement in AME_n of the feed.

If the process of expansion causes alteration to the nutrients, such as an increase in starch and lipid digestibility, a higher AME_n would be expected for the treatments expanded at higher temperatures. On the other hand, damage to some nutrients because of the expansion process, would decrease its availability and results in a lower AME_n. Theoretically, the expanded feed must have had a higher AME_n than the non-expanded treatment, since the degree of gelatinisation occurring during expanding is higher than when feed is not expanded. The treatment expanded at 115°C was expected to have the highest AME_n, as the degree of starch gelatinisation should be the highest for this treatment.

Materials and methods

Housing

The trial was conducted at the broiler and layer units at the University of Pretoria's Hatfield experimental farm from 4 February 2010 to 18 February 2010. The duration of the trial was 14 days.

Birds

Eighty (80) 19-day-old chickens were obtained from Daybreak farms. The 80 chickens were randomly placed in the layer cages on day 19, where they were adapted and then fed the trial feed from day 22 until 32 days of age. The house was divided into 5 blocks. The chickens were individually caged and 4 neighbouring cages represented one replicate. Each treatment was replicated 5 times, one replicate per block. One cage was kept open between each replicate in a block and also between blocks.

Feed

There was one feed formulated for each phase and the only difference between the four treatments were the processing conditions, with one treatment being non-expanded and the other three treatments being expanded at 95, 105 and 115°C, respectively.

The following feed treatments were tested in this trial:

Treatment A – Non-expanded feed; Starter crumbs, Grower 4.5mm pellets, Finisher 4.5mm pellets
Treatment B – Semi expanded feed (95°C); Starter crumbs, Grower 3.2 mm pellets, Finisher 3.2mm pellets
Treatment C – Expanded feed (105°C); Starter crumbs, Grower 3.2 mm pellets, Finisher 3.2mm pellets
Treatment D – Fully expanded (115°C); Starter crumbs, Grower 3.2 mm pellets, Finisher 3.2mm pellets

These treatments applied to all three feeding phases: starter, grower and finisher phases. Birds were raised on the same standard starter crumble, until commencement of the trial. The treatment starter, grower and finisher feed was fed from days 19 to 24, 25 to 28 and 31 to 32, respectively. Feed intake for the starter, grower and finisher were measured over a 48 hour period.

The feeding schedule is given in Table 7.1. Birds were fed according to days on feed, and feed was weighed out, recorded and discarded at the end of day 24 (end of the starter phase) and day 28 (end of the grower phase) and at the end of the finisher phase. Birds were fed *ad libitum*.

Table 6.1 The feeding schedule (feed allocations and days on feed)

Feed	**Feeding period (days)**	**Approximate feed intake (g/bird)**	**Feed allocation (kg)/pen (4 Chicks)**
Starter	5	600	2.4
Grower	4	480	2.0
Finisher	4	520	2.1

Statistical design

A randomised block design was used in this trial. There were five blocks, with 4 replicates per block. Each replicate consisted of four individually caged birds next to one another. Block 1 contained cages 1 to 4; block 2 from 5 to 8; block 3 from 9 to 12; block 4 from 13 to 16 and block 5 from 17 to 20). One replicate per treatment was randomly assigned to each of the five blocks (Table 7.2)

Table 6.2 Allocation of treatments to pens

Treatment	**Cages**				
A Non-expanded feed	4	8	11	16	20
B Expanded 95 treatment	3	5	12	14	18
C Expanded 105 treatment	2	7	9	15	17
D Expanded 115 treatment	1	6	10	13	19

There was only one fixed factor in this trial (treatment). Since the treatments in this trial were unstructured, simple analysis of treatment means was the most appropriate statistical analysis to use on these data. The generalised linear model (GLM) function in Minitab was used in preference to the balanced ANOVA so that *post hoc* multiple comparison tests could be run on the treatment means, in cases where the GLM found significant differences in performance between treatments. The *post hoc* multiple comparison tests used was the Bonferroni test, which is appropriate for small numbers of comparisons and stricter than the Tukey's test. The confidence level was set at 95%.

Block effects were accounted for by including 'block' as a random factor in the model.
The variables that were analysed were AME_N and lipid digestibility. This could be calculated from the following measurements: feed weighed in and feed weighed out, total excreta output and determining the dry matter, nitrogen content, fat % and gross energy of both the feed and the excreta.

Experimental procedure

Eighty chicks were placed in the layer cages and allowed to adapt to the cages for 3 days. During this period the birds were fed the experimental starter feed. Adequate time was allowed between collection periods of the different feeds for the birds to adapt to new feed and to ensure that there was no more of the previous feed left in the intestine of the bird. Chicks were fed 3 times a day to ensure *ad libitum* feed intake with a minimum risk of feed wastage. Plastic sheets were hung underneath the cages during the 48 hour collection periods for the collection excreta. The sheets containing the faecal matter were weighed and the empty weight of the sheets subtracted. The amount of feed given to the birds were weighed in at the beginning of the 48 hour collection period and at the end of each phase the left-over feed was weighed back and the difference taken as the feed intake of all four birds within the replicate.

Mortalities were removed from the cages and were not replaced, as the new chicks would not have been adapted. Feed and excreta were analysed for dry matter, nitrogen, fat and gross energy content.

