Assessment of behaviour and egg production of laying hens kept in cages and floor systems on a commercial farm in South Africa

by

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Declaration

I, Timothy Chilemba hereby declare that this thesis, submitted for the MSc(Agric) Animal Science: Livestock Production and Ecology degree at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at any other University.

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Abstract

There is considerable pressure to eliminate the use of conventional cages in commercial layer production systems. Nonetheless, the assessment of alternative methods that can ensure the hen's ability to perform different behaviours while simultaneously enhancing productivity and economic efficiency on the farm remains incomplete. The current study was conducted on a South African commercial farm at the following GPS coordinates: 26º23’27” S28º52’07” E, over an 8-week period using Lohmann Brown laying hens at different ages and in different housing systems with different stocking densities. The study assessed the behaviour and production parameters of laying hens kept in cages and floor systems during daytime hours (7:00 AM to 3:00 PM), focusing on dustbathing, nesting, feather pecking, and perching behaviours, as well as body condition scores. Body weights, egg production, and feed intake were recorded on weekly intervals. Eggs were collected daily between the hours of 8:00 am and 10:00 am in all housing systems to determine egg production and egg quality. Behavioural observations were done using a video camera and trained observers. On average, 79.2 percent of hens were observed dust bathing for a duration of 22.63 minutes. The least prevalent behaviour observed was feather pecking, with an average percentage of 35.4 hens were being pecked. After a period of six weeks, it was also observed that 41.67% of the hens in the floor system had developed mud balls on their toes that exceeded 3 cm in length. Hens kept on low stocking density (6-tier with 6 birds per cage and enriched cages) had a higher body weight and laid bigger eggs, compared to hens on low stocking density. Egg output ranged between 56.25% and 97.77% across housing systems and stocking densities. The results of this study provide evidence of the relationship of poultry behaviour, poultry welfare and production parameters. The present study also demonstrated the effects of stocking density on different production (body weight, egg production and body condition) parameters need consistent monitoring to optimise welfare in the layer house. The findings from this study may be used to inform different stakeholders on new advances in the management of commercial layers to encourage on-time detection and management of certain welfare-related behavioural concerns.

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List of abbreviations

APAW	Africa platform for animal welfare
AOS	Android operating systems
B	Width
cm^3	Cubic centimetre
CC	Conventional cage
CSPro	Census and survey processing system
EC	Enriched cage.
FAWC	Farm animal welfare committee
FC	Feather condition
FS	Floor system
FTP	File transfer protocol
g	Grams
GDP	Gross domestic product
HD	High definition
kg	Kilograms
Kv	Volume coefficient
L	Length
mm	Millimetre
OIE	World organization for animal health
P	Probability
r	Correlation Coefficient
RFID	Radio frequency identification detectors
SAPA	South African poultry association
SPSS	Statistical package for the social sciences

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Chapter 1: Introduction and literature review

1.1 Introduction

The poultry industry in South Africa significantly contributes to the nation's gross domestic product (GDP). As of 2021, poultry production accounted for 20.9 percent of overall agricultural gross value and 43 percent of total animal output (SAPA, 2022). In addition, the poultry sector employs close to 110 000 individuals and provides support to several businesses throughout the poultry value chain (Nkukwana, 2018). It is important to note that chicken products account for 65.3 percent of South Africa's total meat and egg consumption, with an average per capita consumption of 7.33 kilograms of chicken eggs and 39.53 kilograms of chicken meat (SAPA, 2022)

The significance of global egg production increased during the inter-war period, which denotes the period between the First and Second World Wars (Stadelman et al., 2017). After the World War II food supplies were severely depleted with a pressing need to maximise food production, which resulted in establishment of the intensive poultry production systems as known today, with little consideration given to animal welfare (Elson et al., 2011).

Modern commercial egg production is characterised by layers that are housed in high-intensity housing designed to maximise productivity and profitability. However, there are certain disadvantages to these housing systems, including the fact that they cause congestion and stressful social behaviour in birds, increase their vulnerability to diseases and cannibalism, and deprive birds of food and perch space (Dikmen et al., 2016). As indicated by Webster (2001) some of the modern intensive layer production systems tends to be in violation of the five freedoms established by the Farm Animal Welfare Council in 1997.

Over the past two decades, three common commercial egg-production housing systems have been used around the world: conventional cages, enriched cages, and free range or barn systems. The conventional cage system, which was developed in the 1930s as an alternative form to backyard housing system is characterised by the presence of at least four hens per cage that are either in an environmentally controlled or open-sided house, depending on the scale of production (Sosnówka-Czajka et al., 2010). According to poultry housing guidelines, the available space for layers in conventional cage systems should be greater than 465 cm^2 (Neijat et al., 2019).

Enriched cages were first developed in Germany in the 1980s and have continued to be improved ever since (Appleby et al., 2004). With the enriched cage housing system there is more room for hens, each with over 750 cm^2 of space per hen, and they are fitted with a nest perch, a scratching area, and provision is made for a nail shortening (Lay Jr et al., 2011). Normally, the birds in free-range systems are kept in houses that are provided with dust bathing areas, nesting boxes, and aviaries depending on the house design and each hen has more than 5 000 cm^2 of space (Campbell et al., 2017). One key distinction between free range and barn housing systems is that in a free-range system birds have access to the outdoor area, while in barn systems birds do not have access to the outdoor area (Krawczyk & Gornowicz, 2010).

In accordance with the World Organisation for Animal Health (OIE), birds should be able to express their natural behaviours, such as nesting, scratching, pecking, and dust bathing, without fear or suffering (Bhanja & Bhadauria, 2018). The current commercial laying cage density of 22 birds per square meter is too high for each bird to express the appropriate natural behaviour and have enough space to move around. Hens in cages are content with a stocking density of 3 to 4 birds per square meter because they have more space to exhibit a wider range of behaviours (Zimmerman et al., 2006).

As reported by Travel et al. (2011) several factors can affect egg production and egg quality, including the hen's genetic composition, feeding strategy, management practises, physiological status, laying age, egg processing and storage conditions. The effects of space allowance in conventional cages show that when floor space is reduced by 300 cm^2 per hen, mortality increases and egg production, body weight, and feed utilisation efficiency decrease (Sarica et al., 2008). For example, a study by Kannan and Mench (1996) found that a decrease in the space allocation per bird from 1394 to 697 cm2 resulted in an elevation of plasma corticosterone levels for birds housed in two-bird cages. As a response to these effects, the European Union has banned the use of conventional cages in favour of enriched cages, which provide hens with scratching and pecking structures to increase their well-being (European Commision, 2011). A total of 49.9 percent of the EU market is currently occupied by enriched cage farming, which is followed by floor systems (32.5 percent) and organic farming (6.2 percent) (Dalle Zotte et al., 2021).

South Africa is a developing and middle-income country with a diverse production and economic environment. Poultry farmers are frequently confronted with several issues, including disease control and biosecurity regulations (SAPA 2022). Even though poultry farmers seek to maintain appropriate livestock husbandry practices, animal welfare features as perceived by animal welfare organisations is not considered a top priority by the South African poultry industry. Despite these practices, some poultry farmers can circumvent the challenges that come with non-cage systems that have management standards like that of cage systems. This is evident from the number of egg producers affiliated with SAPA and remaining in business Currently, there is no convincing evidence that non-cage systems are superior for bird welfare, besides ethical considerations on hens standing on wire-cages 24/7 for 80 weeks of egg production (Bell, 2002).

As a response to these growing animal welfare concerns, there has been a recent spike in interest of cage systems designed to better suit hens' needs while also reducing production costs and retailers have expressed their preference for a supply of free-range eggs rather than those from caged layers (Al-Ajeeli et al., 2018). It is hard to overlook the growing number of animal welfare organisations, such as Compassion in World Farming (South Africa), who are requesting that the present conventional cage size of 450 cm^2 be adjusted and that new cages with additional space for each hen be constructed. Eliminating the use of battery cages is the extreme option; thus, investigation for alternative systems and improved management practices combined with the adoption of minimum standards for enriched cage systems is paramount. As a result, research into alternative housing systems and practices was carried out, and minimum standards were adopted for describing and comparing the welfare traits, egg production and quality of layers housed in conventional cages, enriched cages, and floor system.

1.2 Aim

The overall aim of this study was to assess the behaviour and production of laying hens kept in cages and floor systems on a commercial farm in South Africa.

The following objectives were established to achieve the overall goal of this study:

1. To collect welfare parameters in enriched cages and floor systems with layers by human observation and video technology
2. To assess the effects of stocking density and housing system on body condition score, body weight and egg production for layers in conventional cages, enriched cages, and floor systems.
3. To evaluate the inter- and intra-repeatability of subjective scoring on layers kept in the conventional cages, enriched cages, and floor systems.
4. To assess the external egg quality for layers in conventional cages, enriched cages, and floor systems

1.3 Literature review

1.3.1 Introduction

The housing conditions of layer hens continue to be a major animal welfare concern for consumers, egg producers, and legislators (Sherwin et al., 2010). Due to rising urbanisation and the resulting decrease in farmable land, poultry farmers are required to increase the density of their flocks in order to make the most efficient use of their facilities without sacrificing profitability (Jahanian & Mirfendereski, 2015). From a production point of view, stocking density is defined as the weight-based number of birds per unit area expressed as the mass per unit area (Dozier et al., 2006). However, this definition may not meet the proposition of matching stocking density to the welfare of birds regardless of the type of housing system.

Several studies have found that increased stocking density has a negative impact on several aspects of poultry production such as feed intake (Tang et al., 2012), body weight and average weight gain (Yanai et al., 2018; Zhang et al., 2018), higher birds' mortality (Benyi et al., 2006), poor egg quality (Kang et al., 2018) and the general behaviour and welfare of chickens (Robins & Phillips, 2011). In this section, literature has been reviewed on the three most widely used commercial egg-production systems (conventional cages, enriched cages, and floor systems) with reference to welfare parameters, body weight, egg production, and egg quality.

1.3.2 Brief overview of poultry farming in South Africa

In South Africa, a diverse range of poultry species, including ducks, turkeys, geese, guinea fowl, and quails, are reared for human consumption. However, it is noteworthy that chicken is the most extensively reared species for commercial purposes (Amoako et al., 2020). Chicken farming involves the rearing of chickens with the primary objective of producing broilers for meat and layers for egg production. This industry serves as a primary source of protein for a significant proportion of the South African population, constituting up to 65.3 percent of the local animal protein consumption (SAPA, 2022). According to Idowu et al. (2018), the rearing of poultry is commonly observed in close proximity to urban centres due to the high demand and availability of a receptive market for poultry-related products. Currently, the country has approximately 121 and 24 breeding farms for broilers and layers, respectively. An estimated 103 894 738 broilers are reared in 42 farms, as well as 28 675 080 layers in 28 farms. In Table 1.1 the provincial distribution of layer farms (breeder, rearing and in-lay) was summarised.

Table 1.1 Provincial distribution of layers in South Africa (SAPA, 2022)

Province	Layer birds	Percent of total layer birds
Eastern Cape	923 283	3.2 %
Free State	4 629 878	16.1 %
Gauteng	7 199 553	25.1 %
KwaZulu-Natal	2 945 032	10.3 %
Limpopo	1 079 830	3.8 %
Mpumalanga	2 013 282	7.0 %
North West	3 264 359	11.4 %
Northern and Western Cape	6 619 863	23.1 %
Grand Total	**28 675 080**	**100 %**

However, the topic of bird welfare remains a subject of discussion due to the substantial expenses linked to the adoption of these systems (Dikmen et al., 2016). Table 1.2 presents a summary of the primary requirements, highlighting the similarities and differences among the three major systems of layer production.

Table 1.2 Summary of primary differences and similarities between the three major layer production systems

Parameter	Conventional Cage	Enriched Cage	Free Range
Space per bird	465 cm^2	750 cm^2	5 000 cm^2
Cages	Provided	Provided	Not provided
Perches	Not provided	Provided	Provided
Foraging Materials	Not provided	Provided	Provided
Nest Boxes	Not provided	Provided	Provided

1.3.3 Poultry Welfare

It has been well documented that poor bird welfare has a negative impact on the overall quality of poultry output (Lay et al., 2011). As defined by the World Organisation for Animal Health, animal welfare is referred to the state in which an animal is healthy, comfortable, well-fed, safe, and able to express its innate behaviour and is not suffering from unpleasant states such as pain, fear, or distress (Teale & Moulin, 2012). Animal welfare issues started to get more attention after the Brambell Committee in the UK released a report in 1965 calling for livestock to be granted five freedoms in terms of the right to lie down, get up, stretch, and groom themselves without being restricted in their movements (McCulloch, 2013). Many organisations, such as the World Health Organisation, have accepted and expanded the five freedoms to encourage chicken production, which are currently being used (Correa et al., 2013). These five freedoms are as follows:

a) Freedom from hunger and thirst - the birds should have access to fresh water and feed without traveling more than 5 to 7 meters to obtain access to feed or water.
b) Freedom from discomfort - birds should be provided with a shelter that has adequate resting area and proper ventilation with provisions for free movement.
c) Freedom from pain, illnesses, and injury - birds should be vaccinated at appropriate ages to protect them from a variety of common diseases such as Newcastle disease. The farm should also ensure strict biosecurity measures to minimise exposure to other potential disease organisms.
d) Freedom to express natural behaviour - the common example in hens is nesting behaviour, perching, foraging (scratching and pecking), dust bathing.
e) Freedom from fear and distress - the birds should not be exposed to activities that trigger responses such as attempts to escape, produce a defensive behaviour, or freezing in place.

There are several factors that influence animal welfare, including genetics, hatching, upbringing, adult housing habitat, the techniques of transit and slaughter used, and, to a significant extent, the attitudes, and standards of care of their caretakers (Bhanja & Bhadauria, 2018). In intensive poultry production, there are several potential issues, such as stocking density, poor social conditions, heat stress, or difficulties accessing essential resources which can lead to welfare deterioration and poor performance (Tactacan et al., 2009). Many of these factors can be mitigated through well-established management practices that create an optimal environment for birds. The advancement of technology has made a significant contribution to the welfare of poultry in terms of housing systems, feeding methods and composition, and the way these chickens are handled in a commercial setting (Karcher & Mench, 2018). According to Sherwin et al. (2010), any poultry production system that does not comply with the Five Freedoms will be subject to criticism for its failure to promote poultry welfare.

The primary objective of a farmer is to optimise egg production with the aim of enhancing business profitability. Consequently, the farmer shall provide appropriate housing, adequate nourishment and preventative measures against diseases, and ensure adequate lighting and air circulation. If the farmer adheres to this guidance, the majority of welfare issues will be resolved. However, this does not imply that the farmer possesses a comprehensive understanding of the quintessential principles of welfare reform. Farmers who use the deep litter method, for instance, are more likely to think about hen welfare than those who use cages (Stadig et al., 2015). This is likely because modern cages are adapted to accommodate a wide range of animal welfare standards. Unless the farmers have some understanding of animal welfare, they are not likely to create an environment that is conducive to the birds' health and happiness. According to Stadig et al. (2015), farmers who use the deep litter method tend to exhibit greater concern for hen welfare as compared to those who use cages. The probable reason for this is that contemporary cages have been modified to cater to diverse animal welfare criteria. Farmers who lack knowledge of animal welfare may not be able to establish a suitable environment that promotes the well-being and contentment of the birds. Such information can be learned through schooling, workshops, and reading (Špinka, 2019). Farmers typically do not place a high priority on animal welfare since they view animals primarily as a resource to be exploited for optimum productivity.

1.3.4 Methods of assessing poultry welfare

Welfare principles can be deduced from the five freedoms, which are taken into account when evaluating the well-being of chickens. The four pillars are proper nutrition, adequate shelter, physical well-being, and ethical conduct. Based on these principles, the criteria for evaluating welfare are developed as indicated in Table 1.3.

Table 1.3 The principles and criteria used to develop welfare assessment methods. (Naggujja et al., 2020)

Welfare Principles	Welfare Criteria	Measures
Good feeding	Absence of prolonged hunger	Quantity of feed per bird per day
	Absence of prolonged thirst	Drinker space
Good Housing	Thermal comfort	Temperature in the poultry house
	Comfort around resting	Available perch space per bird
	Ease of movement	Stocking density
Good health	Absence of diseases	Diseases, mortalities, and vaccines
	Absence of injuries	Footpad lessons
	Absence of induced pain	Beak trimming
Appropriate behaviour	Expression of social behaviour	Cannibalism
	Expression of laying behaviour	Nesting boxes
	Good reception to animals	Fear of strangers
	Positive emotional state	Fear of pets and predators.

After establishing these concepts and criteria, it becomes imperative to ascertain how the welfare of the animals can be evaluated. As demonstrated by Naggujja et al. (2020), the evaluated domains may take the form of resource-based, animal-based, or management-based assessments. The process of resource-based evaluation involves the consideration of factors such as food and water sources, as well as nesting areas. On the other hand, animal-based evaluation takes into account aspects such as animal well-being, production levels, and animal behaviour. Lastly, management-based evaluation involves the assessment of factors such as nesting materials, dust bathing trays, and bird mortality, as noted by Kumar et al. (2021)

1.3.5 Poultry health, welfare, and production

Poultry diseases are more likely to spread in poorly managed houses, which is bad for the chickens' welfare and productivity. According to Chain-Guadarrama et al. (2019), it is critical to manage the environment where birds are raised in a manner that is consistent with the local climate. Due to improper management of drinkers, foot pad lesions are most frequently detected in damp areas of the litter. According to Scanes and Christensen (2019), there is a correlation between watering equipment and the prevalence of foot pad dermatitis. Birds raised in houses with open water containers had a higher prevalence of food pad dermatitis than birds raised in homes with water nipples (Chain-Guadarrama et al., 2019).

The welfare of animals is undermined when they undergo distress and the primary categories of distress examined in animals comprise of pain and distress, anxiety, privation, and dissatisfaction. According to Duncan (1998), pain is a significant form of suffering that has an indirect impact on an animal's well-being.In order to reduce cannibalism and feed waste, beak cutting is used. According to (Glatz & Underwood, 2020), it is preferable to perform it on day old chicks as this entails trimming between a quarter and a third of the bird's top beak or both its upper and lower peaks. Debeaking causes some discomfort, however if done on young birds, the pain is minimised.

According to Kumar et al. (2021) research, laying hens consume approximately 120 grammes of feed on a daily basis. The allocation of feeding and watering areas for laying hens is typically contingent upon the specific equipment employed. According to Abd El-Hack et al. (2022) review paper, the appropriate feeding and watering spaces for each adult laying hen in the United States are 10-12 cm and 2.5-3.0 cm, respectively. It is imperative to ensure that the laying hen's diet comprises adequate quantities of all the essential nutrients, given that the bird can consume only approximately 118-120 grammes of feed per day. Laying hens exhibit the ability to modulate their feed consumption in order to fulfil their energy requirements. A decrease in feed intake is observed if birds are exposed to high environmental temperatures, whereas an increase in feed consumption is observed in birds when exposed to low temperatures. The reason for this is that chickens necessitate increased energy expenditure to maintain thermoregulation in colder environments. The purpose of this measure is to prevent nutritional inadequacies in order to improve the well-being and efficiency of the avian population, as stated by Chain-Guadarrama et al. (2019).

