LOHMANN INFORMATION

How the housing system can affect egg quality

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Isabelle Ruhnke graduated in Veterinary Medicine from the Freie Universität Berlin, Germany, and performed work for her doctoral thesis on glucose transport and gastrointestinal diseases at the Gastrointestinal Laboratory at Texas A&M University, USA. Her PhD on the impact of feed technologies and feed particle size on broiler chickens and laying hens was completed at the Institute of Animal Nutrition, Freie Universität Berlin. After 8 years of applied research on nutrition, health and welfare of chickens became her passion, so Dr. Ruhnke decided to dedicate her research to the nutritional management of free-range laying hens at the University of New England, Australia. Isabelle is now the Head of Poultry Division of the Department of Veterinary Medicine at Freie Universität Berlin, Germany..

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ABSTRACT

The internal and external quality of table eggs is of crucial importance to the egg industry and the consumer, as a variety of markets have different demands. To meet this demand, several housing systems have been established, which allow for different breeds and strains to generate their eggs. This article summarises common challenges seen in various housing systems and shares information that can help to overcome typical pitfalls. Housing system has no impact on egg shape but inconsistent information has been obtained on egg weight, egg shell breaking strength, shell thickness, cracked eggs and dirty eggs. An impact on shell colour could be observed where free-range hens had lighter shell colour compared to barn and caged hens. The housing system may affect food safety and egg quality especially due to challenges associated with nest box use as well as ingestion of dioxin and lead contaminated soil, but does not necessarily impact the Salmonella prevalence as all housing systems have the potential to produce eggs of inferior external and internal quality depending on how they are managed. Furthermore, special emphasis is provided on new insights into the impact of free-range flock sub-populations on laying performance and egg quality.

While egg production differs with range usage, egg quality shows little difference between ranging and non-ranging hens. Awareness of typical pitfalls associated with the different housing systems and their impact of egg quality allows for prevention and preparedness, resulting in the reliable outcome of immaculate and safe eggs with minimal losses and hence improved sustainability of the industry.

INTRODUCTION

It has been estimated that approximately 6.5 billion hens are used worldwide for egg production *(Windhorst et al., 2013)*. Assuming 320 eggs/hen/year with an average weight of 65g/egg, this would result in an annual production of 2.080 trillion eggs and an egg mass of 135.2 million tonnes. The internal and external quality of eggs is of crucial importance to the egg industry and the consumer, as various markets have different demands. To meet this demand, several housing systems have been established, which allow for different breeds and strains to generate their eggs. For example, Asia houses the world's largest percentage of laying hens (61.3%; 2.9 billion), where >80% of these are kept predominantly in conventional cage housing systems. In contrast, the second largest egg producer, the European Union (including the UK), houses approximately 400 million laying hens with only 50.4% of these hens kept in (enriched) cages (Eurostat, 2011; Windhorst 2013). While climatic opportunities, resource availability, retailer marketing strategies and the consumers' perception about hen welfare influence the producers' decision on farming a specific housing system, the consumers' perception about egg quality is also relevant. In a survey among 345 consumers in the UK, more than 50% believed that there is a difference in egg taste depending on the housing system and 35% believed that taste is the main distinguishing feature between cage and free-range eggs *(Parrot, 2004)*.

However, the external and internal egg quality is impacted by multiple factors including hen breed or strain, epigenetics, pullet quality, light intensity, duration and wavelength, hen age, body weight and body condition, the nutritional status of the hen, the current diet, drinking water quality, stress including heat stress, housing and management as well as the disease status of the flock (**Figure 1**; *Aerni et al., 2005; Englmaierova et al., 2014; Lordelo et al., 2016; Roberts, 2004; Roberts, 2008; Singh and Cowieson 2013; Tumova et al., 2003; Van Horne 1996)*.