The following formulas were used to determine AME_n and lipid digestibility:

$$AME_n = (GE_{in} - (GE_{out} - EEL +- \text{N-energy})) / FI$$

$$\text{Lipid digestibility} = (\text{Lipid intake} - \text{Lipid output}) / \text{Lipid intake}$$

Results

The AME_n for the starter, grower and finisher phases are given in Table 6.3.
The starter feed expanded at 115°C had a significant lower AME_n than the other treatments (Table 6.3). For the grower and finisher feeds there were no significant differences between the treatments, although the expanded 95 and 105°C treatments had numerically higher AME_n values.

Table 6.3 Mean AME_n (MJ/kg) for expanded and non-expanded feeds fed to broilers (means ± standard deviation)

	AME (ME/kg) ‡		
	Starter	Grower	Finisher
Feed			
A Non-expanded	12.50^{a} (±0.25)	12.01^{a} (±0.25)	12.03^{a} (±0.25)
B Expanded 95°C	12.55^{a} (±0.26)	12.12^{a} (±0.23)	12.31^{a} (±0.26)
C Expanded 105°C	12.57^{a} (±0.33)	12.28^{a} (±0.27)	12.38^{a} (±0.33)
D Expanded 115°C	12.05^{b} (±0.28)	12.01^{a} (±0.14)	11.94^{a} (±0.62)
F-prob			
Feed	0.006	0.158	0.148
Block	0.038	0.114	0.586
Variation accounted for, %	74.27	56.49	44.24

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

Lipid digestibility for the expanded and non-expanded grower phases are given in Table 6.4.

All three of the expanded treatments had significantly higher lipid digestibility values than the non-expanded treatment with no significant differences between the expanded treatments. Expanded feed showed a 3% improvement in lipid digestibility (Table 6.4).

Table 6.4 Mean lipid digestibility for expanded and non-expanded feeds fed to broilers (means ± standard deviation)

	Lipid Digestibility (%) ‡
	Grower
Feed	
A Non-expanded	86.8^{a} (±0.018)
B Expanded 95°C	89.6^{b} (±0.009)
C Expanded 105°C	90.0^{b} (±0.016)
D Expanded 115°C	89.8^{b} (±0.024)
F-prob	
Feed	0.017
Block	0.182
Variation accounted for, %	67.44

‡ Within columns, values with different superscript letters differ significantly, $p < 0.05$

Discussion

The trial showed that the expanding of feed had no significant effect on the AME_n when fed to broilers. The expanded 95°C and 105°C treatments had slightly higher AME_n values (but not significantly so) compared to the non-expanded treatment. Expanding of feed prior to pelleting led to an increase in lipid digestibility. Improved lipid digestion is one of the advantages when feed is expanded (Peisker, 1994). The expanded 105°C treatment had the highest AME_n for all the phases and also the highest lipid digestibility for the grower feed, which was 3 % higher than the non-expanded treatment. These results indicated that the expansion of feed at 105°C had the most beneficial effect on nutrient digestibility when fed to broilers.

Conclusion

Expansion of feed improved the lipid digestibility when fed to broilers. This improvement in lipid digestibility alone was not sufficient to increase the AME_n value of the feed, although expanding of feed at a temperature of 105°C tends to result in a better AME_n when fed to broilers.

Chapter 7
General conclusion and recommendations

General conclusion

Four experiments were conducted to evaluate the performance of birds under various conditions when they were fed expanded and non-expanded feed. Expanding of feed prior to pelleting is known to have numerous advantages when fed to broilers. These advantages were investigated. One of the advantages of feeding birds expanded feed is an improvement in feed conversion ratio and there was a definite improvement in feed conversion ratio (FCR) in all of the trials conducted.

The aim of Experiment 1 (Chapter 3) was to determine if there were any advantages when expanded feed were fed to broilers under heat stress and non-heat stress conditions, as well as the effect of heat stress on broiler performance. Results indicated that there was no significant influence on final body weight when birds were fed expanded feed, rather than non-expanded feed, under heat stress conditions. Expanded feed did however result in a better FCR from Week 4, when fed to birds under heat stress as well as under non-heat stress conditions. The induced heat stress resulted in lower final body weights. This was due to a decrease in feed intake from birds under heat stress, without any significant effect on FCR. Mortality rate increased when birds were exposed to heat stress.

The aim of Experiment 2 (Chapter 4) was to determine if pellet size influenced broiler performance and if there was a difference in broiler performance when the same size pellets, with one treatment being expanded and the other one not, were fed to broilers. Feeding birds expanded feed resulted in a definite advantage over non-expanded feed early in the trial with the birds receiving the expanded feed having a better FCR and growth rates than the birds fed the non-expanded feed. This indicated that there was alteration to nutrient availability when feed is expanded, which has an advantage when fed to younger birds. Birds fed expanded feed had significantly lower final body weights. This might be attributed to an expanding temperature (90°C) which were insufficient for proper starch gelatinisation and nutrient alteration for older broilers. Pellet size influenced feed intake and subsequently the FCR of birds. The birds which were fed the bigger 4.5mm pellets had higher feed intakes and poorer FCRs than those fed the 3.2mm pellets, but ended the trial with significantly higher body weights.

Experiment 3 (Chapter 5) was conducted to determine the expanding temperature which will lead to the best broiler performance. The results showed that expanding feed at temperatures between 95 °C and 105°C gave the best performance when fed to broilers. When these temperatures were exceeded

birds, had poorer weekly FCR during the last two weeks and ended with significantly poorer cumulative FCR figures.