1.3.6 Poultry welfare legislation

The purpose of animal welfare regulations is to mitigate the occurrence of unwarranted harm inflicted upon animals. The United Kingdom has enacted several Acts pertaining to animal welfare, including the Animal Protection Act of 1911, the Agriculture Act of 1968, and the Animal Welfare Act of 2006 (Bayne et al., 2021). The aforementioned actions are typically intended to mitigate the occurrence of animal distress in various forms. The European Commission has also established a set of minimum standards for safeguarding all farmed animals, as outlined in the Council Directive 98/58/EC (European Commission, 2011). Animal welfare laws are implemented in Canada with the objective of preventing animals from experiencing any form of suffering and has legislative acts that pertain to the protection of animals. These include the Cruelty to Animals Act, which prohibits intentional or unjustifiable cruelty towards animals, the Health of Animal Act, which safeguards animals from unnecessary suffering during transportation, and the Meat Inspection Act, which seeks to ensure the well-being of food animals during handling and slaughter (Casoli et al., 2005).

Animal welfare laws are largely absent in many African nations, and even when they do exist, their enforcement is often minimal. According to Africa Platform for Animal Welfare report, the disregard for animal welfare in the processes of farming, transportation, and slaughter has resulted in suboptimal productivity (APAW, 2021). In parallel to legislative measures implemented in Britain, South Africa, upon its establishment as a Union in 1910, enacted its inaugural animal welfare law, namely The Prevention of Cruelty to Animals Act, 8 of 1914 (Bilchitz & Wilson, 2022). This development underscores the ambivalent stance towards animals.

As for poultry production, the practise of exerting dominance over other animals while simultaneously providing some degree of welfare protection, as outlined in The Animals Protection Act, 71 of 1962, has persisted across various governmental administrations. The objective of this legislation is to mitigate the occurrence of disease conditions among poultry species (Wilson, 2019). The Meat Safety Act of 2000 is a pertinent legislation, especially concerning farmed animals. The Act primarily pertains to ensuring food safety standards for animal products and meat (Bilchitz & Wilson, 2022). However, specific regulations that have been established in this regard also incorporate provisions for the ethical treatment of live animals. This includes guidelines for their transportation to abattoirs and humane practises during the slaughtering process (Wilson, 2019). Therefore, it presents unexplored prospects for addressing specific facets concerning animals utilised in the context of food production and contentious methodologies.

1.3.7 Poultry behaviour

1.3.7.1 Nesting behaviour

A better understanding of laying hens' behavioural needs can provide evidence for or against using certain environmental resources in housing designs (Cooper & Albentosa, 2003). Hens tend to prepare for nesting before laying begins, and this behaviour is hormonally regulated with effects on feed intake. The provision of nest boxes in caged or non-caged systems before laying has proven to have a high value for laying hens in terms of welfare (Cooper & Appleby, 2003). Nesting behaviour in chickens occurs prior to oviposition, during which the bird seeks an appropriate location to lay the egg. This behaviour is an example of primary behaviour that is motivated by internal factors and is not influenced by the external environment (Costa et al., 2012) and it is characterised by excessive mobility and exploratory activity, and a unique vocalization known as the gackel-call (Duncan, 1998).

A study on preferences and behaviours has shown that hens have a strong desire to access enclosed nesting areas (Weeks & Nicol, 2006). When a hen does not have access to a suitable nest, her nesting behaviour becomes erratic (Hunniford & Widowski, 2018); and prior to laying, hens are more actively engaged in a locomotory behaviour for a longer period (Engel et al., 2019); a behaviour known as stereotypical pacing, which is often taken to be an indication of frustration (Appleby, 2004).

The relationship between the absence of a nesting box and stress physiology still needs further attention, even though no differences on short-term or long-term glucocorticoids levels in hens that had or did not have access to a nest box have been noted (Cronin et al., 2008b). Albeit, Cronin et al. (2012a) reported that hens that sat for longer and less often before laying eggs had lower levels of corticosterone in their blood, regardless of whether they had a nest box or not. Studies have also demonstrated that egg retention in the eggshell gland happens when nesting space has been restricted (Hughes et al., 1986).

1.3.7.2 Dust bathing

Each animal's behaviour has a natural range that is affected by a variety of internal and external factors; for instance, light exposure, substrate, the presence of parasites, heat, and pleasure (Olsson and Keeling, 2005). Dust bathing in chickens involves sprinkling the litter onto and in between the fluffed feathers and then enclosing the litter by flattening the feathers (Van Liere, 1992). The main reasons why hens dust bathe is to remove fat and ectoparasites from the feathers, thereby improving the structure and arrangement of feathers (Orság et al., 2011).

It is known that hens will dust bathe at the same time while following a sequence that is relatively predictable, and it assumed that this synchronisation is caused by social facilitation (Van Liere, 1992). According to Lundberg and Keeling (2003), an adult hen tends to dust bathe for an average of 27 minutes once every other day as shown in Figure 1.1. Colson et al. (2007) also studied hen behaviour when they were provided with dust bathing materials either in a cage or on a floor system. They found that hens kept in cages dust bathed more often and for longer periods of time as compared to hens kept on a floor system, which suggests that caged hens had more desire to dust bathe. On the other hand, Guesdon and Faure (2008) did not observe any differences between the number of laying hens that were raised in floor pens and cage systems.

In a study to find out which material chickens prefer for dust bathing, Wall et al. (2008) found that Hy-Line White and Hy-Line Brown layers kept in furnished cages preferred to dust bathe in sawdust instead of sand. This is similar to earlier observations by Appleby et al. (2002) that birds prefer to peck, rest, and groom themselves in litter rather than bathe in sand. On the contrary, when it comes to foraging behaviour, it does not appear that laying hens have a distinct preference for either peat, sand, or wood shavings (De Jong et al., 2007).

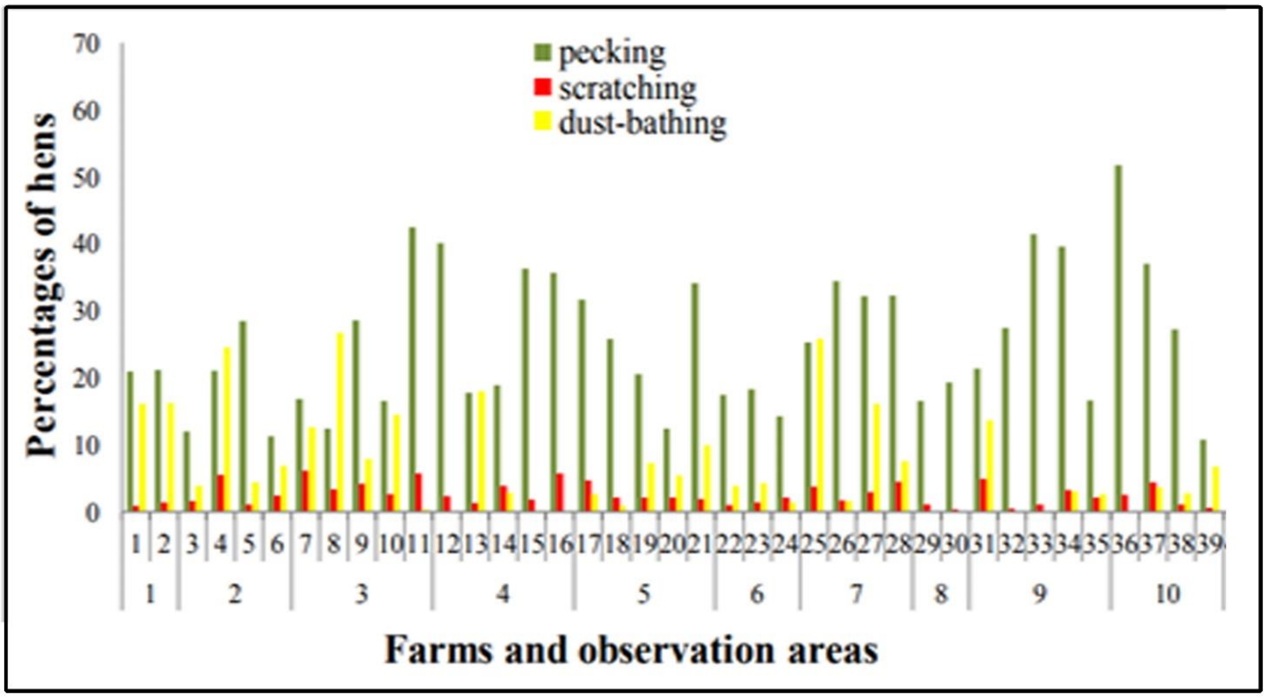

Figure 1.1 Percentages of pecking, scratching, and dust-bathing hens on 22 farms (Lundberg & Keeling, 2003)

1.3.7.3 Perching

It has been reported that some management practices used in poultry production, such as the provision of perches, can contribute to an improvement in the overall health and welfare of poultry (Pettit-Riley & Estevez, 2001). A study by Hester et al. (2013) noted that giving pullets perches increases gross and relative thigh muscle deposition, as well as the total leg muscle deposition. During the developmental stage, it is likely that physical activity, like climbing on and off the perches often when there is light, helps to stimulate muscle growth (Hester et al., 2014). Sandusky and Heath (1988) found that adding barriers or ramps to the house increased the breast and leg muscles in broilers, indicating that house design can encourage exercise and improve overall physical condition. However, Hester et al. (2014) found that increase in keel bone mineralisation that come as a result of having access to perches in rearing or laying houses does not prevent the higher rate of keel bone fractures at the end of laying cycle.

Perches are not only important for the development of bone strength, but birds also use them for the purpose of resting and sleeping. It is possible that the provision of perches in layer houses is also a valuable source of environmental enrichment. Perching is also advantageous to the hens as it provides a prospect for them to escape pecking from other hens (Pettit-Riley & Estevez, 2001). With regards to the preference for perching structures, Liu et al. (2018) found no difference for the perches that were round or hexagonal.

It was reported by Liu et al. (2018) that when the hens began to exhibit consistent perching behaviour, with the laying hens spending 10% of their time on the perches during the day and over 75% of their time on the perches at night. Donaldson and O'Connell (2012) discovered that at night hens are willing to walk around the whole house to access perches. A study by Blokhuis et al. (2005) also found that up to 100 percent of the birds were perching at night.

In laying hens, the stocking density can influence the use of the perching structures (Chen & Bao, 2012). According to Guo et al. (2012), a larger group size can stimulate perching as opposed to a smaller group. Hongchao et al. (2013) demonstrated in a similar study that there were higher incidents of perching among large chicken groups (64 hens) compared to smaller chicken groups (48 hens). In contrast to these findings, a study conducted by Newberry et al. (2001) found that the number of hens perching in larger groups (120 hens) was lower than the number perching in smaller groups (15 hens). In addition, perching is influenced by stimulation and social facilitation (Pettit-Riley & Estevez, 2001), and competition (Newberry et al., 2001).

1.3.7.4 Feather pecking

Feather pecking can occur both during the rearing and laying cycles, and this behaviour can cause serious economic and hen welfare problems as results in damaged feathers, body injuries or wounds, and even death of chickens (Rodenburg et al., 2013). Feather pecking is common in both caged as well as non-cage housing systems for rearing birds (Appleby & Hughes, 1991), and therefore beak trimming is the most common method used in controlling pecking damages. These measures, however, have a negative impact on the well-being of birds as a result of the behavioural modifications that are expected to occur due to persistent pain (Duncan et al., 1989).

Dust bathing materials and the presence of foraging material in a chicken house are some of factors that can affect feather pecking (Rodenburg et al., 2013). Vestergaard et al. (1993) showed that hens raised on unsuitable dust bathing substrates pecked each other more as compared to those provided with suitable materials. In support of this, Blokhuis (1989) discovered that access to foraging materials reduced feather pecking and proposed that feather pecking is a type of redirected foraging ground pecking behaviour. A study by Dixon and Duncan (2010) found that peat material which is a good dust bathing material but not foraging reduced early feather pecking behaviour in layers. De Jong et al. (2013) who later studied the importance of litter use in the early life of hens (rearing house) found that providing chicks with litter increased foraging and decreased feather pecking until they were four weeks old.

Feather pecking also can be linked to a high stocking density more especially in a free-range house with a stocking density of more than 12 birds/m^2 where the risk of feather pecking has shown to increase (Huber-Eicher and Audigé, 1999). Studies on the effects of stocking density, and management on semi-commercial flock sizes in non-cage systems, showed that hens housed at lower stocking densities had a lower incident of feather pecking in the early stages of the egg laying cycle compared to those housed at higher densities of 12 birds/m^2, although hens at the highest densities showed an increase of feather pecking and body wounds towards the end of their production cycle (Bestman & Wagenaar, 2003; Van de Weerd & Elson, 2006)

Two types of feather pecking have been described in the literature namely gentle and severe pecking (Savory, 1995). Gentle feather pecking does not result in any feather damage in the recipient bird, while severe feather pecking results in feather loss on the back, neck, and wings, as well as the vent and tail area of the recipient hen (De Jong et al., 2013). Feather pecking that result in bald spots raises the possibility of tissue pecking and subsequent cannibalism, which could lead to death. Gentle feather pecking, however, is not necessarily a precursor to severe feather pecking (Rodenburg et al., 2013). The prevalence of severe feather pecking at the end of the laying period in commercial flocks in the UK has been found to be 65 percent in free range systems and 89 percent in caged systems (Drake et al., 2010) and 52 percent in Dutch free-range hens (Bestman & Wagenaar, 2003).

1.3.8 Body condition scores

The condition of the birds' integument greatly affects how their health and well-being are interpreted, as is the case when assessing the effectiveness of alternative housing systems for mass production (Tauson et al., 2005). To evaluate the impact of various factors on health and well-being, such as housing, feed, genotype, beak trimming, lighting programmes, different scores have been widely used for the feet and skin of laying hens as the most studied integument (Freire et al., 1999). Scores for plumage condition may be very helpful in explaining why the bird is using more energy than usual. For example, by explaining that feather pecking activities or wear are possible causes of increases in energy requirement due to poor insulation of the body (Tauson et al., 2005).

Over the years, many different approaches to scoring hens have been proposed, for example Fölsch et al. (1980) and Grashorn and Flock (1987) used a planimetry to estimate wound areas of birds. When it comes to subjective scoring, two overarching ideas have been more prevalent. One is the use of a global score for the entire bird's plumage, as done previously by like Hughes and Duncan (1972), and the other is the more common practise of assigning separate scores to different parts of the bird's anatomy, as done by Lidfors et al. (2005). The first idea provides a broad but helpful overview of the hen skin. Damme and Pirchner (1984) used a 4-point scale to find a significant relationship between the number of points and the total feather weight.

However, a total body score alone is inadequate to describe or explain the various factors that may contribute to the plumage's deterioration, such as feather pecking (Kjaer, 2000) and neither this technique be used to reveal how much heat is being lost from various parts of the body (Tauson et al., 2005). For example, if a bird's tail or rump feathers are in poor condition, it may be that feather pecking is the primary cause of plumage deterioration; however, this still does not result in significant heat losses. However, the same damage to the back and breast region may result in severe heat losses and excessive energy intake due to poor insulation (Dixon & Duncan, 2010).

A scoring system to measure body condition scoring should be easy to use, quick to complete, and show a good repeatability, with the ability to show consistent statistical differences when comparing potential treatments (Tauson et al., 2005). Independent scorers can detect the same statistical differences between, same cage designs, as demonstrated by Tauson et al. (1984) were they rated five different body parts on a scale from 1 to 4, and the overall agreement was good. According to Lidfors et al. (2005), a detailed scoring method for the integument of the birds using as many as 11 body parts for the plumage condition yielded good inter-observer agreement with an inter-observer correlation coefficient of r = 0.78.

1.3.9 Use of outdoor area and mud balls development

It is critical in layer production to have an outside range because it encourages natural behaviours, such as foraging and dust bathing. Good range utilisation and greater canopy cover on ranges may help prevent or reduce feather pecking (Bright et al., 2011). According to Shimmura et al. (2008) providing an outdoor run reduces the likelihood of feather pecking, and a higher proportion of hens using the outdoor run during the egg-laying period was linked to a lower risk of feather pecking (Lambton et al., 2010). Aside from providing additional opportunities for exploratory pecking, effective range use also reduces the stocking density within the flock, making it easier for the birds to move around (Gilani et al., 2014).

The number of hens seen outside can inversely be related to the size of the flock and this behaviour can also be affected by other things, like the number of birds in the flock and whether they have access to the outdoor area (Gilani et al., 2014). In a free-range housing system Hegelund et al. (2005) discovered that only 9% of layers in the house went outside, but a previous study by Nicol et al. (2003) found that an average of 14 percent to 22 percent of birds in the house went outside. As a for broilers a large-scale study that was conducted found that the highest percentage of broilers ever spotted outside at any given time was also 14 percent (Whittingham et al., 2003).

During the wet season, areas outside the chicken houses and in front of the pop holes can become muddy. If chickens have access to the outdoor area during such conditions, the increase disease outbreaks and the formation of mud balls on the chickens' toes are inevitable, thereby reducing the hen’s ability to forage and dust bathe (Gilani et al., 2014). In addition, if the chicken house had wet areas caused by water nipple leaks, muddy areas are formed thereby enhancing the development of mud balls on the tips of their toes over time. Not only are these mud balls uncomfortable, but the mud can also harbour microbes and parasitic insects, making their removal an important management practice (Webster, 2001). Dealing with the problem in its earliest stages is by far the best and simplest course of action.

It has been reported that birds observed visiting the outdoor area, were the same birds that appeared on the outdoor every time (Richards et al., 2011). To test this theory, transponder tags were attached to birds, and measurements of how often individual birds visited the pop-holes revealed that the range was used by 48 to 90 percent of the tagged hens over a period of 14 days, while 20 percent used it every day (Gebhardt-Henrich & Fröhlich, 2010). According to Richards et al. (2011) however, 80 percent of the flock studied used pop holes and visited the outdoor area, while the remaining 20 percent did not use them at all. It can be noted that while the total number of birds seen on the range may be small, a significant portion of the flock appears to be out and about on a regular basis.