In addition, various interactions such as genotype and environment should be considered and, while many

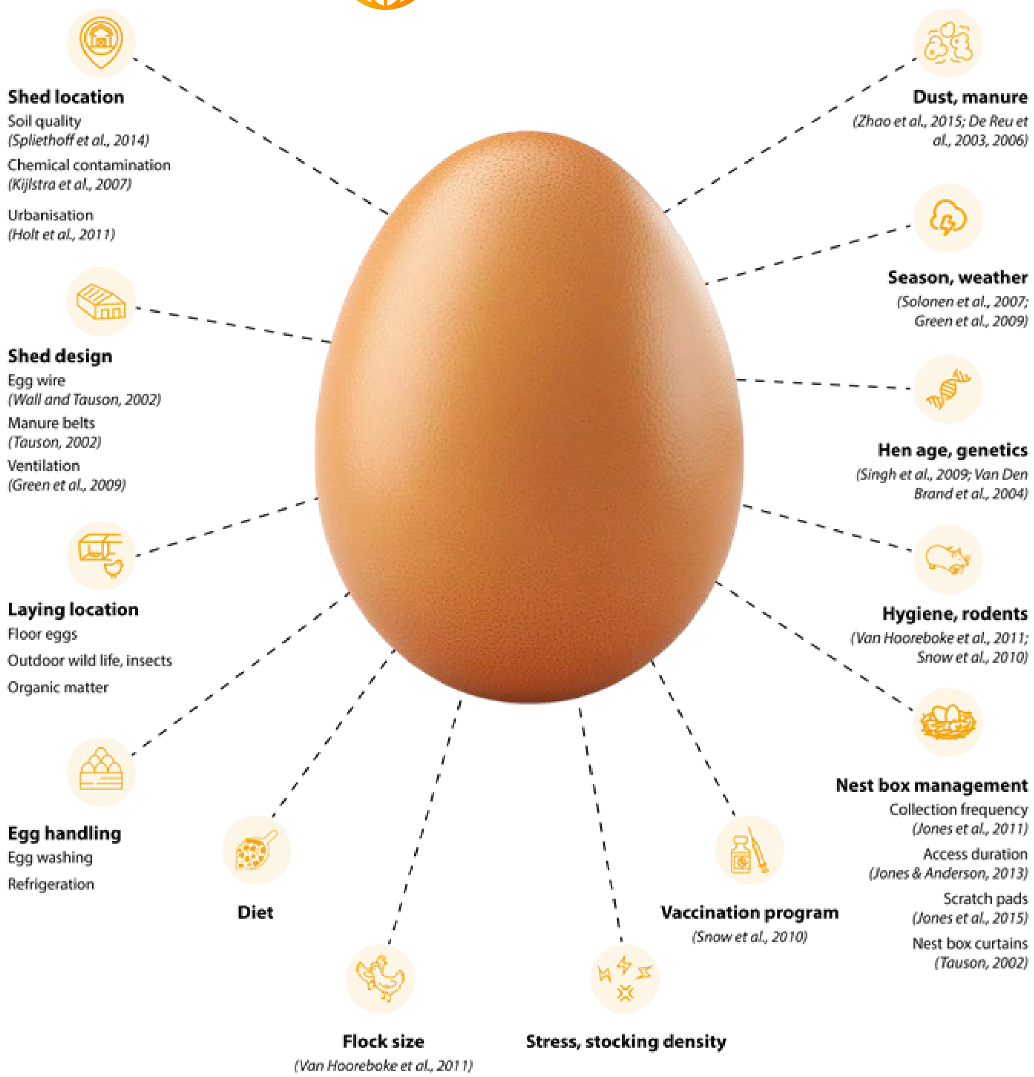


Figure 1.
Factors that impact egg quality. In the majority of cases, compromised egg quality is multifactorial.

factors mentioned above may be challenging to control (weather, shed location, hen age etc.), others can be manipulated easily (management including egg handling and vaccination) to achieve the desired outcomes *(Singh et al., 2009)*. Poor egg quality does not necessarily mean that all hens in a flock produce eggs of reduced quality, but rather that the variability within the flock increases (**Figure 2**). Unsurprisingly, the majority of challenges apply to the free-range egg industry, where a larger range of factors increases the variability further, thus increasing the likelihood of compromised hen performance.