Feed analyses for Vitamin A and B_1 showed that expanding feed had no significant effect on Vitamin A availability, but feed expanded at 115°C may have some damaging effects on Vitamin B_1 levels. Pellet quality increased as the temperature at which feed was expanded increased.

Experiment 4 (Chapter 6) was conducted to determine if the apparent metabolisable energy (AME_n) and lipid digestibility of feed can be altered by the expanding of feed. The only significant difference in AME_n was the Starter feed from the Expanded 115°C, which was significantly lower than the other treatments. This may explain the higher feed intakes of birds fed this treatment for the first two weeks of Experiment 3. Expanding of feed had no significant influence on the AME_n of feed. However, it improved the lipid digestibility of the grower feeds.

Pellet size affects feed intake, weight gain and FCR. Feeding broilers bigger pellets led to increased feed intakes, higher body weights and poorer FCR. Expanded feed improved early broiler performance and thus when expanded and non-expanded feed of the same pellet size (3.2mm) were fed to broilers, the expanded feed led to an improvement in body weight and FCR. Expanding of feed also improves lipid digestibility which improves broiler performance. Expanding of feed between 95 and 105°C gives the best broiler performance and also has no significant influence on vitamin A and B_1 stability. Pellet quality increased with an increase in expanding temperature.

Recommendations

The use of an expander may be justify according to the experiments reported here, especially if the increase in feed output rate at the mill is considered, along with the reduction in the amount of fines that need to be reworked and the significant improvement in feed conversion ratio when fed to broilers (without significant effects on body weight).

Further studies on the use of expanders in broiler feed manufacturing needs to be conducted; especially the effect of expanded feed on final body weights of broilers must be investigated as results were contradictory. The birds fed expanded pelleted feed under heat stress conditions might have shown a larger response if the heat stress induced was 1 or 2°C higher and the experiment was done for a period of 42 days and not 35 days. In the experiment conducted to establish the best expanding temperature, the addition of a 3.2 mm non-expanded treatment would have given more data regarding the differences between 3.2 mm expanded and 3.2 mm non-expanded feed (Chapter 5).

References

AI Bustany, Z., 1996. The effect of pelleting an enzyme-supplemented barley-based broiler diet. Anim. Feed Sci. Technol. 58. pp. 283-288.

Al-Fataftah, A. A. & Abu-Dieyeh, Z.H.M., 2007. Effect of Chronic Heat Stress on Broiler Performance in Jordan. Int. J. of Poult. Sci. 6. pp. 64-70.

Allred, J.B., Fry, R.E., Jensen, L.S. & McGinnis, J., 1957. Studies with chicks on improvement in nutritive value of feed ingredients by pelleting. Poult. Sci. 36. pp. 1284–1289.

Angulo, E., Brufau, J., & Esteve-Garcia, E., 1996. Effect of a sepiolite product on pellet durability in pig diets differing particle size and in broiler starter and finisher diets. Anim. Feed Sci. and Technol. 63. pp.25–34.

Behnke, K.C., 1994. Factors affecting pellet quality. Maryland Nutrition Conference. Dept. of poultry Science and Animal Science, College of Agriculture, University of Maryland, College Park.

Behnke, K.C., 1996. Feed manufacturing technology: current issues and challenges. Anim. Feed Sci. Technol. 62. pp. 49–57.

Bregendahl, K., Sell, J.L. & Zimmerman, D.R., 2002. Effects of low protein diets on growth performance and body composition of broiler chicken. Poult. Sci. 81. pp. 1156–1167.

Briggs J.L., Maier, D.E., Watkins, B.A. & Behnke, K.C., 1999. Effects of ingredients and processing parameters on pellet quality. Poult. Sci. 78. pp.1464–1471.

Búléon, A., Colonna, P., Planchot, V. & Ball, S., 1998. Starch granules: structure and biosynthesis. Int. J. Biol. Macromol. 23. pp. 85–112.

Cahaner, A., Pinchasov, Y. & Nir, I., 1995. Effect of high dietary protein under high ambient temperature on body weight, breast meat yield and abdominal fat of broiler stocks differing in growth rate and fatness. Poult. Sci. 74. pp. 968-975.

Calet, C., 1965. The relative value of pellets versus mash and grain in poultry nutrition. World's Poult. Sci. J. 21. pp. 23-52.

Carmen, A., France, M., Macleod, G. & Julie, E., 1991. Alleviation of acute heat stress by feed withdrawal or darkness. Br. Poult. Sci. 32. pp. 219-225.

Cavalcanti, W.B., 2004. The effect of ingredient composition on the physical quality of pelleted feeds: a mixture experimental approach. Ph.D. dissertation. Manhattan, KS: Kansas State University.

Coelho,M., 1994. Comparison with pelleting and extrusion: Vitamin stability in expanders. Feed Management 45(8). pp. 10-15.

Cornetto, T.L. & Estevez, I. 2001. Behavior of the domestic fowl in presence of vertical panels. Poult. Sci. 80. pp. 1455–1462.

Cramer, K.R., Wilson, K.J., Moritz, J.S. & Beyer, R.S., 2003. Effect of sorghum-based diets subjected to various manufacturing procedures on broiler performance. J. Appl. Poult. Res. 12. pp. 404–410.

Daghir, N.J., 1983. Effect of lysine and methionine supplementation of low protein roaster diets fed after six weeks of age. Poult. Sci. 62. pp. 572–575.

Dale, N.M. & Fuller, H.L., 1979. Effects of diet composition on feed intake and growth of chicks under heat stress. I. Dietary fat levels. Poult. Sci.. 58. pp. 1529-1534.