1.3.10 Egg production and quality traits.

The number of eggs a hen lays is the single most important metric used to evaluate its productivity in a layer operation. Several factors can affect egg quality traits including genotype, breeding and housing system, management, nutrition, age, and weight changes in birds (Duman et al., 2016). Furthermore, the hens' housing system is an external factor that affects both hen productivity and egg quality. Hughes and Dun (1984) found that between the 20th and 68th week of their study period, ISA Brown layers produced 251 eggs in a battery-system versus 245 eggs in a free-range system, showing a statistically significant difference in production between the two-housing system. Appleby et al. (2004) also reported that hens kept in cages laid 242 eggs and hens in a free-range housing system laid 224 eggs although there was a greater rate of shell cracks in the eggs laid from hens in the cage system. Klecker et al. (2003) reported that hens kept in conventional cages exhibited the highest egg laying rate at 86%. In comparison, hens kept in enriched cages had a slightly lower rate of 83.2%, while those in free range systems had the lowest rate at 61.7%. The researchers attributed this disparity to the behaviour of hens in free range systems, as they consumed their own eggs. Comparing the egg production of layers housed in conventional and enriched cage systems, Vits et al. (2005) found that enriched cages produced more eggs, but the eggshells were weaker as compared to the conventional cages.

Egg quality traits like shell thickness, breaking strength, shell colour, albumen height, and yolk height are highly valued by consumers and are also essential for layer and breeder flocks to possess characteristics for successful hatching (Lewko & Gornowicz, 2011).

Different nutrients have been shown to affect egg quality in previous studies (Hosseinzadeh et al., 2010) but determining the exact causes and effects can be challenging, and some egg quality traits can only be obtained after considerable time and effort. Conventional cage systems have been shown to improve laying hen performance in several ways, including increased egg production, lower mortality rates, and higher feed consumption and feed conversion ratios (Valkonen et al., 2010). Haugh units, albumen, and yolk indices were all found to be higher in eggs produced in cage systems compared to those produced in other systems (Tumova & Ebeid, 2003).

Various studies have yielded divergent findings when investigating the impact of hen age on eggshell characteristics. Yannakopoulos and Tserveni-Gousi (1987) conducted a study which revealed that hen eggs exhibited a greater thickness in their eggshells. Similarly, Yannakopoulos et al. (1994) discovered that eggshell thickness remained consistent across different age groups. Furthermore, their research indicated that the quality of eggshells exhibited significant variation based on the specific housing system employed, including conventional cages, enriched cages, and free-range systems. In comparison to eggs collected from hens raised on free-range farms, Van Den Brand et al. (2004) found that caged hens had superior shell quality (in terms of strength and thickness), albumen and yolk index. Another factor that affects egg quality in terms of housing system is the rate of cracked eggs shells. Wall & Tauson (2002) found that the lowest percentage in fully furnished cages, followed by conventional cages and then free-range systems. The rate at which eggs with cracked however is not only an issue related to housing system but can also be attributed to the methods of collecting eggs (Ledvinka et al., 2012a).

With regards to stocking density, egg weight, egg mass, and hen-day egg production were all lower for White Leghorn hens housed in the highest stocking density (2,000cm^2/hen) compared to the other three densities (1,000cm^2/hen, 667cm^2/hen, and 500 cm^2/hen), although the hens with the highest stocking density had a higher feed conversion (Saki et al., 2012). Further research using conventional cages and stocking densities of 5 or 7 Hy-Line hens per cage found that stocking density did not affect egg mass during weeks 28–33 of production, but reduced egg mass was seen for weeks 33–38 (Jahanian & Mirfendereski, 2015). Another study compared Hy-Line Brown hens housed in furnished cages to hens housed in conventional cages with the same stocking density (Meng et al., 2014). They discovered that while egg weight was the same for all cage types, eggs from the conventional cages had lower Haugh units and albumen heights. Singh et al. (2009) compared the effects on egg laying and egg quality in conventional cages and floor system using four different hybrids. They discovered that the housing system significantly affected the live weight and mortality of the hens, but had no effect on feed consumption; furthermore, the hens kept on floor system had higher body weight, egg, and yolk weights.

1.4 Video technology as a non-invasive tool for behavioural observation.

Farmers use animal behaviour informally every day to evaluate the health and welfare of the animals in their care (Weary et al., 2009). More primarily, farm assurance inspectors, researchers, and veterinarians keep systematic and quantitative records of how farm animals act. For example, they use numerical scoring systems to keep track of lameness or injuries in cattle (Pandolfi et al., 2017).

For the identification, tracking, and monitoring of animals' behaviour and health, image processing technology can be used in livestock farming and supply chain management (Kashiha et al., 2013; Kashiha et al., 2014). For that purpose, a camera is connected to a computer via a capture card forms part of the image processing system. An external hard drive is used to store the encoded video files that were captured by the camera and there after decoding and analysis of the videos follows (Kashiha et al., 2014). Animal behaviour is either recorded manually through direct video observations or automated means of tracking behavioural features (Wurtz et al., 2019). There are different devices that give information about animal behaviour, and these may include animal-based sensors that are put on the animal (tags or device collars) to sense activity and environment-based sensors such as radio frequency identification (RFID) detectors, microphones, and a wide range of camera technologies (Rahman et al., 2018).

In poultry production, the use of image-based analytical techniques typically centres on identifying and locating chicken positions as well as monitoring various behavioural activities and calculating their distribution pattern (Wurtz et al., 2019). Leroy et al. (2006) recognised five distinct behaviours namely standing, sitting, grooming, scratching, and pecking phenotypes in a study that aimed to locate caged hens by using image pre-processing segmentation. In their study, Lundberg and Keeling. (2003) employed an infrared camera that was affixed to the automatic feeder system and positioned on the upper part of an egg belt. Through the utilisation of an image-based method, the researchers successfully achieved a precise count of 79% of the hens' legs within the cages, as well as accurately detected 95% of the foreign objects present on the egg belt. Refer to Figure 1.2 for a visual representation of this technique. To test hens' preference for ammonia levels, Kashiha et al. (2014) used cameras to view four connected cages and found that their image-based system was successful at a 95% success rate in tracking a single hen in each of the cages.

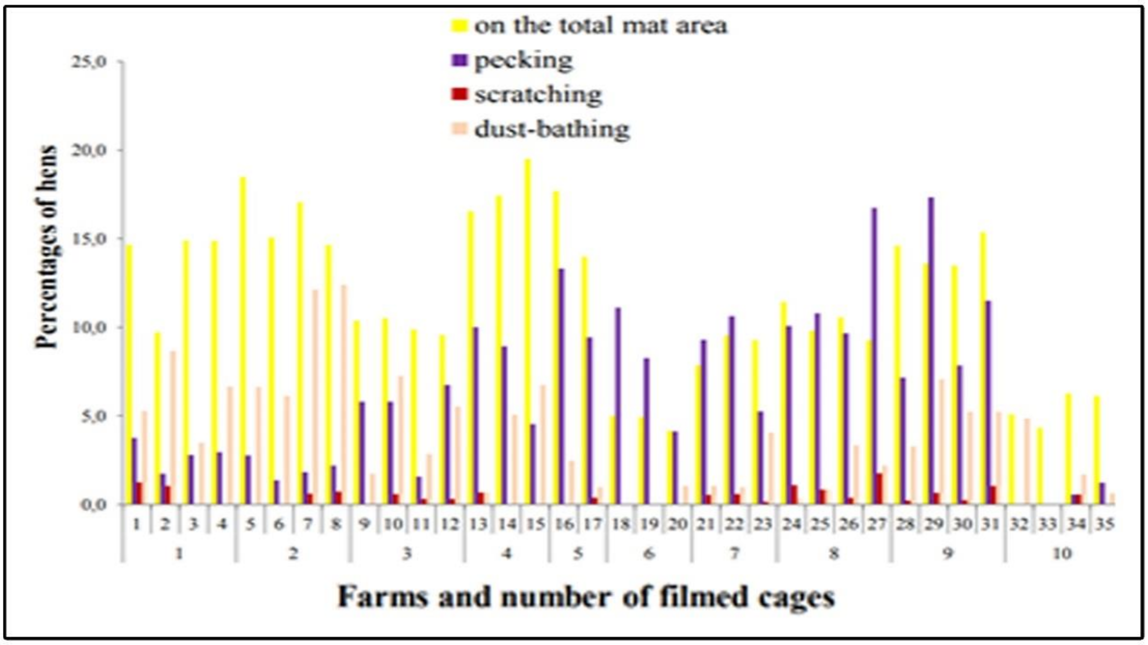

Figure 1.2 Video observation of hens pecking, scratching, and dust bathing (Lundberg & Keeling, 2003)

1.5 Inter and intra observer reliability.

Ethologists need to determine the level of consistency of behavioural observation measurements made by different raters from the same group (Harvey, 2021). Choosing the appropriate method to test the reliability of your score can be challenging, and many papers on reliability testing have been written for human medicine and may not fully apply to studies related to animal behaviour (Gwet, 2008). For example, cineradiographic pharyngeal swallowing assessment showed high intra and interobserver variability, with Kappa coefficients ranging from 0.22 for decreased pharyngeal constriction to 0.84 for Zenker's diverticulum, as observed by Ekberg et al. (1988). Reliability in the study of animal behaviour refers to the frequency with which an event occurs or the degree to which measurement error confounds results (Harvey, 2021).

When assessing inter-rater reliability, scientists compare the likelihood that two or more trained raters will arrive at the same rating for a set of study subjects. Multiple people can test the reliability of a scoring system, or inter reliability, by simultaneously scoring the same group of animals in a video or live observation (Rousson et al., 2002). Keepers of zoo animals, for instance may use a rating scale to rate their understanding with the animal within a brief time frame to evaluate the measurement tool's inter reliability (Wallis et al., 2014). Contrarily, intra-rater reliability looks at whether the same rater consistently assigns the same scores to multiple subjects (Harvey, 2021). This usually involves re-scoring video footage or re-scoring the same animal within a short enough time frame that the animal should not have changed. The concept of intra-rater reliability is often misunderstood for test-retest reliability, which is merely a form of temporal consistency (Rousson et al., 2002). Consistency within the animal over time is assessed by having the same person score the same animal at two or more time points. As test-retest reliability coefficients incorporate rater measurement error and bias with animal, they must be smaller than intra-rater reliability coefficients (Harvey, 2021). Test-retest reliability in the context of personality research is typically assessed using rank order correlations like Spearman's rank to assess intra- and inter-individual consistency and to locate behaviours that may be indicative of stable individual differences (Harvey et al., 2016).

Inter and intra-rater reliability is crucial for the study of animal behaviour. According to Devine (2003), a larger sample size is required to reliably test your hypothesis if the ethogram is not well-defined and there is ambiguity in the behavioural categories. Inter and intra rater reliability are not only useful metrics for benchmarking the training of a pool of raters but can also be useful to report outcomes in a study (Gwet, 2008). For instance, a new rater’s inter-rater reliability can be evaluated multiple times during training up until it reaches a sufficient threshold (Svartberg & Forkman, 2002). Perfect agreement is uncommon and should not be expected even with regular training and stringent criteria for qualifying as a rater (Ruefenacht et al., 2002).

1.6 Conclusion

The housing systems used for laying hens possess the capacity to offer either a satisfactory or an unsatisfactory level of welfare for the hens. Yet again, the housing conditions and stocking density of hens have the potential to influence their behaviour, egg production, and egg quality. In order to assess the statistical variations among different chicken's body parts, a comprehensive scale can be employed. Research has also shown that the potential of video image processing technology to achieve diverse objectives, includes the identification, tracking, and monitoring of chicken's behaviour. Finally, the use of inter- and intra-rater reliability scoring is a valid method to determine the level of consistency among different criteria established by separate raters within a specific group.

Chapter 2: Materials and Methods

2.1 Study site and ethical clearance

The study was conducted at Leslie farm in Mpumalanga with the support and consent of the Rossgro Poultry Eggs (GPS coordinates: 26°23’27” S28º52’07” E). The company was founded in 1964 and is made up of several farms that are involved in fresh egg production, as well as poultry feed manufacturing. The Ethics Committee of the Faculty of Natural and Agricultural Sciences at the University of Pretoria (NAS269/2020) granted approval to conduct the study.

2.2 Materials

2.2.1 Housing system and breed

The study was conducted over a duration of 8 weeks. This farm has two types of housing systems: namely, floor system (FS) and conventional cages (CC) as shown in Figure 2.1. The enriched cages (EC), which consisted of modified CC were developed according to the requirements for the study (Figure 2.2). At the time of the study, the farm kept around 280 000 layers of different breeds (Lohmann Brown, Hy-line Silver, and Amberlink), ranging from 18 to 75 weeks of age.

The Lohmann Brown laying hens were used in this study, at different ages and in different housing systems. The hens in the EC and CC systems, were 27 weeks old. The hens in the FS houses were 47 weeks old, since there were no 27-week-old Lohmann Brown hens in any of the farm's FS housing systems at the time. The study was conducted over a period of six weeks with a two-week adaptation period prior to the data collection. All housing systems were provided with an equal amount of feed, which was available *ad libitum* to all the birds across housing systems.

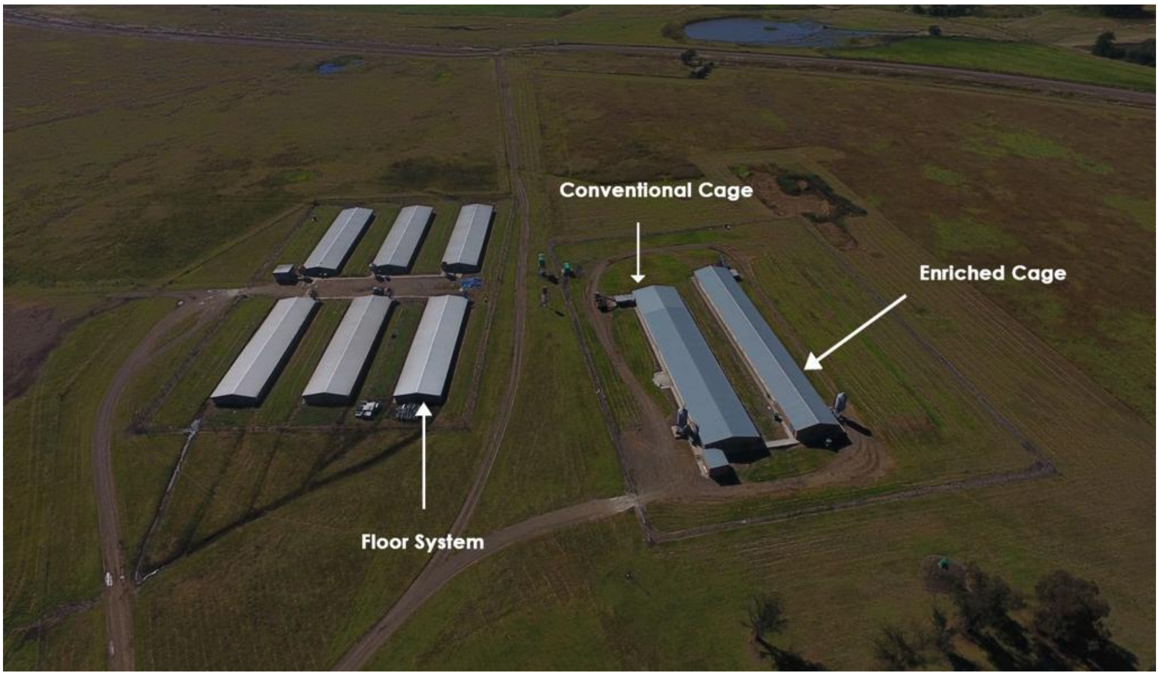

Figure 2.1 Depiction of the entire farm.

2.2.1.1 Floor system

The floor system consisted of a naturally ventilated house with the following dimensions: 57m length x 2.5m height x 14m width. In this house, a section of 12.5m x 2.5 x 4m, length, height and width were partitioned using chicken wire to house 500 birds resulting into a stocking density of 10 birds/m^2 as recommended by 2018 SAPA Code of Practice Guide (SAPA, 2018). This stocking density allowed the birds to have the space allowance of 1000 cm^2 per bird. Seventy-five nesting boxes were allocated in this section allowing for eight hens to access a nest as recommended by 2018 SAPA Code of Practice Guide (SAPA, 2018). A total of 48 hens aged 47 weeks were randomly selected from the 500 birds and tagged on both legs with an adjustable numbered white strap that could be easily identified on video recordings or visual observation.

Using the recommendations of SAPA The house had waterlines with a nipple drinking system and feeders. In accordance with the guidelines provided by SAPA, the house had fifty nipples were provided thus one nipple for every twelve birds and a 12cm feeding space allowance per bird. Perches were also provided, and each perch had five metal bars (150 cm long, 3.1 cm diameter), giving each hen a space allowance of 15 cm, and in total 10 perches were available for the birds in accordance with the guidelines set forth by SAPA. An elevated scaffold was placed against the back wall to aid in carrying out visual observations without interfering with the chicken's behaviour (Figure 2.1). The house also included doors that could be opened to allow access to the outdoor space. In the outside sections, kikuyu grass and wired fencing were used to contain the birds.

Figure 2.2 Scaffold for observing chickens.

2.2.1.2 Conventional cages

The conventional cage system consisted of a two-tier and a four-tier battery house system that used Abbi-fan ventilators for ventilation. The two-tier layer house was fitted with wire cages that was adjusted to the sizes of 45 x 40 x 33.4 cm in length, height, and width to accommodate two birds per cage, and to 45 x 40 x 30 cm in length, height, and width to accommodate three hens per cage as shown in Figure 2.3. The hens were placed at two different stocking densities, with the first stocking density of two birds per cage allowed a cage floor area of 750 cm^2 and the second hens stocking density of three birds per cage allowed a cage floor area of 450 cm^2 per bird.

Figure 2.3 Conventional cage housing system with 6 birds per cage

The four-tier layer house was also fitted with wire cages that were adjusted to 70 x 50 x 51,5 cm in length, height, and width to accommodate eight birds per cage and to 70 x 50 x 64.3 cm in length, height, and width to accommodate six birds per cage. The first stocking consisting of eight birds per cage permitted a space allowance of 450 cm^2 per bird, and the other stocking density consisting of six birds per cage permitted a space allowance of 750 cm^2 per bird. Both housing systems were fitted with a waterline containing nipples and used an automatic gantry feeding system. In total, 192 randomly selected hens aged 27 weeks' old were used as summarised in Table 2.1 below and each hen was fitted with an adjustable numbered white strap that was attached on both of her legs for easy identification.

Table 2.1 Summary of conventional cage systems at different stocking densities

Housing system	Age (Weeks)	Space allowance	Water nipples (Per cage)	Total number of birds
2 Tier (2 birds/cage)	27	750 cm^2 per bird	2	48
2 Tier (3 birds/cage)	27	450 cm^2 per bird	2	48
4 Tier (6 birds/cage)	27	750 cm^2 per bird	4	48
4 Tier (8 birds/cage)	27	450 cm^2 per bird	4	48

2.2.1.3 Enriched cage system

For the purpose of the study, eight wire cages in an environmentally controlled house were modified to a size of 120 x 50 x 64,3 cm in length, height and width. As shown in Figure 2.2, these cages were modified according to the specifications for enriched cages recommended by the SAPA, and they included a nesting area as well as a perch that was 120 cm long and 3.1 cm in diameter, allowing a perching space allowance of 15 cm per hen. The space allowance for the 6 randomly selected birds, excluding the nesting box was 750 cm^2 per bird. The housing systems was fitted with waterline containing two nipples and an automatic gantry feeding system was used.