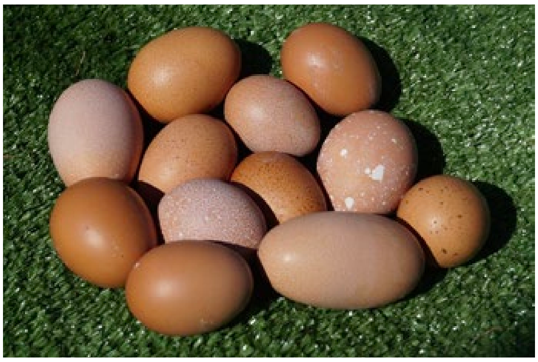
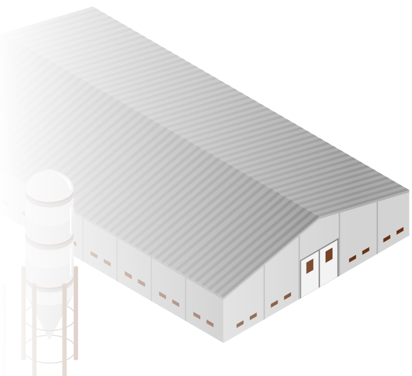


Figure 2.
Variety of egg shell quality including calcification spots, pale eggs, elongated eggs, double yolkers and variable egg size. All eggs were obtained from the same flock during the first week of lay (18 weeks of age).

This article summarises common challenges seen in various housing systems and shares information that can help to overcome typical pitfalls. Furthermore, special emphasis is provided on new insights about the impact of free-range flock sub-populations on laying performance and egg quality.



CAGE SYSTEMS

Conventional Cages

Hens housed in conventional cages demonstrated better egg production compared to furnished cages or non-cages farming system when system or floor eggs were not managed, but showed equal results when hens were trained to use the nest boxes *(Guesdon and Faure, 2004; Karcher et al., 2015; Wall and Tauson, 2002)*. The highest incidence of damaged eggs has been described in inadequately managed aviary and free-range systems and the lowest in cage systems *(Abrahamsson and Tauson, 1995; Hughes et al., 1985)*. The design of the nest box can significantly improve the incidence of dirty eggs *(Abrahamsson and Tauson, 1998)* and can be a main reason for the equivocal results obtained in studies that compared conventional cages to furnished cages or aviaries *(Abrahamsson et al., 1995; Abrahamsson and Tauson, 1998; Guesdon and Faure, 2004; Tauson et al., 1999)*. Similarly, equivocal results can be obtained regarding microbiota egg contamination, which is attributed mostly to dust exposure of the eggs associated with manure belt management, egg collection frequency, nestlocation, shed design, egg handling and various other factors *(Carrique-Mas et al., 2009; Jones and Anderson, 2013; Tauson, 2002; Zhao et al., 2015;* ***Figure 1****)*. However, clear results have been obtained about the prevalence of the antimicrobial resistance associated with various bacterial contaminants *(Alvarez-Fernandez et al., 2012; Harisberger et al., 2011; Schwaiger et al., 2008)*. While Alvarez-Fernandez et al., (2012) found 19.2% of all E. coli isolates to be susceptible to all antimicrobials tested, 80.8% of these samples were resistant to one (22.5%) or more (58.4%) antibiotics. Similar to the findings of Schwaiger et al., (2008) the highest prevalence of resistant strains was found in caged systems and was explained the highest stocking density and flock size, resulting in highest infection pressure which would require a more frequent use of antimicrobials.