Deaton, J.W., F.N. Reece & B.D. Lott, 1984. Effect of differing temperature cycles on broiler performance. Poult. Sci. 63. pp. 612-615.

Donald, A.M., 2001. Review. Plasticization and self-assembly in the starch granule. Cereal Chem. 78. pp. 307–314.

Falk, D., 1985. Pelleting cost center. In: Feed manufacturing Technology 3. ed. McEllhiney, R.R.

Fancher, B., Rollis, D. & Trimbee, B., 1996. Feed processing using the annular gap expander and its impact on poultry performance. J. Appl. Poult. Res. 5. pp. 386-394.

Gaillard, T., 1987. Starch availability and utilization. In Starch: Properties and Potential. pp. 1–15.

Galobart, J. & Moran, E.T., 2005. Influence of Stocking Density and Feed Pellet Quality on Heat Stressed Broilers from 6 to 8 Weeks of Age. Int J. of Poult Sci. 4 (2). pp. 55-59.

Gary, D., Butcher, D.V.M., Ph.D. & Richard Miles, Ph.D., 2003. Heat Stress Management in Broilers

Goelema, J.O. Smits, A., Vaessen, L.M. & Wemmers, A., 1999. Effects of pressure toasting, expander treatment and pelleting on in vitro and in situ parameters of protein and starch in a mixture of broken peas, lupins and faba beans. Anim. Feed Sci. and Technol. 78. pp. 109- 126.

Goelema, J.O., Hof, G., van der Poel, A.F.B. & Tamminga, S., 1996. Effect of particle size, cold pelleting, steampelleting and expander treatment on the rumen degradability of a compound feed for ruminants. J. Dairy Sci. 79(1). pp. 142.

Hamilton, R.M.G. & Proudfoot, F.G., 1993. Ingredient particle size and feed texture: effects on the performance of broiler chickens. Anim. Feed Sci. and Technol. 51. pp. 203-210.

Han, X.Z. & Hamaker, B.R., 2001. Amylopectin fine structure and rice starch paste breakdown. J. Cereal Sci. 34. pp. 279–284.

Heffner L.E. & Pfost, H.B., 1973. Gelatinization during pelleting. Feedstuff .45. pp. 33.

Hermansson, A.M. & Kidman, S., 1995. Starch – a phase-separated biopolymer system. In: Biopolymer Mixtures. eds. Harding, S.E., Hill, S.E., Mitchell, J.R. pp. 225–245.

Holm, J., Lundquist, I., Bjorck, I., Eliasson, A.C. & Asp, N.G., 1988. Relationship between degree of gelatinisation, digestion rate in vitro, and metabolic response in rats. Am. J. Clin. Nutr. 47. pp. 1010–1016.

Howlider, M.A.R. & Rose, S.P., 1987. Temperature and the growth of broilers. World's Poult. Sci. J. 43. pp. 228-237.

Howlider, M.A.R. & Rose, S.P., 1989. Rearing temperature and the meat yield of broilers. Br. Poult. Sci. 30. pp. 61-67.

Howlider, M.A.R. & Rose, S.P., 1992. The response of growing male and female broiler chickens kept at different temperatures to dietary energy concentration and feed form. Anim. Feed Sci. Technol. 39. pp. 71-78.

Hurby, M., Hamre, M.L. & Coon, C.N., 1995. Predicting amino acids requirements for broilers at 21.1 ◦C and 32.2 ◦C. J. Appl. Poult. Res. 4. pp. 395–401.

Inborr, J. & Bedford, M.R., 1993. Stability of feed enzymes to steam pelleting during feed processing. Anim. Feed Sci. and Technol. 46. pp.179-196.

Jacobs, H. & Delcour, J.A., 1998. Hydrothermal modifications of granular starch, with retention of the granular structure: A review. J. Agric. Feed Chem. 46. pp. 2895–2905.

Johnston, S.L., Hines, R.H., Hancock, J.D., Behnke, K.C., Traylor, S.L., Chae, B.J. & Han, I.K., 1999. Effect of conditioners (standard, long-term and expander) on pellet quality and growth performance in nursery and finishing pigs. Asian–Aust. J. Anim. Sci.12. pp. 558–564.

Kaliyan, N. & Morey, R.V., 2008. Factors affecting strength and durability of densified biomass products. Biomass and bio energy. 33. pp. 337 – 359.

Kamran, Z., Mirza, M.A., Haq, A.U. & Mahmood, S., 2004. Effect of decreasing dietary protein levels with optimum amino acids profile on the performance of broilers. Pak. Vet. J. 24. pp. 165–168.

Kestin, S.C., Knowles, T.G., Tinch, A. F. & Gregory, N.G., 1992. The prevalence of leg weakness in broiler chickens and its relationship with genotype. Vet. Rec. 131. pp. 190–194.

Li, Y. & Liu, H., 2000. High-pressure densification of wood residues to form an upgraded fuel. Biomass and Bioenergy. 19. pp.177–186.

Lucht, H.W., 2001. Expanded feed and broiler production, Int. Poult. Prod.. 9 (6). pp. 39.

Lundblad, K.K., Hancock, J.D., Behnke, K.C., Prestløkken, E. McKinney, L.J. & Sørensen, M., 2008. The effect of adding water into the mixer on pelleting efficiency and pellet quality in diets for finishing pigs without and with use of an expander. Anim. Feed Sci. and Technol. 150. pp. 295–302.