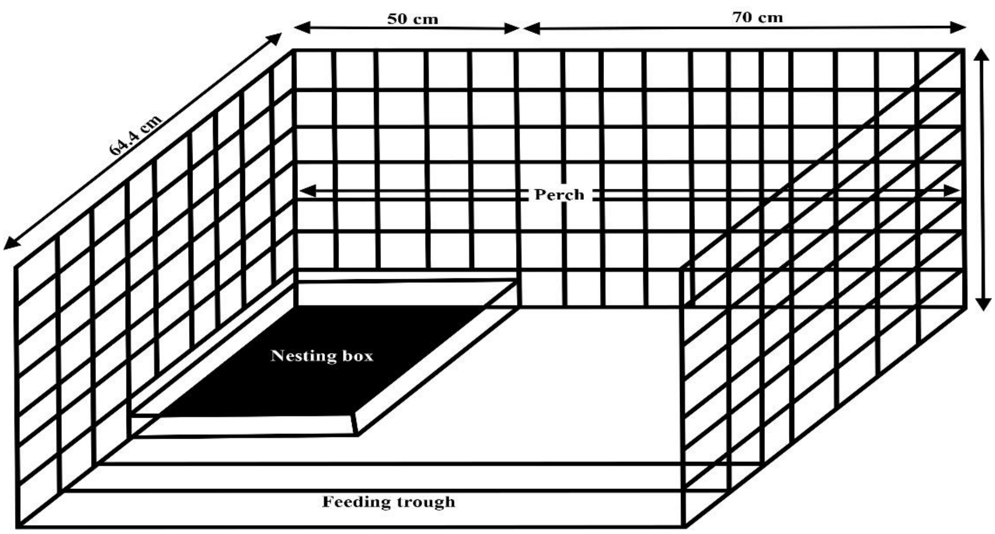

Figure 2.4 Design of a cage modified to mimic an enriched cage.

2.2.2 Camera installation

High-definition digital surveillance cameras (Bushnell Trophy Cam HD, Model Number: 119774) were installed and carefully placed throughout the hen house to capture footage of the chickens' various behaviours at various times of the day. For the floor system, a total of ten cameras were used. Four cameras were put in each corner of the house, and the other six cameras were set up from the middle, one metre apart and directly opposite each other, as shown in Figures 2.3. All the cameras were set at a height of 0.5m above the ground for maximum visibility. Four cameras were used in the enriched cage system and were set up in one row, as shown in Figure 2.4. Video cameras were not present in the conventional cage housing system as behavioural parameters were solely monitored in the enriched cages and floor housing system. All the video recordings collected everyday were saved on an external hard drive.

Figure 2.5: Examples of camera positioning in the FS

Figure 2.6: Example of camera positioning in the EC

2.3 Methods

2.3.1 Hen behaviour

The hens were given a two-week adaption period prior to data collection for them to get used to someone observing them, and during this time, a veterinarian who worked as a consultant for Rossgro and the researcher trained ten selected staff members on how to monitor and document different hens' behaviours. In each of the two housing systems, a trained observer collected data within the specified period without interfering with the hen's behaviour. Video cameras were also used to record the different behaviours at 2 minutes intervals, and the data from the video cameras was used to validate the data collected by trained observers. Inter- and intra-observer reliability tests were performed for the data collected using human observation and video cameras. This was achieved by comparing the data derived from human observation with the data captured in video recordings to determine the level of agreement between the two sources. The 48 tagged hens in the FS were observed for perching, feather pecking, nesting, and dust bathing behaviours. In the enriched cage system, the 48 tagged birds were only observed for perching, nesting and feather pecking behaviours since the enriched cages did not have dust bathing material like the FS.

The major aspects of dust bathing, which comprised of bill raking, head rubbing, scratching with either one or two legs, side-lying, ventral laying, and vertical wing shaking (Kruijt, 1964), were only recorded as an event. When a hen's body touched the litter, it was recorded as the start of a dust bathe. The dust bathe ended when the hen got up and did not do any of the essential features of dust bathing within 10 seconds. Since chickens have a daily circadian cycle and dust bathe most often in the afternoon, data was collected between 11:30 and 15:00 (Mishra et al., 2005). Human observation and video data collection on feather pecking, outdoor visitation, perching, and nesting activities were recorded between 07:00 to 15h00 as described in Table 2.2.

Table 2.2 Description of recorded hens' behaviour.

Behaviour	**Description**	**Observation times**
Dust bathing	Whenever a hen is seen rubbing her head and sides, crouching, and moving her feet and wings to raise dust into her ruffled plumage when on the litter.	11h30 to 15h00
Perching	Any time a hen is spotted on the perch, whether seated or standing. Other actions taken while on the perch were not recorded.	07h00 to 15h00
Pecking	Whenever a hen was pecked on any part of its body by another hen and then fled because of the attack.	07h00 to 15h00
Nesting	Every time a hen is seen using the nesting box. The observation did not include what was going on inside the nest	07h00 to 15h00
Outdoor visitation	Whenever a hen is observed visiting the outdoor area.	07h00 to 15h00

2.3.2 Body weight, size of mud balls and body condition measurements

All tagged hens' body weights were recorded on the same day, at the beginning (Week 1), middle (Week 3), and end of the trial (Week 6). This was done by placing a plastic bucket on a scale and then taring the scale back to zero. Then a hen was put in the bucket, and the weight of the bucket was recorded. The hens' body condition was assessed by evaluating the feathers condition (FC) on the neck, breast, vent, back, wings, and tail, as well as the condition of their wounds on the back and comb. This was done concurrently by the two trained members and the researcher, who used a scale of 1 to 4, with 1 representing the lower possible score and 4 representing the best possible score, as described by Tauson et al. (2005) which is summarised in Table 2.3. Inter and intra repeated tests were done on the subjective scores collected by the researcher and two staff members. This was achieved by comparing the data collected by all the 3 raters to determine the level of agreement between them. The measurement of mud balls on the feet of chickens was done using a ruler. The scoring system for the hen was based on the length of the mud balls, whereby a score of 0 was assigned if a hen did not have any mud ball, a score of 1 was assigned if the mud balls measured between 1 and 2 cm, a score of 2 was given if they measured between 2 and 3 cm, and a score of 3 was given if the mud balls exceeded 3 cm in length.

Table 2.3 Summary of lesion and body condition scoring in the three housing systems

Condition	Description	Score
Feather condition	Signs of damaged plumage at the head, back and base of the tail area	1, 2, 3, 4
Body wounds due to cannibalism	Signs of cut areas around the body	1, 2, 3, 4
Development of mud balls	Any mud ball seen around the hens' feet	0, 1, 2, 3

2.3.3 Egg production and quality

Egg production was recorded daily between the hours of 8:00 am and 10:00 am in all housing systems by counting the total number of eggs laid on the nest, the floor, and the tray as part of the Rossgro program. To assess external egg quality traits, a total of 864 egg specimens were collected during a six-week observation period in each of the different housing systems, which had a 15-day interval between each collection. A total of 238 eggs were collected on day one, fifteen, and thirty, and were sent to Chemunique Laboratory Ltd (South Africa) for an external egg quality assessment on the same day. The analysis involved measuring the egg weight, volume, shell thickness, dry shell weight and breaking strength for the eggs that were stored at room temperature.

Each egg was weighed on a digital scale that was accurate to the nearest 0.01 gm. Digital Vernier callipers were used to measure the egg's length (L) and width (B), and the shape index was determined by multiplying the ratio of the two dimensions by 100 (Anderson et al., 2004). As suggested by Narushin (2005), the formula (3.115-0.0136*L+0.0115*B) L*B was used to calculate the egg's surface area. In accordance with the formula proposed by Arad and Marder (1982), the breaking strength of each egg was determined by multiplying its egg weight by a factor of 0.915. The equation ($V = Kv*LB^2$), where the predicted volume coefficient (Kv = 0.507), was utilised to calculate the egg volume from the measured values of egg length and egg breadth (Hoyt, 1979). To calculate the dried shell weight, the shells were exposed to air for 24 hours. A digital scale then was used to measure the weight of each dry shell. The shell thickness was calculated using the egg total weight divided by its shell weight. The thickness of eggshells was determined using a screw gauze micrometre and an average of four measurements.

2.4 Quantitative Data Management

As shown in Addendum A, a data collection tool was developed to take into account various behaviour and production parameters, which include egg production, body weight, and body condition scores. This tool was then converted into an electronic data entry tool by coding and programming it is using CSPro v7.5. Logic, skip patterns, and consistency checks were utilised during data to prevent entry problems, and data collection was then carried out on android operating systems (AOS) smartphones. Changes on the applications were uploaded to the File Transfer Protocal (FTP) server where the data collected could be downloaded or changes made to the updated forms. Once data was collected, it was uploaded to the FTP server the data could quickly be checked before exporting it to Microsoft Excel for further analysis. IBM SPSS Statistics Ver 27 was used to analyse the data.

2.5 Statistical Analysis

The descriptive statistical means, standard deviations, and frequency and percentage counts were calculated to describe the data. The Shapiro-Wilk test (McHugh, 2012) was performed to test for normal distribution, the data was found to be not normally distributed as a result the non-parametric test (Independent-Samples Median Test) was performed to determine if there were any significant differences in egg production, quality, and hen weight between the housing systems. The Spearman correlation was performed to evaluate if there is a correlation between behavioural and production parameters (McHugh, 2012). The Fleiss Multirater Kappa was performed to determine the level of agreement between the raters on body condition scoring and the data collected using human and video-based observation (Fleiss, 1971). Finally, cross-tabulations were done to determine the change of body conditions on different levels.

Chapter 3: Results

3.1 Descriptive statistics of behavioural parameters

The study used human and video-based observations to examine the behaviour of hens in the floor system and enriched cage system. For the floor system, observations were made on the 48 hens during dust bathing, perching, feather pecking, outdoor visits, and nesting behaviours, whereas for the enriched cages, observations were made on the 48 hens' feather pecking nesting and perching behaviours. Table 3.1 shows the mean, standard deviation, and average percentage of hens that performed different behaviours observed over the six weeks study period. In the floor system, the average number of hens seen dust bathing was 39., and the average dust bathing duration was 22.63± 2.13 minutes. The least prevalent behaviour observed was feather pecking, with an average percentage of 35,4 hens being pecked.

Table 3.1 Descriptive statistics for behaviour parameters on floor system and enriched cage during the 6 weeks

Behaviour	Housing System	Mean ± SD	Average Percentage of Hens
Dust bathing	Floor System	39.79 ± 4.83	79.2
Perching	Floor System	27.94 ± 7.64	55.1
Feather pecking	Floor System	29.39 ± 4.95	58.3
Visiting outdoor area	Floor System	45.43 ± 1.17	91.7
Nesting behaviour	Floor System	37.25 ± 7.43	75
Perching	Enriched cages	47.69 ± 9.72	95.3
Feather Pecking	Enriched cages	17.23 ± 0.11	35.4
Nesting behaviour	Enriched cages	46.29 ± 0.11	93.75

Table 3.2 shows the total number and percentage of birds in the FS that developed mud balls on their toes because of walking on wet surfaces either inside the house or when visiting the outdoor area. After 6 weeks, 41.67 percent of the hens in the floor system developed large mud balls on their toes that were longer than 3 cm in length.

Table 3.2: Mud ball size quantification after 6 weeks in the FS

Score	Number of birds	Percentage of birds
0	13	27.08
1	6	12.50
2	9	18.75
3	20	41.67

Note: 0 = no ball, 1 = 1 cm to 2 cm, 2 = 2 cm to 3 cm, 3 = more than 3 cm

3.2 Relationship between hens' behaviour and production parameters

Spearman's Rank Correlation (Spearman's rho) was employed to determine whether the behaviors and production parameters of the associated hens were positively or negatively correlated. Table 3.3 presents the correlation observed between various production parameters of different behaviours in the enriched cage system, along with the corresponding significance levels. Additionally, the table provides information on the number of hens showing the mentioned correlation. Feather pecking behaviour and body weight was the only statistically significant correlated pair (r = 0.442) with a p value of 0.002 by all the 48 hens.

Table 3. 3: Relationship between different welfare and production parameters in enriched cage

		Perching	Feather Pecking	Nesting	Body weight
Perching	C. Coefficient	--			
	Sig. (2-tailed)				
	N	48			
Feather Pecking	C. Coefficient	0.194			
	Sig. (2-tailed)	0.238			
	N	17	--		
Nesting	C. Coefficient	-0.174	-0.474		
	Sig. (2-tailed)	0.238	0.238		
	N	48	48	--	--
Body weight	C. Coefficient	-0.128	**-0.442****		
	Sig. (2-tailed)	0.387	**0.002**		
	N	48	**48**	48	48

Table 3.4 shows the Spearman's Rank Correlation Coefficient pairs for the floor system that were either positively or negatively correlated. The significant pairs ($P < 0.05$) that showed a positive correlation were body weight vs size of the mud balls, body weight vs nesting behaviour, size of the mud balls vs feather pecking and feather pecking vs perching behaviour. The negatively correlated behavioural and production parameters pairs with P value less than 0.05 were body weight vs perching and feather pecking, nesting behaviour vs perching and feather pecking, size of the mud balls vs dust bathing and perching and outdoor visitation vs feather pecking.

Table 3.4: Relationship between different behaviour and production parameters in floor system

		Dust bathing	Perching	Feather Pecking	Outdoor Area Visitation	Size of Mud Balls	Nesting behaviour	Body weight
Dust bathing	C. Coefficient	--						
	Sig. (2-tailed)							
	N	38						
Perching	C. Coefficient	0.220	--					
	Sig. (2-tailed)	0.243						
	N	30	36					
Feather Pecking	C. Coefficient	-0.019	**0.722****	--				
	Sig. (2-tailed)	0.939	0.005					
	N	18	19	28				
Outdoor Area Visitation	C. Coefficient	-0.256	-0.328	**-0.074***	--			
	Sig. (2-tailed)	0.126	0.067	0.032				
	N	37	32	24	44			
Size of Mud Balls	C. Coefficient	**-0.589****	**-0.542****	**0.427***	0.236	--		
	Sig. (2-tailed)	0.001	0.001	0.026	0.127			
	N	38	35	27	43	47		
Nesting behaviour	C. Coefficient	0.178	**-0.608****	**-0.570****	0.273	-0.181	--	
	Sig. (2-tailed)	0.285	0.012	0.002	0.073	0.223		
	N	38	36	28	44	47	48	
Body weight	C. Coefficient	-0.113	**-0.381***	**-0.268****	-0.083	**0.409****	**0.465****	--
	Sig. (2-tailed)	0.501	0.022	0.007	0.578	0.006	0.001	
	N	38	36	28	47	44	48	48

3.3 Descriptive statistics for body weight

The average body weights of the hens across all the six housing systems are shown in Table 3.5. At the beginning of the trial, the 48 hens in the floor system weighed an average of 2.10 kg, which was more than the average of the 48 hens in the other housing system. By the end of the trial, the average weight of all hens in the different housing systems had increased except for the floor system, which saw a decrease to 1.90 kg from its initial weight.

Table 3.5 Initial and final average body weights of hens housed in different systems.

Housing System	Mean ± SD (Initial Weights)	Mean ± SD (Final Weight)
2-tier (3 birds/cage)	1.85 ± 0.15	1.88 ± 0.15
2-tier (2 birds/cage)	1.87 ± 0.16	1.89 ± 0.23
4-tier (8 birds/cage)	1.84 ± 0.27	1.86 ± 0.21
4-tier (6 birds/cage)	1.84 ± 0.16	1.86 ± 0.15
*Floor system	2.10 ± 0.27	1.90 ± 0.31
Enriched cage	1.83 ± 0.17	1.84 ± 0.13

***Note**: There is a difference in age between the floor and cage systems.

3.4 Comparison of stocking density and body weight

The study also used a pairwise comparison test to determine if there were statistically significant differences between the average body weights and housing stocking densities of hens in conventional and enriched cages. This pairwise comparison which did not include the 47-week-old hens from the FS, found that the hens from EC and 2-tier (2 birds/cage) were heavier than the birds in the other systems. Figure 3.2 shows the five housing systems that had statistical differences with a $P < 0.05$ and Table 5.5 in the list of Addendum C shows the statistical differences in more detail. The pairs are 2-tier (2 birds/cage) and 4-tier (8 birds/cage), and 2-tier (2 birds/cage) and 4-tier (6 birds/cage),

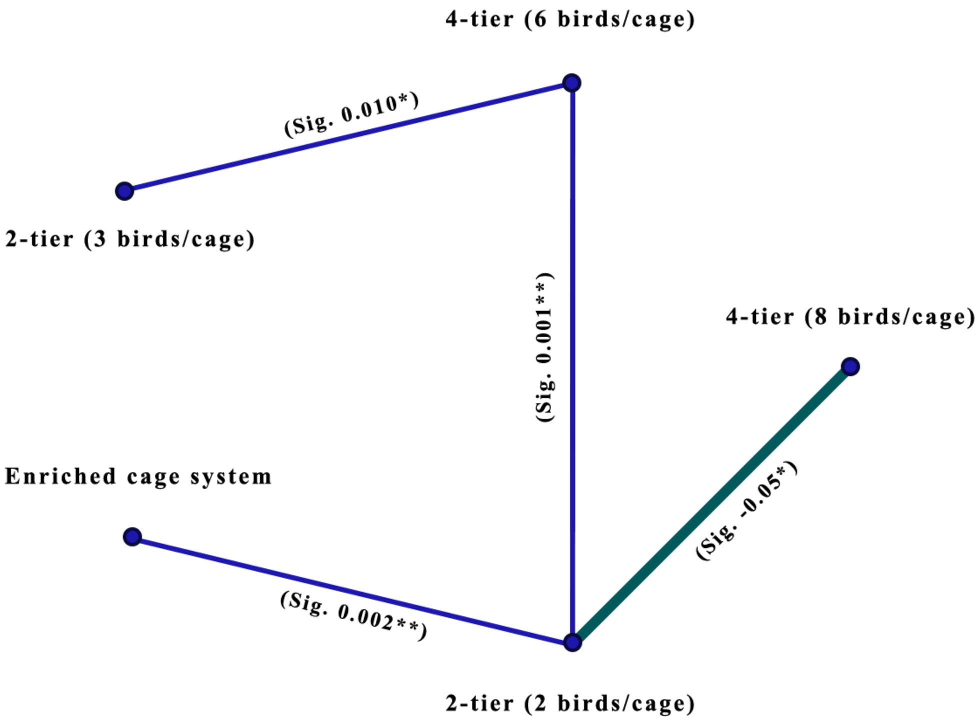

Figure 3.1 Pairwise body weight comparison of housing systems**.** Each node shows the sample average rank.