Mahmoud, K.Z., Edens, F.W., Eisen, E.J. & Havenstein, G.B., 2003. Effect of ascorbic acid and acute heat exposure on heat shock protein 70 expression by young white leghorn chickens. Comp. Biochem. and Physiol. 136. pp. 329–335.

May, J.D., Lott, B.D. & Deaton, J.W., 1989. Poult. Sci., 68. pp. 91.

McIntosh, J.I., Slinger, S.J., Sibbald, I.R. & Ashton, G.C., 1962. Factors affecting the metabolizable energy content of poultry feeds. 7. The effects of grinding, pelleting and grit feeding on the availability of the energy of wheat, corn, oats and barley. 8. A study on the effects of dietary balance. Poult. Sci. 41. pp. 445-456.

Mitchell, M.A. & Sandercock, D.A., 1995. Creatine kinase isoenzyme profiles in the plasma of the domestic fowl (Gallus domesticus): effects of acute heat stress. Res. in Vet. Sci. 59. pp.30–34.

Moritz, J.S., Wilson, K.J., Cramer, K.R., Beyer, R.S., McKinney, L.J., Cavalcanti, B., Mo, X., 2003. Effect of formulation density, moisture, and surfactant on feed manufacturing, pellet quality, and broiler performance. J. Appl. Poult. Res. 11. pp.155–163.

Morris, T., 1999. Experimental Design and Analysis in Animal Science

Moulois, G., 1991. Trials on use of expanders : a new way of feed processing. Advance in Feed Technol. 2. pp 22-30.

Murray, S.M., Flickinger, E.A., Patil, A.R., Merchen, N.R., Brent, J.L. & Fahey, G.C., 2001. In vitro fermentation characteristics of native and processed cereal grains and potato starch using ileal chyme from dogs. J. Anim. Sci. 79. pp. 435–444.

Mushraf, N.A. & Latshaw, J.D., 1999. Heat increment as affected by protein and amino acid nutrition.World's Poult. Sci J. 55. pp. 233–239.

Obernberger, I. & Thek G., 2004. Physical characterisation and chemical composition of densified biomass fuels with regard to their combustion behavior. Biomass and Bioenergy. 27. pp. 653–669.

Payne J.D., 1978. Improving quality of pellet feeds. Milling Feed and Fertilizer. 162. pp. 34–41.

Peisker, M., 1992. High-temperature-short-time conditioning: physical and chemical changes during expansion. Feed Int. February. pp. 5–8.

Peisker, M., 1994. Influence of expansion on feed components. Feed Mix. 2. pp. 26–31.

Pellet cost center In: Feed manufacturing technology 4. pp. 115.

Pettersson, D., Graham, H. & Aman, P., 1991. The nutritive value for broiler chickens of pelleting and enzyme supplementation of a diet containing barley wheat and rye. Anim. Feed Sci. Technol. 33. pp. 1-14.

Pfost H.B., 1964. The effect of lignin binders, die thickness and temperature on the pelleting process. Feedstuffs 36(20). pp.54.

Pipa, F. & Frank, G., 1989. High-pressure conditioning with annular gap expander. A new way of feed processing, Adv. Feed Technol. 2. pp. 22-30.

Plavnik, D. & Wan., 1995. Nutritional effects of expansion and short time extrusion on feeds for broilers Anim. Feed Sci. and Technol. 55. pp. 247-251.

Proudfoot, F.G. & Hulan, H.W., 1982. Effects of reducing feeding time using all mash or crumble pellet dietary regimes on broiler chicken performance, including the incidence of acute death syndrome. Poult. Sci. 61. pp. 750-754.

Proudfoot, F.G., Hulan, H.W. & McRae, K.B., 1982. The effects of crumbled and pelleted feed on the incidence of sudden death syndrome among male chicken broilers. Poult. Sci. 61. pp. 1766-1768.

Rahman, M.S., Pramanic, A.H., Basak, B., Tarafdar, S.U. & Biswas, S.K., 2002. Effect of feeding low protein diets on the performance of broilers during hot humid season. Int. J. Poult. Sci. 1. pp. 35–39.

Ratnayake, W.S., & Jackson, D.S., 2009. Starch gelatinization. Advances in Feed and Nutrition Research. 55. pp 221-268.

Reece F.N., 1966. Temperature, pressure, and time relationships in forming dense hay wafers. Transactions of the ASAE 9. pp. 749–751.

Reece, F.N., Lott, B.D. & Deaton, J.W., 1985. The effects of feed form, grinding method, energy level and gender on broiler performance in moderate (21 "C) environment. Poult. Sci. 64. pp. 1834-1839.

Reece, F.N., Lott, B.D. & Deaton, J.W., 1986. The effects of hammer mill screen on ground corn particle size, pellet durability and broiler performance. Poult. Sci. 65. pp. 1257- 1261.

Riaz, M.N., 2007. Extruders and Expanders in Pet Feed, Aquatic and Livestock Feeds. pp. 91-131.

Richardson W. & Day E.J., 1976. Effect of varying levels of added fat in broiler diets on pellet quality. Feedstuffs. 48. pp. 24.

Robohm, K.F., 1992. Adjustable roll gap: benefits to energy demand, throughput and pellet durability. Feed Int. 13. pp. 30–35.

Rumpf, H., 1962. The strength of granules and agglomeration. In: Agglomeration. Eds. Knepper, W.A. pp. 379–418.