The space allowance for the housing systems was 750 cm^2 per bird in the 2-tier (2 birds per cage), 4-tier (6 birds per cage), and enriched cages. Space allowance of 450 cm^2 per bird was used in the 2-tier (3 birds per cage) and 4-tier (8 birds per cage) housing system.

3.5 Descriptive statistics of body condition scores

Table 3.6 below shows the change in percentage in body condition in the FS. Three observers scored the condition of 288 birds across all housing systems at the start (week 1), middle (week 3), and end (week 6) of the study period. This included the scoring of the hens' condition of the neck, breast, cloaca, back, wings, tail, and extent of the wounds on the back and comb and. In week 1, more than 90% of the hens in the FS had an average good score for the overall condition of their different body parts, except for their tails condition, where only 77.78% of the birds had good scores.

Table 3.6 Change in percentage of body condition of floor system hens during the 6 weeks.

Parameter (Condition)	Initial (Wk. 1), %			Intermediate (Wk. 3), %			Final (Wk. 6), %		
	Poor	Average	Good	Poor	Average	Good	Poor	Average	Good
Condition of neck	0	9.52	90.48	3.70	20.63	75.66	6.88	19.05	74.07
Condition of breast	0	3.17	96.83	0.53	4.76	94.71	0.53	6.88	92.59
Condition of cloaca	0	0	100.00	0.53	5.82	93.65	1.59	3.70	94.71
Condition of back	0	1.59	98.41	2.65	3.70	93.65	1.59	3.70	94.71
Condition of wings	0	1.06	98.94	0	1.59	98.41	1.59	1.06	97.35
Condition of tail	2.65	19.58	77.78	2.12	9.52	88.36	1.06	8.47	93.65
Condition of Rear wounds	0	0	100.00	0	0.53	99.47	1.06	1.59	97.35
Condition of Comb wounds	0	1.59	98.41	0	1.53	98.81	0	0	98.21

Scores Key: 0 to 1 is Bad, between 1 to 2 is Average, and between 2 to 3 is Good.

In terms of the condition of the cloaca, back, wings, and wounds on the comb, there was no substantial difference for the CC and EC, with at least 95% of the hens in each stage rated as good (Addendum C). The condition of the hen's neck in Table 3.7 went through substantially changes shifting from poor to moderate, and ultimately to satisfactory over the course of the six-week period. Substantial changes were noted in the 4-tiers (6 birds/cage), where an average of 2.7 percent of the birds scored poorly in week 6 from 0 percent in week 1.

Table 3.7 Change in percentage of neck condition of conventional and enriched cages during the 6 weeks.

Housing system	Initial (Wk 1), %			Intermediate (Wk 3), %			Final (Wk 6), %		
	Bad	Average	Good	Bad	Average	Good	Bad	Average	Good
4-tier (6 /cage)	0	0	100	2.7	18.9	78.4	2.7	24.3	73.0
4-tier (8 /cage)	0	0	100	0	0	100	0	0	100
2-tier (2 /cage)	0	2.7	97.3	0	16.2	83.8	0	8.1	73.0
2-tier (3 /cage)	0	0	100	2.6	5.1	92.3	0	10.3	89.7
Enriched cage	0	2.6	97.4	0	17.9	82.1	2.6	10.3	87.2

Scores Key: 0 to 1 is Bad, between 1 to 2 is Average, and between 2 to 3 is Good.

In Table 3.8, only birds from the 4-tiers (8 birds/cage) housing system had good breast condition scores whilst the other tiers had a combination of poor and average scores. Most of the birds that scored poorly were from the EC, where an average of 0.7% of the hens had a poor rating in the first week, increasing to 7.7% in the sixth week.

Table 3.8 Change in percentage of breast condition of conventional and enriched cages over 6 weeks.

Housing	Initial (Wk. 1), %			Intermediate (Wk. 3), %			Final (Wk. 6), %		
system	Bad	Average	Good	Bad	Average	Good	Bad	Average	Good
4-tier (6 /cage)	2.7	2.7	94.6	0	0	100	0	0	100
4-tier (8 /cage)	0	0	100	0	0	100	0	0	100
2-tier (2 /cage)	2.7	5.4	91.9	0	0	100	0	2.7	97.3
2-tier (3 /cage)	0	20.5	79.5	0	10.3	89.7	0	7.6	92.3
Enriched cage	0.7	17.8	70.5	5.1	12.8	82.1	7.7	0	92.3

Scores Key: 0 to 1 is Bad, between 1 to 2 is Average, and between 2 to 3 is Good.

3.6 Intra and inter repeatability scoring of body condition and behaviour parameters data.

The Kappa score was used to determine the level of agreement in the data collected by the three observers on the hens' body conditions. As shown in Table 3.9 below, the three observers had an initial level of agreement that ranged from 0.3 to 0.7, indicating a fair degree of agreement. Higher levels of agreement above 0.6 are seen in the later stages, especially regarding the condition of the neck feathers.

Table 3.9 Kappa values of 3 observers' overall agreements on body condition parameters over 6 weeks

Parameter	Initial (Wk. 1)	Intermediate (Wk. 3)	Final (Wk. 6)
Feather condition of neck score	0.32	0.75	0.68
Feather condition of breast score	0.55	0.74	0.74
Feather condition of vent/cloaca score	0.91	0.80	1
Feather condition of back score	0.52	0.80	0.73
Feather condition of wings score	0.92	1	0.98
Feather condition of tail score	0.51	0.79	0.92
Condition of wounds on the rear	0.96	0.72	0.92
Condition of wounds on the comb	0.77	0.62	0.76

Scores Key: Less than 0 is No Agreement, 0.00 to 0.20 is Slight Agreement, 0.21 to 0.40 is Fair Agreement, 0.41 to 0.6 is Moderate Agreement (the boundary of the acceptable level of agreement), 0.61 to 0.80 is Substantial Agreement, and 0.8 to 1 is almost Perfect Agreement.

The Kappa score was also used to determine the level of agreement between data collected using human observation and the data collected using video cameras for the different behavioural parameters. Table 3.10 shows that there was perfect agreement for all the parameters with the exception for feather pecking which had 0.57 level of agreement.

Table 3.10 also shows the percentage of chickens whose data was missed during human observation but recovered from data recorded through the video. The video recordings data recovered all the 40.8 percent of dust bathing data missed during human observation.

Table 3.10 Kappa values of human and video recordings and missing observation data.

Behavioural parameter	Keppa Score	Missed data by human observer (%)
Dust bathing	1	40.8
Outdoor visit	0.91	11.3
Perching	1	38.3
Feather pecking	0.92	57.9
Nesting behaviour	0.87	33.26

Scores Key: Less than 0 is No Agreement, 0.00 to 0.20 is Slight Agreement, 0.21 to 0.40 is Fair Agreement, 0.41 to 0.6 is Moderate Agreement (the boundary of the acceptable level of agreement), 0.61 to 0.80 is Substantial Agreement, and 0.8 to 1 is almost Perfect Agreement.

3.7 Egg Production Descriptive Statistics

Table 3.11 presents descriptive information on egg production for 48 chickens housed in various housing systems. This covers the mean, total number of chickens and eggs laid, and total percentage of hens that laid eggs during the 6 weeks study period. The floor system had the fewest eggs (810) with a total production percentage of 56.25, while the enriched cage system had the most eggs (1408) with a production percentage of 97.77.

Table 3.11 Descriptive statistics on egg production after 6 weeks

System	Number of birds	Mean ± SD	% of laying hens	Total eggs (48 birds)
2 tier (3/cage)	48	42.25 ± 0.69	87.70	1263
2 tier (2/cage)	48	41.70 ± 0.55	85.97	1238
4 tier (8/cage)	48	46.38 ± 1.74	95.97	1382
4 tier (6/cage)	48	45.13 ± 1.27	94.09	1355
Enriched system	48	47.17 ± 1.01	97.77	1408
*Floor system	48	27.13 ± 0.26	56.25	810

***Note**: There is a difference in age between the floor and cage systems.

Table 3.12 displays the total percentage of hens that laid on the floor or in nesting boxes in the enriched cage and floor system houses, as well as the total number of eggs found on surfaces. At least 37.51 percent of the hens in the floor system laid 304 eggs on the floor over the course of six weeks.

Table 3.12 Descriptive statistics on eggs collected from nesting boxes or floor over 6 weeks.

Preferred egg location	System	Total number of eggs	% of laying hens
Eggs collected on the nest	Floor system	506	62.51
Eggs collected on the floor	Floor system	304	37.49
Eggs collected on the nest	Enriched cage	1349	95.83
Eggs collected on the egg belt	Enriched cage	59	4.16

3.7.1 Comparison of egg production and stocking density

The average number of eggs laid and housing stocking densities of hens in both CC and EC were compared using the pairwise comparison and found that there were no statistically significant differences between the houses with a p value greater than 0.05 (Addendum C). Since all the hens in the other housing systems were only 27 weeks old at the start of the trial, the pairwise comparison excluded hens from the floor system that were 47 weeks old at the time.

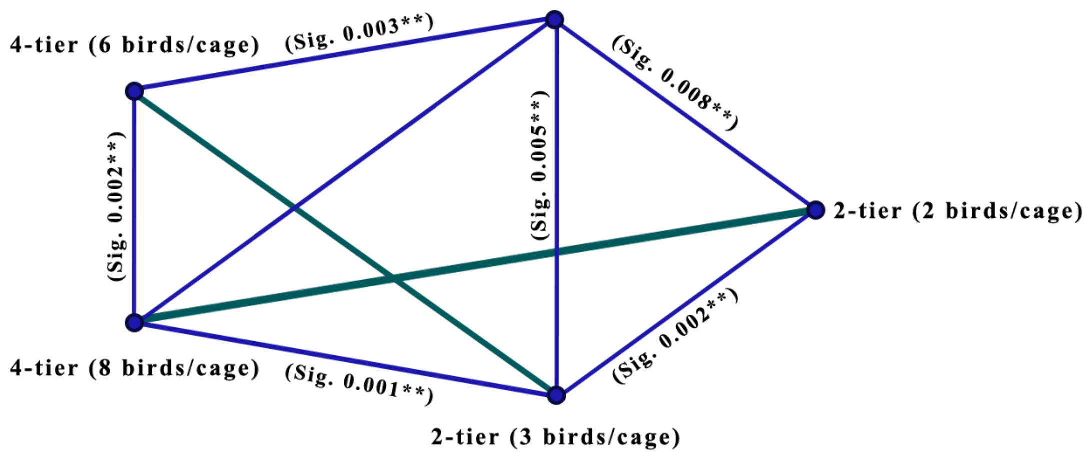

Figure 3.2 Pairwise comparison of egg production in EC and CC. Each node shows the sample average rank.

These were the housing systems' space allocations: 2-tier (2 birds per cage), 4-tier (6 birds per cage), and enriched cages had space allowance of 750cm^2 per bird whilst for the 2-tier (3 birds per cage) and 4-tier (8 birds per cage) had 450cm^2 per bird. The 2-tier (2 birds/cage) and 4-tier (8 birds/cage) had a p value of 0.003 and the 2-tier (3 birds/cage) and 4-tier (6 birds/cage) pairs had a p value of 0.015 as depicted in Figure 3.3, and Addendum C provides a more in-depth of significance levels.

3.8 External egg qualities

Table 3.13 is a summary of the external egg characteristics (egg weight, volume, breaking strength, shell thickness, and dry shell weight) of the observed housing systems, along with their mean, minimum, and maximum values. The average egg weights for the floor system were 60.64 g and had a volume of 55.11 ml.

Table 3.13 Descriptive statistics of external egg quality traits

Parameter	Housing System	Mean±SD	Minimum	Maximum
Egg weight (g)	Floor system	60.64 ± 6.98	22.54	72.60
	4-tier (6 birds/cage)	55.11 ± 4.28	45.30	63.80
	4-tier (8 birds/cage)	54.07 ± 3.37	47.30	64.90
	2-tier (2 birds/cage)	54.52 ± 4.42	47.80	68.60
	2-tier (3 birds/cage)	55.12 ± 4.02	46.60	65.70
	Enriched cage	53.21 ± 3.07	46.50	58.70
Egg volume (cm^3)	Floor system	63.19 ± 4.27	55	75
	4-tier (6 birds/cage)	56.98 ± 4.50	47	66
	4-tier (8 birds/cage)	55.88 ± 3.55	48	67
	2-tier (2 birds/cage)	56.06 ± 4.49	49	71
	2-tier (3 birds/cage)	56.77 ± 4.32	48	69
	Enriched cage	55.00 ± 3.23	48	61
Breaking strength (g)	Floor system	38.31 ± 7.96	15.39	51.39
	4-tier (6 birds/cage)	48.08 ± 11.28	15.58	64.28
	4-tier (8 birds/cage)	50.30 ± 9.33	16.72	69.04
	2-tier (2 birds/cage)	50.41 ± 8.29	32.48	74.59
	2-tier (3 birds/cage)	54.25 ± 7.30	31.19	66.47
	Enriched cage	47.62 ± 11.65	13.94	75.55
	Floor system	6.17 ± 0.69	3.81	7.43
Dried shell weight (g)	4-tier (6 birds/cage)	5.69 ± 0.61	3.89	7.04
	4-tier (8 birds/cage)	5.67 ± 0.45	4.66	6.96
	2-tier (2 birds/cage)	5.55 ± 0.69	2.67	6.49
	2-tier (3 birds/cage)	5.81 ± 0.62	3.81	6.83
	Enriched cage	5.53 ± 0.56	3.62	6.44
	Floor system	0.61 ± 0.46	48	0.31
Shell thickness (mm)	4-tier (6 birds/cage)	0.60 ± 0.47	48	0.34
	4-tier (8 birds/cage)	0.67 ± 0.47	48	0.33
	2-tier (2 birds/cage)	0.56 ± 0.46	48	0.33
	2-tier (3 birds/cage)	0.58 ± 0.48	48	0.33
	Enriched cage	0.55 ± 0 .46	48	0.31

3.9 Comparative analysis of treatments

The study used the independent sample median test to see if stocking density has an impact on the external egg parameters: egg weight, egg volume, egg breaking strength, eggshell thickness, and dried shell weight. Space allocations were as follows: 2-tier (2 birds per cage), 4-tier (6 birds per cage), and enriched cages had 750cm^2 per bird; 2-tier (3 birds per cage) and 4-tier (8 birds per cage) had 450cm^2 per bird.

3.9.1 Egg weight

The Independent Sample Median test revealed that, there were significant differences (P < 0.05) for the egg weight. The results indicated that the 4-tier (6 birds/cage) system produced the heaviest eggs compared to the other systems, followed by the 2-tier (3 birds/cage) system and the enriched cage system. The following pairs: enriched cage and 4-tier (6 birds/cage) with P = 0.003, and enriched cage and 2-tier (3 birds/cage) with P = 0.002 demonstrated statistically significant differences at the 0.05 level of significance as shown in Figure 3.4 and detailed in Addendum C.

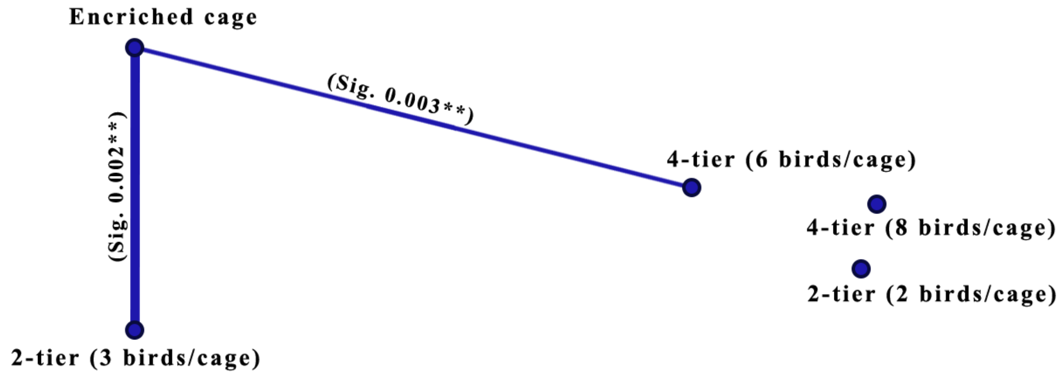

Figure 3.3 Pairwise comparison of the egg weight and stocking density. Each node shows the sample average rank.

3.9.2 Egg Volume

As shown in Figure 3.4 and listed in Addendum C the 2-tier (2 birds/cage) and EC with a p value of 0.005, and the 2-tier (3 birds/cage) and EC with a p value of 0.001 pairs shows the housing systems with significant differences (P < 0.05). The independent media test revealed substantial differences in egg volume across the housing systems with P < 0.05. The 4-tier (6 birds/cage) and 4-tier (8 birds/cage) chickens produced the highest volumes, whereas the enriched cage hens produced the least volume.

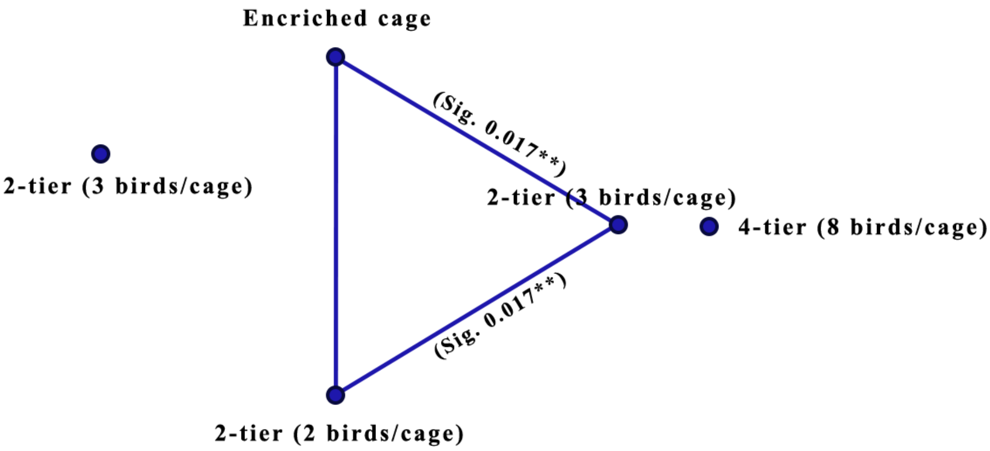

Figure 3.4 Pairwise comparison of the egg volume in housing systems. Each node shows the sample average rank.

3.9.3 Egg breaking strength.

Figure 3.5 and the data in Addendum C shows the pairs ((2-tier (2 birds/cage) and 2-tier (3 birds/cage) P = 0.002 and 2-tier (3 birds/cage) and 4-tier (8 birds/cage)P = 0.012 that there were statistically significant differences (P < 0.05) among the five housing systems. The 2-tier (3 birds/cage) system had the highest, followed by the 2-tier (2 birds/cage) system, while the enriched cage system had the lowest egg breaking strength as found by the independent media test.

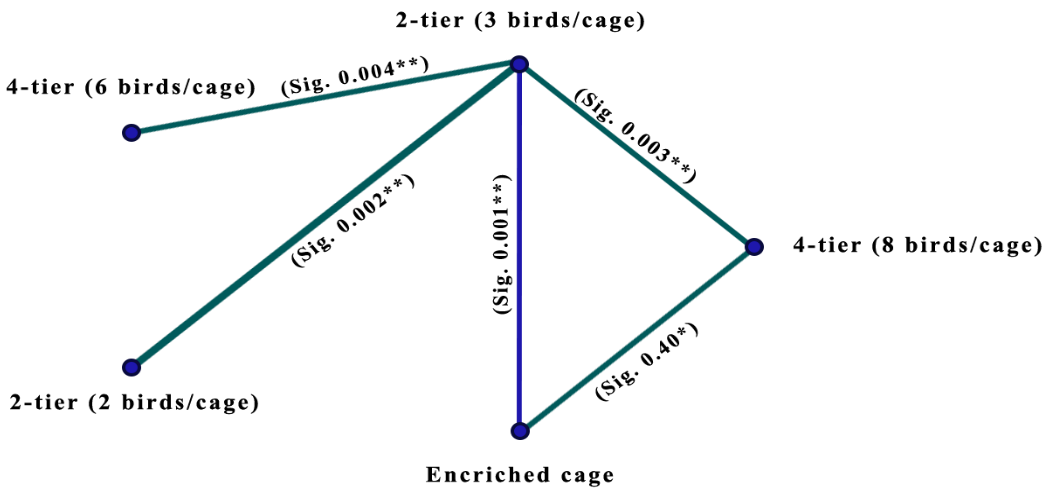

Figure 3.5 Pairwise comparison of the egg breaking strength in different housing system. Each node shows the sample average rank.

3.9.4 Dried shell weight

The Independent Sample Median test showed significant dry shell weight differences between the five housing systems. The eggs from the 2-tier (3 birds/cage) system had the highest dry shell weight, whereas the enriched cage system had the lowest. The pairwise comparisons found statistical differences between the pairs of 2 tier (2 birds/cage) and 2-tier (3 birds/cage), 4-tier (8 birds/cage) and EC, and 4-tier (6 birds/cage) and EC as shown in Figure 3.7. and in Addendum C.

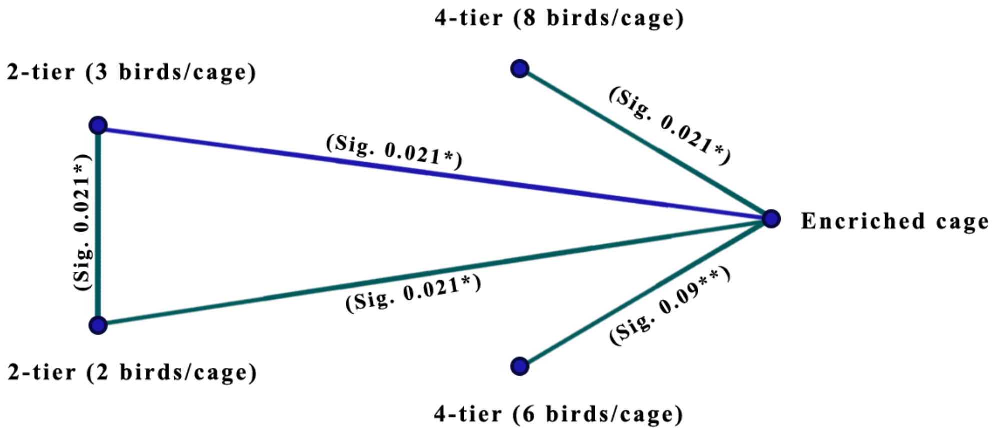

Figure 3.6 Pairwise comparison of the dry shell weight in housing systems. Each node shows the sample average rank.

3.9.5 Egg Shell Thickness

The study revealed no significant differences in eggshell thickness between the six housing systems using an Independent Sample Median test. However, the pairwise comparisons revealed different statistical differences between the pairs of 2-tier (2 birds/cage) P = 0.015 and 4-tier (6 birds/cage), and 2-tier (2 birds/cage) and 4-tier (8 birds/cage) P = 0.008 as shown Figure 3.8 and Addendum C.

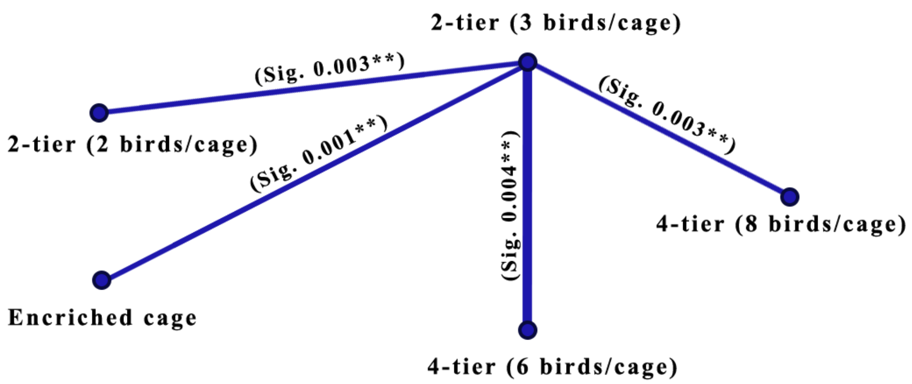

Figure 3.7 Pairwise comparison of the eggshell thickness in housing systems. Each node shows the sample average rank

Chapter 4: Discussion

There is considerable pressure to eliminate the use of conventional cages in commercial layer production systems. However, the capabilities of alternative systems to balance the hen's freedom to perform natural behaviours and reduce the feather pecking disorder while the farm maintains its objectives to optimise hen productivity, biosecurity and economic efficiency have not been fully tested. It is important for poultry farmers to develop good production values, which includes housing hens in an environment that promotes good welfare. Recent spikes in consumer demand for healthier eggs and concerns about animal welfare (Al-Ajeeli et al., 2018) highlight the need of housing systems that simultaneously meet the welfare needs of chickens while keeping production costs low. From a South African perspective, field studies that have gathered reliable data to inform this seemingly inevitable change is very scanty, if any is available. In order to monitor poultry production with minimal negative consequences on the hens' welfare, a study to assess the behaviour and production of laying hens kept in conventional cages, enriched cages and floor systems with different stocking densities was conducted on a commercial farm in South Africa.

4.1 Behaviour parameters

This study involved collecting behavioural data from hens over a duration of six weeks, using video cameras and human observers to record the various behavioural activities exhibited by the chickens. These behaviours include dust bathing, perching, feather pecking, nesting, and use of outdoor area by the hens. On average, dust bathing time for the 48 hens in the FS was 22.63 minutes, which was consistent with the 20 to 27 minutes observed in other studies (Sewerin, 2002; Van Liere et al., 1990; Vestergaard, 1982), but was shorter than the 45 minutes found by Moesta et al. (2008). The duration and frequency of dust bathing among hens are subject to variation based on factors such as their housing conditions and breed, as noted by Van Rooijen (2005).

Previous research on chickens housed on a floor system found that an average of 66.6% of hens dust bathed (Vestergaard, 1982), and this is slightly lower than the average of 79.2% of hens that were found dust bathing in the current study. The practical purposes of dust bathing are to clean the feathers (Lay Jr et al., 2011), eliminate skin parasites, control the lipid content of the feathers, and preserve the plumage (Olsson & Keeling, 2005). However, studies on chickens' motivation to dust bathe are inconclusive, with some showing no evidence of hens' motivation to dust bathe (Lay Jr et al., 2011).

This study found that an average percent of 75 of hens in the floor system and all hens (100%) in the enriched cages utilised the perching structures during the day, which was higher than the 55 percent reported in the Farm Animal Welfare Council (FAWC, 2010). The FS findings also contradict the average perching percentage of 28% during the day and 91% at night for hens in the floor system that was observed by Struelens et al. (2008). However, the EC results are consistent with the findings of Hester (2014), who reported that 85 to 100 percent of hens housed in different cage systems used the perching structures during the day. The inclusion of perching structures within a chicken house has been identified as a critical factor, as it serves to enhance the available space in a floor housing system (Cordiner & Savoury, 2001). Additionally, it promotes the activity of hens and offers a secure location for other chickens to seek refuge from aggressive hens (Yan et al., 2014).

Feather pecking has become a major economic and welfare concern in the poultry industry, having been observed in all kinds of housing systems, such as cages, enriched cages, and free-range systems (Bestman et al., 2009). According to Bessei and Kjaer (2015), feather pecking is often initiated by a small proportion of birds and can spread throughout a flock if not curbed early. This is a learned behaviour with the potential to get worse when chickens are reared in large groups with higher stocking densities (Pötzsch et al., 2001). While Coton et al. (2019) found an average of 32.9% hens in the EC system and 23.8% hens in the FS experiencing feather pecking, this study found an even higher average of feather pecking events of 58.3% in the FS and 35.4% in the EC system.

A low percentage of hens utilising the outdoor area was reported by Hegelund et al. (2005), who studied the impact of flock size on range utilisation. They found that the percentage of hens visiting the outdoor area was only 15% in big flocks (>30,000 birds), and less than 40% in small flocks (1 to 1000 birds). Although a larger percentage of hens using the outdoor area was not expected in this study given the small flock size (48 hens), an average of 91.7% of the FS hens utilised the outdoor area when given access. Shimmura et al. (2008) also discovered that an average of 61.5% of hens reared in a small flock utilising the outdoor area. The provision of outdoor access for chickens has a beneficial association with the expression of their innate behaviours, such as foraging, exercising, and exploring. Nonetheless, additional research has indicated that a majority of free-range hens exhibit a preference for remaining in close proximity to the hen house rather than venturing out into the designated outdoor space (Hegelund et al., 2005; Keeling, 1988). According to Knierim (2006), providing outdoor access to hens yields supplementary advantages, including decreased stocking density in the indoor environment, as it stimulates greater mobility and thereby generates more space among the hens.

The presence of moisture in the form of wet litter or soil due to water seepage from the roof or water lines can give rise to the development of muddy surfaces within a poultry facility. When hens stand on a muddy surface, they may develop a dry clump of mud on their feet. Despite the lack of research on chickens with dry mud ball toes, the removal of such toes can be considered a management practise that enhances bird welfare. However, identifying mud balls is not always easy and some hens may be found with large mud balls at the end of their production cycle when they are being culled. The study revealed that 41.67% of the hens had dried mud balls measuring over 3 cm in length on their toes after the six-week period. According to Widowski et al. (2016), hens utilise their feet to perform various activities such as locomotion, perching, and self-grooming. If the hens are restricted in their movements due to physical impediments on their feet, they may not be able to perform certain behavioural activities (Hartcher & Jones, 2017).

4.2 Correlation of behaviour and production parameters

In the EC systems, the only statistically significant correlation found was a negative association between feather pecking and body weight with a p value of 0.002. Fundamentally, this means that the hens' weight loss was directly proportional to the frequency at which the hens were pecked at. According to Cronin and Glatz (2020), the continuous pecking of feathers by fellow chickens' results in the deterioration of the victim's plumage and prompts the affected birds to seek refuge and protection. The reduced mobility and increased stress levels of chickens as a result of evading other birds may lead to a decrease in their daily consumption of feed and water, potentially resulting in a decline in their overall weight. The observed negative correlation within the EC system could potentially be attributed to the reduction in body weight of the birds that were subject to pecking. According to McAdie et al. (2005), the inclusion of perching structures in a caged housing system resulted in a significant reduction in the frequency of pecking incidents experienced by birds. The present investigation reveals a noteworthy observation that the occurrence of feather pecking behaviour did not exhibit any significant correlation with other behavioural patterns, such as perching.

The study found that there was a correlation between body weight and the behaviours of hens in the FS. Specifically, perching and feather pecking showed a significant negative correlation, while nesting and outdoor area visitation showed a significant positive correlation with body weight. The findings of De Haas et al. (2014) and Yin et al. (2017) indicate that the occurrence of feather pecking among hens kept in floor systems resulted in a significant decrease in their body weight. The aforementioned circumstance can be ascribed to the restricted availability of feed and water for the chickens, who were frequently running to evade other chickens, as per the findings of Coton et al. (2019). Furthermore, Milisits et al. (2021) have reported that chickens experience increased energy expenditure during running, which is crucial for the accumulation of body weight. The significance of the feathers of chickens lies in their ability to prevent heat loss from the body. Feather loss due to pecking can have a detrimental effect on the metabolism of the chicken, which may compel the bird to utilise its energy reserves to maintain warmth, as per the findings of Wallace and Mahan (1975). The present study has identified potential factors that may account for the observed association between chicken body weight and feather pecking.

Hens' usage of perches can be influenced by several management factors, including stocking density, lighting programme, and whether or not pullets are provided with perches throughout the rearing period (Hartcher & Jones, 2017). A study by Dikmen et al. (2016)) discovered that chickens with access to perches weighed more and ate more feed than chickens without access to perches. This however contradicts the current study's findings, which show a negative association between perching and body weight. It is likely that significant inverse relationship between body weight and feather pecking is a result of the birds that were pecked more frequently and took refuge on the perching structures. Further evidence supporting this comes from the significant positive correlation found between feather pecking and perching suggesting that the more the birds were pecked at, the more they sought refuge on perching structures.

A high number of dirty eggs can pose a challenge in free-range housing systems, with the primary contributing factors being the build up of dirt in the nesting boxes (Leyendecker et al., 2001) and the laying of eggs on litter instead of the designated nesting boxes (Sosnówka-Czajka et al., 2010). This situation is further complicated by consumer preferences, as some individuals seek to purchase dirty eggs at a reduced cost, while others may choose to abstain from purchasing them altogether. The study revealed that an increase in body weight among hens resulted in a corresponding increase in the amount of time spent in nesting boxes. This was evidenced by a statistically significant positive correlation between body weight and nesting behaviour. Despite the existence of several studies that have demonstrated a favourable correlation between body weight and egg production (Hester et al., 2013; Siegel, 1962), the association between nesting behaviour and body weight has been relatively neglected. Hens are more likely to instinctively engage in nesting behaviour because it is so important to them (Weeks & Nicol, 2006).

Zimmerman et al. (2000) conducted a study which revealed that hens exhibited greater frustration in response to the removal of a nesting box as compared to being deprived of feed and water. This finding highlights the significance of nesting behaviour in chickens. The observed correlation between nesting behaviour and body weight may be attributed to the fact that nesting behaviour was found to be correlated with egg production, as reported by Weeks and Nicol (2006). Additionally, body weight has shown to have an effect on egg production, as noted by Luchkin et al. (2021). Based on the previously mentioned findings, it can be inferred that an augmentation in weight due to favourable welfare conditions (such as increased access to feed and water, and decreased occurrences of feather pecking) is associated with a corresponding increase in nesting behaviour.

This is the first study to report on the correlation between the size of the mud balls and the chickens' behavioural parameters. During the six-week when the study was in progress, it was noted that some of the water nipples lacked cups and resulted into water dripping on the litter. As a result of this, when the hens which visited the areas which had leaking water nipples to drink water, they would end up stepping on wet mud which stuck and accumulated on the chicken toes. A noteworthy correlation was observed between the sizes of the mud balls and the body weights of the chickens, indicating that an increase in the weight of the chicken was accompanied by a proportional increase in the size of the mud balls.

As per the findings of Fanatico et al. (2009), chickens that have sufficient access to feed and water, but do not engage in frequent exercise or running, are prone to weight gain. The study also found that hens which were not subjected to pecking and had sufficient access to feed and water experienced significant weight gains. The absence or minimal presence of mud on the toes of the chickens with a low body weight is an indication that birds that were pecked at did not have access to enough water by visiting the water nipples. The observed positive correlation between body weight and size of the ball formation suggests that birds with greater body weight likely had sufficient opportunity to drink water, potentially by standing on muddy surfaces.

Research has also shown that hens are motivated to engage in a variety of natural behaviours, such as perching and nesting when there are no constrained living conditions preventing them from doing so (Hartcher & Jones, 2017). This observation provides support for the inverse relationship between dust bathing and perching, as indicated by the research findings. The increase in size of mud balls on the feet of chickens resulted in a decrease in the frequency of their engagement in dust bathing and perching. The observed decrease in the birds' ability to effectively perch and engage in dust bathing may be attributed to the accumulation of larger mud balls on their feet, hindering their ability to maintain balance and perform these activities with efficacy.

Yue and Duncan (2003) suggest that chickens may experience frustration and distress if they are unable to engage in various behaviours, which may manifest in the form of repetitive pacing. In addition, the chickens may also resort to feather pecking as a form of aggression if they are prevented from engaging in their natural behaviour (Lay Jr et al., 2011). The significant positive correlation between mud ball size and feather pecking could be explained by the fact that when the mud balls became larger, the hens were unable to perform the preferred behaviours like nesting and dust bathing, resulting into increased frustration, and because they were frustrated the later engaged into feather pecking behaviour. Similarly, studies have found decreased levels of frustration and feather pecking incidences in housing systems where the hens could express behaviours like nesting, perching, and dust bathing (Widowski et al., 2013).

The prioritisation of nesting behaviour in chickens is attributed to its positive impact on their health and well-being, as noted by Weeks and Nicol (2006) and Widowski et al. (2013). According to Dikmen et al. (2016), the utilisation of nests for egg-laying purposes can be beneficial for farmers as it results in cleaner eggs compared to those laid on the floor or litter. Studies evaluating the significance of nesting behaviour to hens have consistently indicated the importance of nest boxes, as demonstrated by various motivation tests (Widowski et al., 2013) Moreover, a negative correlation between feather pecking and egg production was reported by Lay Jr et al. (2011). Consequently, a reduction in egg production may result in a decreased frequency of hens visiting the nesting boxes.

The present study reveals a negative correlation between feather pecking and nesting behaviour, which is not unexpected. The phenomenon of hens being persistently pecked at has been observed to have a negative impact on their nesting behaviour. Specifically, such hens exhibit a reduced tendency to visit nesting boxes and instead tend to seek shelter on perching structures (Cronin et al., 2008a). This behavioural shift results in a decreased duration of time spent by the hens in the nesting boxes, which in turn affects their egg-laying patterns. The observed negative correlation between nesting and perching behaviours may be attributed to feather pecking, as the chickens that were subject to pecking behaviour exhibited an increased duration of perching activities and a decreased duration of nesting box usage. Hunniford and colleagues (2014) discovered that hens exhibit variability in their selection of a laying site. Specifically, their research indicated that a greater number of eggs were initially deposited on the floor, but subsequently, more eggs were laid in the nesting boxes.