Samuels, M.L., 1989. Statistics for the life sciences. Collier MacMillan Publishers, London.

Salmon, R.E., 1985. Effects of pelleting, added sodium bentonite and fat in a wheatbased diet on performance and carcass characteristics of small white turkeys. Anim. Feed Sci. Technol. 12. pp. 223-232.

Schai, E., Broz, J. & Gadient, M., 1991. On the stability of feed additives in expanded compound feeds. Kruftfutter 74(11). pp. 526-528.

Slinger, S.J., 1973. Effect of pelleting and crumbling methods on the nutritional value of feeds. In: Effects of Processing on Nutritional Value of Feeds. National Academy of Sciences. Washington DC. pp. 48-66.

Sloan, D.R., Bowen, T.E. & Waldroup, P.W., 1971. Expansion-extrusion processing of corn, milo, and raw soybeans before and after incorporation in broiler diets. Poult. Sci. 50. pp. 257–261.

Smith I.E., Probert S.D., Stokes R.E. & Hansford R.J., 1977.The briquetting of wheat straw. J. of Agric. Engin. Res. 22. pp. 105–111.

Smith, P.A., Firman, J. D. & Dale, N.M., 1995. Effects of feed processed in an Annular Gap.

Spring P., Newman K.E., Wenk V., Messikommer R. & Vukic Vranjes M., 1996. Effect of pelleting temperature on the activity of different enzymes. Poult. Sci. 75. pp. 357–361.

Stark, C.R., 1994. Pellet quality. I. Pellet quality and its effect on swine performance. II. Functional characteristics of ingredients in the formation of quality pellets. Ph.D. dissertation. Manhattan, KS: Kansas State University.

Stevens, C.A., 1987. Starch gelatinization and the influence of particle size, steam pressure and die speed on the pelleting process. Ph.D. dissertation. Manhattan, KS: Kansas State University.

Statistical Analysis Systems, 2011. SAS User's Guide : Statistics Version 14

Summers, J.D. & Leesons., 1997. Commercial Poultry Production, Second Edition. University Books, Guelph, Ontario.

Svihus, B. & Gullord, M., 2002. Effect of chemical content and physical characteristics on nutritional value of wheat, barley and oats for poultry. Anim. Feed Sci. Technol. 102. pp. 71–92.

Svihus, B. & Zimonja, O., 2009. Effects of processing of wheat or oats starch on physical pellet quality and nutritional value for broilers. Anim. Feed Sci. and Technol. 149. pp. 287–297.

Teeter, R.G & Belay, T., 1996. Broiler management during acute heat stress. Anim Feed Sci Technol. 58. pp.127- 142.

Teeter, R.G. & Smith, M.O., 1987. Proc. Georgia Nutrition Conf., University of Georgia. pp. 160-169.

Thomas, M., van Zuilichem, D.J. & van der Poel, A.F.B., 1997. Physical quality of pelleted animal feed. 2. Contribution of processes and its conditions. Anim. Feed Sci. and Technol. 64. pp.173–192.

Thomas, M., van Vliet, T. & van der Poel A.F.B., 1998. Physical quality of pelleted animal feed. 3. Contribution of feedstuff components. Anim. Feed Sci. and Technol. 76 pp. 59–78.

Turkyilmaz, M.K., 2006. The effect of stocking density on stress reaction in broiler chickens during summer. Turk. J. Vet. Anim. Sci. 2008. 32(1). pp. 31-36.

Turner, R., 1995. Bottomline in feed processing: achieving optimum pellet quality. Feed Management. 46. pp. 30–33.

Vasanthan, T., Bhatty, R.S., 1996. Physicochemical properties of small- and large-granule starches ofwaxy, regular and high amylose barleys. Cereal Chemistry. 73. pp.199–207.

Vest, L., 1996. Interest in expander technology is on the rise in the U.S. Poultry Times No.4. pp. 9.

Wiernusz, C.G. & Teeter R.G., 1996. Acclimation effects on fed and fasted Broiler thermobalance during thermoneutral and high ambient temperature exposure. Br. Poult. Sci. 37. pp. 677-687.

Wood, J.F., 1987. The functional properties of feed raw materials and the effect on the production and quality of feed pellets. Anim. Feed Sci. and Technol. 18. pp.1–17.

Yan, J., Bao, E. & Yu, J., 2008. Heat shock protein 60 expression in heart, liver and kidney of broilers exposed to high temperature. Res. in Vet. Sci. 86. pp. 533–538.

Zaman, Q.U., Mushtaq, T., Nawaz, H., Mirza, M.A., Mahmood, S., Ahmad, T., Babar, M.E. & Mushtaq, M. M. H., 2005. Effect of varying dietary energy and protein on broiler performance in hot climate. Anim. Feed Sci. and Technol. 146. pp. 302–312.

Zügel, U., Kaufmann, S.H.E., 1999. Role of heat shock proteins in protection from and pathogenesis of infectious diseases. Clinical Microbiology Reviews 12. pp. 19–39.

Appendix A

Experiment 1

The raw material and calculated nutrient specifications for each feed used in experiment 1.

Ingredient (% inclusion)	Four phases			
	Prestarter	Starter	Grower	Finisher
Maize	56.86	55.662	58.268	62.025
Fishmeal	6.25	-	-	2.725
Soyabean oilcake 46%	16.0	17.0	15.0	14.525
Fullfat soya 35.5%	8.4	8.0	3.025	-
Sunflower oilcake 38%	5.0	6.0	7.925	7.0
White gluten 60	-	1.8	-	-
Poultry by-product (55M.45V)	2.778	5.55	7.478	5.5
L threonine	0.079	0.079	0.0355	0.026
DL methionine	0.1415	0.129	0.1435	0.199
Lysine HCl	0.355	0.445	0.357	0.296
Oil	0.7	1.872	3.475	3.875
Salt	0.2325	0.3975	0.385	0.31
Sodium bicarbonate	0.22	0.1365	0.0295	-
Monocalcium phosphate	0.98	1.097	0.76	0.32
Limestone	1.725	1.55	1.3	1.0
Mixer meal (feed reworks)	-	-	1.5	2.0
Vit + min				
Phyzyme XP 10000 liq.	0.006	0.006	0.006	0.006
Betafin	0.05	0.05	0.1	0.1
Additives				
ABGP Free 1 (vit Premix)	0.12	0.12	0.06	-
ABGP Free 2 (vit Premix)	0.05	0.05	0.05	0.1
Salinomycin	0.05	0.05	0.05	0.05
Stafac 4% (Premix)	0.05	0.05	0.05	0.05
Calculated analysis (%)				
Dry matter	89.81	90.03	89.962	89.753
Protein	22.267	20.717	18.455	18.34
AME (MJ/kg)	12.67	12.92	13.28	13.506
Fibre	3.41	3.67	3.937	3.627
Fat	5.66	6.518	7.614	7.613
Lysine	1.279	1.13	0.945	0.94
Methionine	0.531	0.454	0.436	0.439
TSAA				
Threonine	0.767	0.701	0.588	0.583
Tryptophan	0.206	0.181	0.1614	0.161
Isoleucine	0.792	0.735	0.646	0.639
Arginine	1.279	1.175	1.066	1.041
Histidine	0.556	0.485	0.428	0.434
Valine	0.895	0.826	0.798	0.800
Serine + glycine	1.761	1.621	1.465	1.447
Calcium	1.09	0.88	0.753	0.656
Av. Phosphorus	0.491	0.39	0.333	0.305
Sodium (mg/kg)	2197.93	2001.13	1698.54	1598.333
Potassium (mg/kg)	7802.54	7649.52	6947.37	6612.584

Experiment 2

The raw material and calculated nutrient specifications for each feed used in experiment 2.

Ingredient (% inclusion)	Four phases			
	Prestarter	Starter	Grower	Finisher
Maize	58.69	55.25	60.2	59.93
Fishmeal	7.83	-	-	-
Soyabean oilcake 46%	13.95	17.61	13.48	13.15
Fullfat soya 35.5%	10.01	10.01	10.01	10.0
Sunflower oilcake 38%	4.99	3.98	3.99	4.0
White gluten 60	-	1.25	-	-
Poultry by-product (55M.45V)	-	5.56	-	6.46
L threonine	0.075	0.08	0.037	0.038
DL methionine	0.131	0.144	0.162	0.159
Lysine HCl	0.311	0.406	0.309	0.309
Oil	0.504	1.731	2.156	3.12
Salt	0.224	0.402	0.396	0.389
Sodium bicarbonate	0.224	0.131	0.024	
Monocalcium phosphate	1.334	1.581	1.277	1.045
Limestone	1.481	1.555	1.33	1.175
Betafin	0.050	0.050	0.050	0.05
ABGP Free 2 (vit premix)	-	-	0.050	0.1
ABGP Free 1 (vit premix)	0.120	0.120	-	-
Olaquindox 10%	0.039	0.04	0.04	0.04
Monensin 20%	0.499	0.05	0.05	0.05
Calculated analysis (%)				
Dry matter	89.62	89.79	89.66	89.74
Protein	22.32	20.56	18.35	18.18
AME (MJ/kg)	12.62	12.81	13.19	13.46
Fibre	3.34	3.31	3.29	3.27
Fat	5.56	6.72	7.32	8.27
Lysine	1.28	1.13	0.949	0.94
Methionine	0.54	0.458	0.442	0.43
TSAA	0.806	0.735	0.694	0.686
Threonine	0.768	0.700	0.589	0.583
Tryptophan	0.209	0.185	0.162	0.160
Isoleucine	0.793	0.735	0.646	0.639
Arginine	1.278	1.175	1.050	1.04
Histidine				
Valine	1.63	0.821	0.732	0.725
Serine + glycine	1.74	1.610	1.453	1.44
Calcium	1.029	0.879	0.747	0.658
Av. Phosphorus	0.502	0.394	0.337	0.295
Sodium (mg/kg)	2194.8	2002.01	1695.42	1595.96
Potassium (mg/kg)	7713.5	7808.83	7114.97	7036.13

Experiment 3

The raw material and calculated nutrient specifications for each feed used in trial 3.