According to Savoury et al. (2006), hens that have access to an outdoor area can engage in foraging activities at their preferred distances, thereby allowing for a greater degree of natural behavioural expression. Research has also shown that when a small fraction of free-range chickens has access to the outdoor area, the house will have many chickens involved in feather pecking incidents (Holt, 2021). In support of this, a study by Green et al. (2000) found increased feather pecking incidents when just under half of the flock utilised the outdoor area. The observed positive correlation between feather pecking and outdoor access in the study can be attributed to the higher percentage (91.7%) of hens that utilised the outdoor area on days when access was provided. The findings are in line with Tanaka et al.'s (2007) research, which demonstrated that chickens provided with outdoor access exhibited a lower frequency of feather pecking occurrences compared to chickens without such access. In contrast, Shimmura et al. (2008) found that the frequency of feather pecking behaviour remained consistent regardless of the presence of an outdoor area.

4.3 Production Parameters

At 47 weeks, the FS hens weighed an average of 2.10 kg, surpassing the suggested average weight range of Lohmanns Brown hens at the same age, which is between 1.80 and 1.90 kgs (Lohmann, 2018). The average body weight decreased to an average of 1.9 kg in the 6^{th} week but remained within the recommended range of 1.84 to 2.01 kgs (Lohmann, 2018) at that age. As for the EC and CC, the average body weight at 27 weeks was between 1.83 to 1.90 kgs, and this weight remained within this range for the subsequent 6 weeks. This is also consistent with the Lohmann Brown management guide (Lohmann, 2018) which shows that the Lohamnn Brown body weight at that age is between 1.76 to 1.94 kgs. Singh et al. (2009) who studied whether caged hens raised at varied stocking densities had similar body weights found a similar body range as that of this study.

The independent media test found that the hens with a low stocking density of 750cm^2 per bird reared in the EC and 2-tier (2 birds/cage) weighed more than the hens with higher stocking density of 450cm^2 per bird, suggesting that low stocking density may contribute to an increase in body weight. Khumput et al. (2019) also found that hens kept at a lower stocking density of 943 cm^2 per bird had a heavier body weight than hens kept at a stocking density of 627.7 cm^2 per bird. This contradicts with what Jalal et al. (2006) found that cage space per hen (342, 413, 516, and 690 cm^2/bird) had no significant effect on body weight changes. Previous research has shown that a high stocking density rate reduces growth rate, feed intake, viability, and feed efficiency (Abudabos et al., 2013; Qaid et al., 2016). The study also found that the effect housing system on body weight was significant with notable pairs of 2-tier (2 birds/cage) and 4-tier (8 birds/cage). The results contradict those of Khumput et al. (2019), who showed that no interactions between housing system and cage stocking density with reference to their body weight.

4.4 Hens body condition scores and stocking density

Feather pecking and cannibalism in laying hens have been identified as significant welfare issues, with substantial economic implications, as highlighted by Rodenburg et al. (2010). The phenomenon of feather loss in chickens can be attributed to various factors, including but not limited to stocking density, nutrition, housing or cage design, litter type, and genetics (Sarica et al., 2008). Furthermore, Sarica et al. (2010) conducted a study which revealed that feather pecking was a major contributor to the substantial feather loss observed in FS. This loss of feathers ultimately resulted in the degradation of the birds' inherent heat shielding layer. According to Erensoy et al. (2021), a significant loss of feathers and consequent elevation in heat loss could result in a feed intake increase of 10 to 30%. The feeding consumption of layers may increase in response to the additional heat required to maintain the bird's warmth after the loss of feathers.

The study found that the initial average score for the condition of the tail feathers in the FS was 77.74%, which improved significantly to a mean score of 93% by the end of the study. However, the average good score of the condition of the neck feathers decreased from 90.48 to 64.07 percent. A similar study found an average good score of 98% for of hen's body condition in FS systems, except for the neck and tail condition, which had less than of 70% as an average good score (Gilani et al., 2013). According to McAdie and Keeling's research in 2002, the primary factor contributing to feather loss on the neck in FS is the feeding equipment and this suggests that the outbreaks of feather loss on the neck may have been exacerbated by this factor.

In the EC and CC, all the plumage of all the hens exhibited a high score of over 95 percent, with the exception of feather loss changes scoring less than 90 percent observed on the neck and breast regions of the chickens. Conversely, Gilani et al. (2013) found no noticeable difference in feather loss for all caged systems as the average score was greater than 90.5%. It is possible feather loss in these areas is a result of the cage design and materials used. As the hens use the neck and breast while they eat and sleep, it rubs with the cages causing significant feather loss in these areas (Yamak & Sarica, 2012).

This study also examined the effects of different cages stock densities (2 hens/cage, 6 hens/cage and EC which had a space of 750 cm^2/bird, and 3 hens/cage, 8 hens/cage which had a space of 450 cm^2/hen) on the body condition of the hens. Although prior studies have indicated that hens raised in enriched cages exhibit a higher feathering score compared to those raised in conventional cages (Tauson et al., 2005), the present study did not find any substantiating evidence for this proposition. This is also in agreement with the findings of Tactacan et al. (2009), it was observed that there was no significant variation in feather condition among Shaver White layer strain hens housed in either conventional or enriched cages.

The existing literature suggests that there is a correlation between high stocking densities and elevated feather loss in hens, which can be attributed to their heightened propensity for aggressive behaviour, feather pecking, and even cannibalism (Moesta et al., 2008). However, a recent investigation conducted by Zepp et al. (2018) has demonstrated that the implementation of enrichment strategies and reduced stocking densities can effectively alleviate feather picking in conventional cages. Although no notable distinctions were observed among the houses, the EC's perfect score of 100% suggests that the utilisation of modified cages equipped with perching structures could potentially enhance the spatial allocation for hens, thereby promoting greater behavioural expression and reduced contact with the cages.

4.5 Inter and intra observer repeatability.

The body condition score of birds was evaluated by three independent observers using a 4-grade scale. The level of agreement between the observers was deemed satisfactory ($r > 0.70$) during the third and sixth week of the study. The initial week's scores for the neck, breast, and tail exhibited a significant decrease below 0.5. The study also revealed a high level of agreement ($r>0.8$) between the data collected through video recording and human observation. A possible reason could be that discerning the occurrence of a specific activity may be comparatively less challenging than conducting a physical assessment of the condition. According to Bateson and Martin (2021), certain correlations may not be accepted by experts if the value of r is near or below 0.7, unless the parameters being measured are of significant importance and pose challenges in terms of measurement. The results of the present study demonstrate similarity to the findings of Milisits et al. (2021), wherein the correlation between the body condition score of hens as assessed by two raters was deemed satisfactory.

The mean scores for different aspects of the hen's body condition were consistently ranked in the same sequence by evaluators. However, one assessor displayed a proclivity for assigning greater points to the condition of the tail and wing plumage during the initial week, which was subsequently rectified in the third week following feedback. The necessity of multiple scorers observing identical parameters is evident due to the possibility of bias. This finding points out the significance of utilising consistent observers to evaluate the plumage condition of hens over the course of the investigation, as their expertise and familiarity with the subject matter will likely increase over time. The unanimous concurrence among the three observers regarding the congruity of the cloacal and wing conditions may imply that the loss of feathers is localised in regions where chickens are regularly subjected to cage exposure or pecking. Upon examination, it was observed that the wing and cloaca region exhibited minimal to no damage, likely due to its relative protection from the adverse conditions.

Despite the high level of agreement between data obtained through human observation and video recordings, the latter proved to be a valuable source of information, as it captured substantial data that was missed by the observers. According to McAdie and Keeling (2002), the sporadic and unpredictable behaviour of hens may lead to the possibility of a human observer failing to capture every activity of the hen. The significance of implementing supplementary welfare monitoring techniques alongside human observers in chicken houses is underscored by the loss of information resulting from missing them during hens behavioural events. The observation that the sole observer within the household failed to record a substantial amount of data on feather pecking also implies that this particular behaviour is a commonly occurring phenomenon among the chickens.

4.6 Egg production and quality

According to the Lohmann management guideline (Lohmann, 2018), the average egg production per hen between 27 to 32 weeks ranges from 92.2% to 95.5%. The hens in the 4-tier system fell within this range, while those in the enriched cage system had 97.77%, and those in the 2-tier system remained at the lower end of this range (85.97 to 87.70%). However, the average egg production in the FS was 56.25% which was very low according to standard at their age which is 90.5 and 91.0% (Lohmann, 2018). This is slightly similar to the study by Englmaierová et al. (2014) which monitored Hy-line hens from the ages of 22 to 32 weeks and found an average egg production of 80% in FS and over 92% in CC and EC respectively.

The issue of dirty eggs has been a significant concern within the poultry industry, with one contributing factor being the tendency of hens to lay their eggs on the litter or soil rather than within the designated nesting boxes. The findings of this study indicate that the utilisation rate of nesting boxes was notably higher among hens in EC, with an average of 95.83%, compared to hens in FS, where only 62.51% of hens utilised the nesting boxes. Several authors (Bovera et al., 2014; Huneau-Salaün et al., 2011) have reported that over 95% of EC hens exhibited nest-laying behaviour. According to Guesdon and Faure's (2008) research, the percentage of hens in enriched cages that laid eggs in the nest ranged from 43% to 68%, and this was contingent upon the stocking densities of the respective housing units. Dikmen et al. (2016) conducted a study to compare the nesting behaviour of EC and FS hens. The results indicated that a higher proportion of eggs (approximately 70%) were laid in nests by EC hens, whereas FS hens laid nearly 94% of their eggs on the litter located on the ground. The study indicates that caged chickens exhibit a preference for secluded nesting areas over wires or the ground, as evidenced by the high percentage of eggs found in nesting boxes of the EC (Cronin & Hemsworth, 2008a).

Various studies have yielded differing results regarding the number of eggs laid by hens housed in various cage or floor systems. Ahammed et al. (2014) and Neijat et al. (2011) have reported insignificant differences, whereas Leyendecker et al. (2001) and Tauson et al. (1999) have found that conventional cage hens tend to lay more eggs than those housed in EC or Floor systems. The present investigation revealed that there were no statistically significant variations between conventional cage (CC) and enriched cage (EC) systems with respect to the quantity of eggs produced under diverse stocking densities (namely, 2 hens/cage, 6 hens/cage and EC with 750 cm^2/bird, and 3 hens/cage, 8 hens/cage with 450 cm^2/hen).

The average egg weight of the FS at 47 weeks was 60.64 g, with a minimum value of 22.54 g and a maximum value of 72.60 g. The remaining 27-week-old chickens in various housing systems had average egg weight within the range of 53.05 to 55.12 g with a minimum weight of 46.50 g and a maximum weight of 65.70 g. According to Lohmann's (2018) guideline on the average egg weight at this age, the standard weight in the FS is 61.01 g, while in both the CC and EC it is 54.01 g. Similar research by Zita et al. (2009) discovered that older hens laid heavier eggs than their younger hens. Overall, the average egg volume in EC and CC was found to be around 55.00 ± 3.23 cm^3, with a minimum of 48 cm^3 and a maximum of 61 cm^3. All the other houses, except for the FS, fell within this range. The FS, which was 47 weeks old at the time, had an average of 63.19 cm^3 of eggs, with a minimum of 55 cm^3 and a maximum of 75 cm^3. Narushin (2005), who reported a mean egg volume of 60.19 cm^3, with a minimum of 52.0 cm^3 and a maximum 70.4 cm^3 for hens that were the age of 40 weeks.

The average breaking strength of an egg in this study was 54.25 g, with the Enriched cages, 4-tier (8 birds/cage), and 2-tier (3 birds/cage) having a higher breaking strength than the 2-tier (2 birds/cage) and 4-tier (6 birds/cage) conditions. On the other hand, Rasali et al. (1993) discovered that layers with higher stocking density had greater egg breaking strength. In terms of the average dry shell weight, which was 5.67 g in this study, Fathi et al. (2007) reported similar average shell weight for hens reared in CC, FS and EC systems. Finally, hens' eggshells were 0.60 mm to mm thick on average. According to Yakubu et al. (2008) the thickness of the eggshells measured in this study were within the range specified for layer chicken (0.64 mm). The shell quality, particularly shell thickness and breaking strength is a crucial bioeconomic feature that egg-laying flock breeders use into their breeding strategies. Eggs with thinner shells are more likely to hatch than eggs with thicker shells (Eeva & Lehikoinen, 1995).

The study findings indicate that eggs with greater weight were produced in 4-tier cages housing 6 birds per cage, with a stocking density of 750cm^2 per bird, as compared to 2-tier cages housing 2 birds per cage. The results align with the studies conducted by Abudabos et al. (2013) and Leyendecker et al. (2001), which demonstrated that hens residing in cages with low stocking densities produced heavier eggs. However, Tůmová and Ebeid (2005) and Pištěková et al. (2006) observed that hens kept on free-range systems produced heavier eggs. Tactacan et al. (2009) conducted a study comparing CC to EC at varying stocking densities and concluded that the cage design did not have any significant impact on egg production, feed intake, or egg weight during the initial day of the hen's life. Studies conducted by Ledvinka et al. (2012b) and Tumova and Ebeid (2003) have indicated that eggs obtained from cage systems exhibit elevated haugh units, albumen indices, and yolk indices. The current investigation revealed that eggs possessing greater breaking strength and dry shell weight were observed in the CC as opposed to the EC. The sole parameter that remained unaffected by both house design and stocking density was the thickness of the shell. Furthermore, several academic investigations have been conducted on the subject of eggshell quality, which have revealed that eggs produced from caged hens exhibit superior quality (Tumova and Ebeid 2005; Lichovnikova and Zeman 2008; Tumova et al. 2009). According to Tumova et al. (2011), eggs laid in cages exhibited reduced eggshell thickness, however, the eggshell strength was comparatively higher.

The current results align with the results stated by Faitarone et al. (2005), which indicated a decline in egg weight, breaking strength, and volume among hens that were housed in lower denser housing conditions. The observed reduction in egg weight among hens kept in higher cage stocking densities was ascribed to a reduction in feed consumption and an elevation in energy expenditure by the researcher. Davami et al. (1987) reported that hens housed in cages with lower density exhibited increased mobility within the cage, which may result in a decrease in stress levels. Food allocation is distributed across multiple physiological processes of the body, including maintenance, growth, reproduction, and health. As per the findings of Onbaşılar and Aksoy's study conducted in 2005, it was observed that a considerable proportion of consumed food is utilised to cope with stressful situations. The present research proposes that the reduction in egg weight observed in populations with elevated densities can be ascribed to this specific circumstance.

Chapter 5: Conclusions

The results of this study provide evidence to the relationship of poultry behaviour and poultry welfare and production parameters. This is important as it may be used to inform different stakeholders on new advances in the management of commercial layers. Certain welfare behavioural concerns may not be obvious to farm managers unless they are closely observed. The behaviours exhibited by hens, such as visiting outdoor areas and nesting boxes, were found to be associated with increased body weight gain.

The reduction of feather pecking behaviour in free-range laying hens can be achieved through the implementation of environmental enrichment strategies such as allowing chickens to access outdoor areas and providing the houses with perching structures. The implementation of feather pecking reduction strategies can be considered a beneficial management practise for promoting the welfare of chickens. In this study, this approach has shown to enhance the expression of natural behaviours such as dustbathing and perching, w contributes to an increase in their body weight. In instances where hens encounter minimal hindrances, such as a reduced presence of mud balls impeding their natural movements, they are more likely to engage in their innate behaviours, including dust bathing and perching.

This study elucidated the impact of stocking density on various production parameters, including body weight, egg production, and body condition, highlighting the necessity of implementing effective welfare measures in poultry facilities. Hens housed in low stocking density systems, such as 6-tier with 6 birds per cage and enriched cages, exhibited greater body weight compared to those in high stocking density systems. Additionally, hens in low stocking density systems produced larger eggs. The study found that stocking density had a significant impact on the body condition, feather loss, and egg quality of the birds. Specifically, the observed effects were attributed to the interactions between the number of birds housed in each cage and the amount of space available to them.

The hens housed in the 2 hens per cage and enriched cages condition exhibited a substantial decrease in feather loss on the breast, wing, vent, tail, and back when compared to the other groups. Therefore, hens that are provided with adequate space to engage in their innate behaviour tend to display reduced instances of feather pecking and an improved feather quality. The findings of the study indicate that the areas of the chickens' bodies that are most susceptible to feather pecking or cage contact exhibit more pronounced feather damage.

It is imperative to have multiple individuals observe the hens' physical state throughout the duration of the study to minimise potential inaccuracies and bias. Consistent communication and feedback to the observers is also crucial. The utilisation of direct observations facilitated the identification of diverse hen behaviours, as it exhibited a high level of acceptability when compared to video recordings. However, the efficacy of direct human observation was limited due to the potential for observer inability to capture all relevant behavioural activities. Additionally, the lack of a mechanism for repeating human observations necessitated the recovery of data from previously recorded video footage. Augmenting the number of observers of chicken behaviours can potentially serve as an effective approach to comprehensively capturing their behavioural patterns. In instances where there is a high population density of individuals within a confined area, there exists a heightened likelihood of interference with the natural behaviours of hens, which may result in a protracted duration of time required to manage the situation. The issue of precision in the observation of hens' behaviours by humans was addressed by the implementation of monitoring technology, such as video cameras, which facilitated the recovery of any absent data. The utilisation of video recordings is advantageous in terms of providing training, assessing the reliability of observers, and reproducing sequences during observation sessions.

5.1 Limitations and recommendations

The planning of this study was short; hence, the hens' ages could not be aligned accordingly. Subsequently, it was difficult to make the necessary production performance comparisons across the different systems. The observations conducted by humans are time consuming, however, necessary in order to draw judgement on human visual acuity in relation to the video recordings. The collected field data can contribute to policy formulation in designing optimal welfare condition in different production systems for commercials layers. This feedback can also help the farmer make informed decisions pertaining to stocking density and flock management in different systems. Moreover, these findings can provide poultry breeders, nutritionists, and producers with a much clearer understanding of the natural behaviours still inherent in the commercial laying hens.

It is recommended that the enhancement of poultry welfare is imperative to achieve optimal productivity in practical, research, educational, and managerial contexts. In poultry management it is important to reduce dump surface in poultry housing by observing good housekeeping practices, using good water containers to prevent spillage and encourage routine checks of poultry houses. Future studies should have a more concise experimental design for ease of management of the difference performance indicators and software's that are affordable and quick to capture and analysis chickens' different behaviours so that the farmers are informed in time to make necessary adjustments. It is further recommended that studies regarding the welfare of chickens should be investigated in terms of finding the best methods for dealing with mud balls and enhancing various hens' behaviours.

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Adendum A: Data Collection Tools as Programmed in CsPro

1 Birds welfare tool

Data collection instance			
QID	Question	Response	*Logic*
DateS	Start date	Y Y Y Y M M D D	*Auto collect*
TimeS	Start time	H H : M M	*Auto collect*
NOI	Name of data collector	1. Timothy 2. Innocent 3. Nthabiseng	*Code for unique data collection instances*
Q1	Housing System	3. Barn cage system 4. Enriched cage	*If 3 then skip to Q2A*
Q2	Cage ID		*Insert code to check cage ID consistency*
Q2A	Is the Chicken ID identifiable?	1. Yes, ID identified 2. No, ID has been guessed 3. No, ID can't be determined at all	*If 3 then skip to Q3*
Q2B	Chicken ID		*Insert code to check chicken ID consistency*
Q3	Did the chicken peck feathers at the time of observation?	1. Yes 2. No	*If 2 then skip to Q4*
Q3A.	Is the time when pecking was done known?	1. Yes 2. No	*If 2 then skip to Q4*
Q3B.	If Yes, what Time did the hens peck the feathers? (indicate in 24hrs format)	H H : M M	
Q4.	Did the hen dust bath at the time of observation?	1. Yes 2. No	*If Q1 <> 3 then skip to Q4D*
Q4A.	Is the time when dust bathing known?	1. Yes 2. No	*If Q4 = 2 then skip to Q5*
Q4B.	If Yes, what time did the hen's body touched the litter and performed dust bathing (indicate in 24hrs format)	H H : M M	
Q4C.	When did the hen stand up and stopped any elements of dust bathing behavior (indicate in 24hrs format)	H H : M M	
Q4D.	Did the hen forage at the time of observation?	1. Yes 2. No	*If Q1 <> 4 then skip to Q5*
Q4E.	Is the time when foraging was done known?	1. Yes 2. No	*If Q4D = 2 then skip to Q5*
Q4F.	If Yes, what time did the hen forage (indicate in 24hrs format)?	H H : M M	*If Q4E = 2 then skip to Q5*
Q5	Did the hen nest at the time of observation?	1. Yes 2. No	*If 2 then skip to Q7.*
Q5A.	Where did the hen nest?	1. Nest (designated place)	

Data collection instance			
QID	Question	Response	*Logic*
		2. Floor	
Q5B.	Is the time when nesting was done known?	1. Yes 2. No	*If 2 then skip to Q7*
Q5C	If Yes, what time did the hen jump into the nest? (indicate in 24hrs format)	H H : M M	
Q7.	Did the chicken perch at the time of observation?	1. Yes 2. No	*If 2 then skip to Q8*
Q7A.	Is the time when pecking was done known?	1. Yes 2. No	*If 2 then skip to Q8*
Q7B.	If Yes, what time when the hen jumped on the Perch? (indicate in 24hrs format)	H H : M M	
Q7C.	When did the hen jump off the Perch? (indicate in 24hrs format)	H H : M M	
Q8.	Did the chicken go outside to the Open Area when the gate opened at the time of observation?	1. Yes 2. No 3. N/A	*If Q1 <> 3 then skip to Q10*
Q10	Comments/ observations		
DateE	Date End	Y Y Y Y M M D D	*Auto collect*
TimeE	Time End	H H : M M	*Auto collect*

2 **Body Condition Score**

Data collection instance			
QID	Question	Response	*Logic*
DateS	Start date	Y Y Y Y M M D D	*Auto collect*
TimeS	Start time	H H : M M	*Auto collect*
NOI	Name of data collector	1. Timothy 2. Innocent 3. Nthabiseng	*Code for unique data collection instances*
Q1	Housing System	1. 2 tier conventional 2. 4 tier conventional 3. Barn cage system 4. Enriched cage	
Q2	Treatment of house system	1. 2 tier conventional - 3 birds 2. 2 tier conventional - 2 birds 3. 4 tier conventional - 8 birds 4. 4 tier conventional - 6 birds	*Insert code for unique valuesets*
Q3	Cage ID	| | |	*Insert code to check cage ID consistency*
Q4	Chicken ID	| | | |	*Insert code to check chicken ID consistency*
Q5.	Feather condition of neck score	1. One	

Data collection instance			
QID	Question	Response	*Logic*
		2. Two 3. Three 4. Four	
Q6	Feather condition of breast score	1. One 2. Two 3. Three 4. Four	
Q7	Feather condition of vent/cloaca score	1. One 2. Two 3. Three 4. Four	
Q8.	Feather condition of back score	1. One 2. Two 3. Three 4. Four	
Q9.	Feather condition of wings score	1. One 2. Two 3. Three 4. Four	
Q10.	Feather condition of tail score	1. One 2. Two 3. Three 4. Four	
Q11	Condition of wounds on the rear	1. One 2. Two 3. Three 4. Four	
Q12.	Condition of wounds on the comb	1. One 2. Two 3. Three 4. Four	
Q13.	Condition of footpad lessions	0. No lesion 1. Mild lesion 2. Severe lesion	
Q14	Comments/ observations		
DateE	Date End	Y Y Y Y M M D D	*Auto collect*
TimeE	Time End	H H : M M	*Auto collect*

3 Body Weight Tool

Data collection instance			
QID	Question	Response	*Logic*
DateS	Start date	Y Y Y Y M M D D	*Auto collect*
TimeS	Start time	H H : M M	*Auto collect*

Data collection instance			[ ] [ ] [ ] [ ]
QID	Question	Response	*Logic*
NOI	Name of data collector	1. Timothy 2. Innocent 3. Nthabiseng	*Code for unique data collection instances*
Q1	Housing System	1. 2 tier conventional 2. 4 tier conventional 3. Barn cage system 4. Enriched cage	
Q2	Treatment of house system	1. 2 tier conventional - 3 birds 2. 2 tier conventional - 2 birds 3. 4 tier conventional - 8 birds 4. 4 tier conventional - 6 birds	*Insert code for unique valuesets*
Q3	Cage ID	[ ] [ ]	*Insert code to check cage ID consistency*
Q4	Chicken ID	[ ] [ ] [ ]	*Insert code to check chicken ID consistency*
Q5.	Chicken Body Weight (kgs)	[ ] [ ] [ ] [ ] : [ ] [ ]	
Q6	Comments/ observations		
DateE	Date End	Y Y Y Y M M D D	*Auto collect*
TimeE	Time End	H H : M M	*Auto collect*

4 Egg Production Tool

Data collection instance			[ ] [ ] [ ] [ ]
QID	Question	Response	*Logic*
DateS	Start date	Y Y Y Y M M D D	*Auto collect*
TimeS	Start time	H H : M M	*Auto collect*
NOI	Name of data collector	1. Timothy 2. Innocent 3. Nthabiseng	*Code for unique data collection instances*
Q1	Housing System	1. 2 tier conventional 2. 4 tier conventional 3. Barn cage system 4. Enriched cage	
Q2	Treatment of house system	1. 2 tier conventional - 3 birds 2. 2 tier conventional - 2 birds 3. 4 tier conventional - 8 birds 4. 4 tier conventional - 6 birds	*Insert code for unique valuesets*
Q3	Cage ID	[ ] [ ]	*Insert code to check cage ID consistency*
Q4A.	Number of eggs harvested from the "nest"	[ ] [ ] [ ]	*If Q1 < 3 then skip to Q4B*
Q4A.	Number of eggs harvested from the "tray (floor)"	[ ] [ ] [ ]	
Q6	Comments/ observations		

Data collection instance													
QID	Question	Response								*Logic*			
DateE	Date End	Y	Y	Y	Y	M	M	D	D	*Auto collect*			
TimeE	Time End	H	H	:	M	M				*Auto collect*			

Adendum B: Hens' body condition score with little or no changes

Table B1 Summary of feather condition of vent assessed in cage systems.

Housing system	Initial (Wk 1)			Intermediate (Wk 3)			Final (Wk 6)		
	Bad	Average	Good	Bad	Average	Good	Bad	Average	Good
4 tier (6/cage)	0	0	100%	0	0	100%	0	0	100%
4 tier (8/cage)	0	0	100%	0	0	100%	0	0	100%
2 tier (2/cage)	0	0	100%	0	0	100%	0	0	100%
2 tier (3/cage)	0	0	100%	0	0	100%	0	0	100%
Enriched cage	0	2.6%	97.4%	0	0	100%	0	0	100%

Table B2 Summary of feather condition of the back assessed in cage systems.

Housing system	Initial (Wk 1)			Intermediate (Wk 3)			Final (Wk 6)		
	Bad	Average	Good	Bad	Average	Good	Bad	Average	Good
4 tier (6/cage)	0	0	100%	0	0	100%	0	0	100%
4 tier (8/cage)	0	0	100%	0	0	100%	0	0	100%
2 tier (2/cage)	0	0	100%	0	0	100%	0	0	100%
2 tier (3/cage)	0	0	100%	0	0	100%	0	0	100%
Enriched cage	0	2.6%	97.4%	0	0	100%	0	0	100%

Table B3 Summary of feather condition on the wings assessed in cage systems.

Housing system	Initial (Wk 1)			Intermediate (Wk 3)			Final (Wk 6)		
	Bad	Average	Good	Bad	Average	Good	Bad	Average	Good
4 tier (6/cage)	0	0	100.0%	2.7%	0	97.3%	0	0	100%
4 tier (8/cage)	0	0	100%	0	0	100%	0	0	100%
2 tier (2/cage)	0	0	100%	0	0	100%	0	0	100%
2 tier (3/cage)	0	0	100%	0	0	100%	0	2.6%	97.4%
Enriched cage	0	0	100%	0	0	100%	0	0	100%

Table B4 Summary of feather condition on the tail assessed in cage systems.

Housing system	Initial (Wk 1)			Intermediate (Wk 3)			Final (Wk 6)		
	Bad	Average	Good	Bad	Average	Good	Bad	Average	Good
4 tier (6/cage)	0	0	100.0%	0	0	100%	0	0	100%
4 tier (8/cage)	0	0	100%	0	0	100%	0	0	100%
2 tier (2/cage)	0	0	100%	0	0	100%	0	0	100%
2 tier (3/cage)	0	0	100%	0	0	100%	0	2.6%	97.4%
Enriched cage	0	0	100%	0	0	100%	0	0	100%

Table B5 Summary of feather condition of body wounds on comb assessed in cage systems.

Housing system	Initial (Wk 1)			Intermediate (Wk 3)			Final (Wk 6)		
	Bad	Average	Good	Bad	Average	Good	Bad	Average	Good
4 tier (6/cage)	0	0	100%	0	0	100%	0	0	100%
4 tier (8/cage)	0	0	100%	0	0	100%	0	0	100%
2 tier (2/cage)	0	0	100%	0	0	100%	0	0	100%
2 tier (3/cage)	0	0	100%	0	0	100%	0	0	100%
Enriched cage	0	0	100%	0	0	100%	0	0	100%

Table B6 Summary of feather condition of body wounds on back assessed in cage systems.

Housing system	Initial (Wk 1)			Intermediate (Wk 3)			Final (Wk 6)		
	Bad	Average	Good	Bad	Average	Good	Bad	Average	Good
4 tier (6/cage)	0	0	100%	0	0	100%	0	0	100%
4 tier (8/cage)	0	0	100%	0	0	100%	0	0	100%
2 tier (2/cage)	0	0	100%	0	0	100%	0	0	100%
2 tier (3/cage)	0	0	100%	0	0	100%	0	2.6%	97.4%
Enriched cage	0	0	100%	0	0	100%	0	0	100%

Adendum C: Detailed pairwise comparisons between different parameters.

Table C1 Pairwise comparisons of body weight against housing system treatments

Housing systems	Test Statistic	Sig.	Adj. Sig.[a]
2 tier (2 birds/cage) to 2 tier (3 birds/cage)	2.685	0.101	1.000
2 tier (2 birds/cage) to 4 tier (8 birds/cage)	3.388	0.066	0.657
2 tier (2 birds/cage) to Enriched cage system	9.412	0.002	0.022
2 tier (2 birds/cage) to 4 tier (6 birds/cage)	11.454	0.001	0.007
2 tier (3 birds/cage) to 4 tier (8 birds/cage)	0.667	0.414	1.000
2 tier (3 birds/cage) to Enriched cage system	2.043	0.153	1.000
2 tier (3 birds/cage) to 4 tier (6 birds/cage)	6.570	0.010	0.104
4 tier (8 birds/cage) to Enriched cage system	2.050	0.152	1.000
4 tier (8 birds/cage) to 4 tier (6 birds/cage)	2.360	0.124	1.000
Enriched cage system to 4 tier (6 birds/cage)	0.094	0.759	1.000

Table C2 Pairwise comparisons of egg production against housing system treatments

Housing systems	Test statistic	Sig.	Adj. Sig.[a]
2 tier (3 birds/cage) to 4 tier (6 birds/cage)	5.968	0.015	0.146
2 tier (3 birds/cage) to 4 tier (8 birds/cage)	13.562	0.001	0.067
2 tier (3 birds//cage) to 2 tier (2 birds/cage)	9.907	0.002	0.016
2 tier (3 birds//cage) to Enriched cage system	6.153	0.005	0.076
4 tier (6 birds/cage) to 4 tier (8 birds/cage)	21.481	0.002	0.17
4 tier (6 birds/cage) to 2 tier (2 birds/cage)	2.199	0.138	1.000
4 tier (6 birds/cage) to Enriched cage system	27.045	0.003	0.000
4 tier (8 birds/cage) to 2 tier (2 birds/cage)	4.536	0.033	0.332
4 tier (8 birds/cage) to Enriched cage system	8.196	0.003	0.066
2 tier (2 birds) to Enriched cage system	9.187	0.008	0.015

Table C3 Pairwise comparison of egg weight against housing system

Housing system	Test Statistic	Sig.	Adj. Sig.[a]
Enriched cage to 4 tier (8birds/cage)	1.007	0.316	1.000
Enriched cage to 2 tier (2birds/cage)	1.845	0.174	1.000
Enriched cage to 2 tier (3birds/cage)	9.789	0.002	0.018
Enriched cage to 4 tier (6birds /cage)	9.090	0.003	0.026
4 tier (8birds/cage) to 4 tier (6birds /cage)	1.389	0.239	1.000
2 tier (2birds/cage) to 4 tier (6birds /cage)	2.348	0.125	1.000
4 tier (8birds/cage) to 2 tier (2birds/cage)	0.003	1.000	1.000
4 tier (8birds/cage) to 2 tier (3birds/cage)	.889	0.346	1.000
2 tier (2birds/cage) to 2 tier (3birds/cage)	1.390	0.238	1.000
2 tier (3birds/cage) to 4 tier (6birds /cage)	.056	0.814	1.000

Table C4 Pairwise comparisons of egg volume against housing systems

Housing system	Test Statistic	Sig.	Adj. Sig.[a]
2 tier (2birds/cage) to 4 tier (6birds/cage)	5.688	0.017	0.171
Enriched cage to 4 tier (6birds/cage)	5.688	0.017	0.171
2 tier (2birds/cage) to 4 tier (8birds/cage)	1.461	0.227	1.000
Enriched cage to 4 tier (8birds/cage)	2.350	0.125	1.000
2 tier (2birds/cage) to Enriched cage	.893	0.345	1.000
2 tier (2birds/cage) to 2 tier (3birds/cage)	3.675	0.055	0.552
Enriched cage to 2 tier (3birds/cage)	3.675	0.055	0.552
4 tier (6birds/cage)- 4 tier (8birds/cage)	1.399	0.237	1.000
4 tier (6birds/cage)- 2 tier (3birds/cage)	.223	0.637	1.000
4 tier (8birds/cage)- 2 tier (3birds/cage)	.506	0.477	1.000

Table C5 Pairwise comparison of egg breaking strength against housing system

Housing system	Test Statistic	Sig.	Adj. Sig.[a]
Enriched cage to 2 tier (2birds/cage)	0.889	0.346	1.000
Enriched cage to 4 tier (8birds/cage)	0.681	0.409	1.000
Enriched cage to 4 tier (6birds/cage)	1.841	0.175	1.000
Enriched cage to 2 tier (3birds/cage)	12.502	0.001	0.004
2 tier (2birds/cage) to 4 tier (8birds/cage)	0.125	0.724	1.000
2 tier (2birds/cage) to 4 tier (6birds/cage)	0.168	0.681	1.000
2 tier (2birds/cage) to 2 tier (3birds/cage)	8.684	0.003	0.032
4 tier (8birds/cage) to 4 tier (6birds/cage)	0.086	0.770	1.000
4 tier (8birds/cage) to 2 tier (3birds/cage)	8.684	0.003	0.032
4 tier (6birds/cage) to 2 tier (3birds/cage)	8.374	0.004	0.038

Table C6 Pairwise comparison of dryshell weight and housing system

Housing system	Test Statistic	Sig.	Adj. Sig.[a]
Enriched cage to 2 tier (2birds/cage)	5.336	0.021	0.209
Enriched cage to 4 tier (8birds/cage)	5.336	0.021	0.209
Enriched cage to 4 tier (6birds/cage)	6.753	0.009	0.094
Enriched cage to 2 tier (3birds/cage)	14.083	0.008	0.002
2 tier (2birds/cage) to 4 tier (8birds/cage)	0.083	0.773	1.000
2 tier (2birds/cage) to 4 tier (6birds/cage)	0.521	0.470	1.000
2 tier (2birds/cage) to 2 tier (3birds/cage)	5.333	0.021	0.209
4 tier (8birds/cage) to 4 tier (6birds/cage)	0.021	0.885	1.000
4 tier (8birds/cage) to 2 tier (3birds/cage)	3.001	0.083	0.832
4 tier (6birds/cage) to 2 tier (3birds/cage)	0.751	0.386	1.000

Table C7 Pairwise comparison of eggshell thickness and housing systems

Housing system	Test Statistic	Sig.	Adj. Sig.[a]
Enriched cage to 2 tier (2birds/cage)	0.889	0.346	1.000
Enriched cage to 4 tier (8birds/cage)	0.681	0.409	1.000
Enriched cage to 4 tier (6birds/cage)	1.841	0.175	1.000
Enriched cage to 2 tier (3birds/cage)	12.502	0.001	0.004
2 tier (2birds/cage) to 4 tier (8birds/cage)	0.125	0.724	1.000
2 tier (2birds/cage) to 4 tier (6birds/cage)	0.168	0.681	1.000
2 tier (2birds/cage) to 2 tier (3birds/cage)	8.684	0.003	0.032
4 tier (8birds/cage) to 4 tier (6birds/cage)	0.086	0.770	1.000
4 tier (8birds/cage) to 2 tier (3birds/cage)	8.684	0.003	0.032
4 tier (6birds/cage)- = 2 tier (3birds/cage)	8.374	0.004	0.038