Ingredient (% inclusion)	Three phases Starter	Grower	Finisher
Maize	56.11	57.21	58.18
Fishmeal	-	-	-
Soyabean oilcake 46%	22.13	14.97	13.78
Fullfat soya 35.5%	5.52	10.00	10.00
Sunflower oilcake 38%	5.87	5.00	5.00
White gluten 60	-	-	-
Poultry by-product 55M.45V)	5.56	8.33	8.89
L threonine	0.055	0.02	0.020
DL methionine	0.219	0.193	0.187
Lysine HCl	0.333	0.286	0.292
Oil	0.700	1.081	1.343
Salt	0.398	0.393	0.384
Sodium bicarbonate	0.133	0.025	-
Monocalcium phosphate	0.951	0.640	0.412
Limestone	1.533	1.311	1.52
Cholien Cl Liq	0.067	0.068	0.067
ABGP Free 2 (vit premix)	-	0.06	0.1
ABGP Free 1(vit premix)	0.138	0.07	-
Olaquindox 10%	0.040	0.04	0.04
Monensin 20%	0.050	0.05	0.05
Avizyme 1502	0.05	0.05	0.05
Phyzyme TPT	0.05	0.05	0.05
Doxyvit	0.1	0.15	-
Calculated analysis (%)			
Dry matter	89.32	89.45	89.43
Protein	20.61	19.29	18.95
AME (MJ/kg)	11.8	12.4	12.6
Fibre	3.52	3.35	3.34
Fat	5.17	6.69	7.05
Lysine	1.1	0.98	0.96
Methionine	0.49	0.45	0.44
TSAA	0.77	0.71	0.70
Threonine	0.68	0.61	0.60
Tryptophan	0.19	0.17	0.17
Isoleucine	0.74	0.69	0.67
Arginine	1.21	1.12	1.09
Histidine	0.50	0.46	0.45
Valine	0.83	0.77	0.76
Serine + glycine	1.63	1.56	1.54
Calcium	0.88	0.75	0.66
Av. Phosphorus	0.40	0.34	0.30
Sodium (mg/kg)	2000.0	1700.0	1600.0
Potassium (mg/kg)	8301.1	7503.9	7308.8

Appendix B
Temperature and lightning profiles

Age (d)	WINTER (40% rH)			SUMMER (50% rH)		
	Lower Temp	**Target Temp**	Upper Temp	Lower Temp	**Target Temp**	Upper Temp
0	34.0	**35.5**	37.0	31.5	**33.0**	34.5
1	34.0	**35.5**	37.0	31.5	**33.0**	34.5
2	34.0	**35.5**	37.0	31.5	**33.0**	34.5
3	33.0	**34.5**	36.0	30.5	**32.0**	33.5
4	33.0	**34.5**	36.0	30.5	**32.0**	33.5
5	33.0	**34.5**	36.0	30.5	**32.0**	33.5
6	32.0	**33.5**	35.0	29.5	**31.0**	32.5
7	32.0	**33.5**	35.0	29.5	**31.0**	32.5
8	32.0	**33.5**	35.0	29.5	**31.0**	32.5
9	30.5	**32.0**	33.5	28.2	**29.7**	31.2
10	30.5	**32.0**	33.5	28.2	**29.7**	31.2
11	30.5	**32.0**	33.5	28.2	**29.7**	31.2
12	28.0	**29.5**	31.0	25.7	**27.2**	28.7
13	28.0	**29.5**	31.0	25.7	**27.2**	28.7
14	28.0	**29.5**	31.0	25.7	**27.2**	28.7
15	27.0	**28.5**	30.0	24.7	**26.2**	27.7
16	27.0	**28.5**	30.0	24.7	**26.2**	27.7
17	27.0	**28.5**	30.0	24.7	**26.2**	27.7
18	25.5	**27.0**	28.5	23.5	**25.0**	26.5
19	25.5	**27.0**	28.5	23.5	**25.0**	26.5
20	25.5	**27.0**	28.5	23.5	**25.0**	26.5
21	24.5	**26.0**	27.5	22.5	**24.0**	25.5
22	24.5	**26.0**	27.5	22.5	**24.0**	25.5
23	24.5	**26.0**	27.5	22.5	**24.0**	25.5
24	23.5	**25.0**	26.5	21.5	**23.0**	24.5
25	23.5	**25.0**	26.5	21.5	**23.0**	24.5
26	23.5	**25.0**	26.5	21.5	**23.0**	24.5
27	23.5	**25.0**	26.5	21.5	**23.0**	24.5
28	23.5	**25.0**	26.5	21.5	**23.0**	24.5
29	23.5	**25.0**	26.5	21.5	**23.0**	24.5
30	23.5	**25.0**	26.5	21.5	**23.0**	24.5
31	23.5	**25.0**	26.5	21.5	**23.0**	24.5
32	23.5	**25.0**	26.5	21.5	**23.0**	24.5
33	23.5	**25.0**	26.5	21.5	**23.0**	24.5
34	23.5	**25.0**	26.5	21.5	**23.0**	24.5
35	23.5	**25.0**	26.5	21.5	**23.0**	24.5

Lightning schedule

Day	Day Light	Darkness
1	23:00	01:00
2	23:00	01:00
3	23:00	01:00
4	23:00	01:00
5	23:00	01:00
6	23:00	01:00
7	14:00	10:00
8	14:00	10:00
9	14:00	10:00
10	14:00	10:00
11	14:00	10:00
12	14:00	10:00
13	14:00	10:00
14	14:00	10:00
15	14:00	10:00
16	16:00	08:00
17	16:00	08:00
18	16:00	08:00
19	16:00	08:00
20	16:00	08:00
21	16:00	08:00
22	16:00	08:00
23	18:00	06:00
24	18:00	06:00
25	18:00	06:00
26	18:00	06:00
27	18:00	06:00
28	18:00	06:00
29	20:00	04:00
30	20:00	04:00
31	20:00	04:00
32	20:00	04:00
33	20:00	04:00
34	20:00	04:00
35	20:00	04:00