Enriched Cages

Similar to conventional cage studies, research conducted on eggs produced in enriched cages has demonstrated equivocal results on egg quality and food safety *(Jones et al., 2015; Jones et al., 2016; Mallet el at., 2006;* ***Table 1; 2****)*. The number of eggs laid outside the nest box and cracked eggs of enriched cages could be reduced by providing attractive nesting, resulting in comparable egg production between various housing or farming systems *(Gast et al., 2013, Gast et al., 2014; Guesdon et al., 2006; Jones et al., 2015; Huneau-Salaün et al., 2010; de Reu et al., 2009)*.

Table 1.
The impact of the housing system on egg safety. All differences recorded were of statistical significance ($p<0.05$).

Indicator Organisms	Cage (Conventional)	Cage (Enriched)	Barn	Free-Range	Organic	Backyard	Reference
Enterobacteriaceae		Not sig. different	Not sig. different				De Reu et al., 2009
	Not sig. different		Not sig. different		Not sig. different		De Reu et al., 2006
Aerobes	Lower	Lower	Higher				Huneau-Salaün et al., 2010
	Lower	Higher					Mallet et al., 2006
	Higher		Lower				Jones and Anderson, 2013
Enterobacteriaceae	Lowest		Higher	Highest			Jones and Anderson, 2013
Coliforms	Lowest			Highest			Jones et al., 2011
Coliforms	Lowest		Higher				Singh et al., 2009
Aerobes	Lowest	Lower	Highest in floor eggs, lowest from nest boxes				Jones et al., 2015

Salmonella **spp - experimental setting**

S.Enteritidis	Not sig. different	Not sig. different	Not sig. different				De Vylder et al., 2009
S.Enteritidis	Lower		Higher				De Vylder et al., 2011
S.Enteritidis	Higher	Lower					Gast et al., 2013
S.Enteritidis	Not sig. different	Not sig. different					Gast et al., 2013
S.Enteritidis	Not sig. different	Not sig. different					Gast et al., 2014
S.Enteritidis	Higher	Lower					Gast et al., 2014
S.Enteritidis	Higher	Lower					Gast et al., 2014

Salmonella spp - commercial housing

Indicator Organisms	Cage (Conventional)	Cage (Enriched)	Barn	Free-Range	Organic	Backyard	Reference	Country
Various, mostly S.Enteritidis, Typhimurium, Heidelberg	Higher		Lower	Lower			Namata et al., 2008	Belgium
Various, mostly S.Enteritidis, Typhimurium, Heidelberg	Higher						Huneau-Salaün et al., 2009	France
Various, mostly S.Enteritidis, Typhimurium, Heidelberg	Not sig. different	Not sig. different	Not sig. different	Not sig. different	Not sig. different		Pieskus et al., 2008	Lithuana
Various, mostly S.Enteritidis, Typhimurium, Heidelberg	Not sig. different		Not sig. different	Not sig. different	Not sig. different		Van Hoorebeke et al., 2010	Belgium
Various, mostly *S.Braenderup, Kentucky*	Higher	Lower	Lower				Jones et al., 2016	USA
Various, mostly *S.Braenderup, Kentucky*	Higher	Lower	Lower				Jones et al., 2016	USA
Various, mostly S.Enteritidis, Typhimurium, Heidelberg		Not sig. different	Not sig. different	Not sig. different	Not sig. different		Van Hooreboke et al., 2010	Belgium

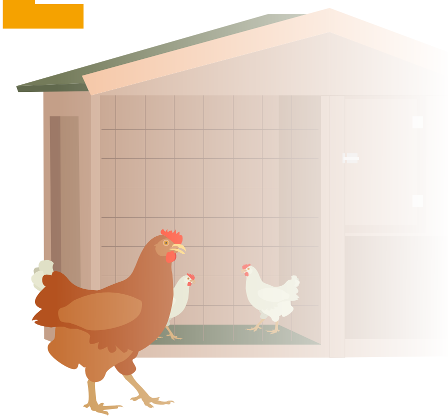
Campylobacter spp - commercial housing

Indicator Organisms	Cage (Conventional)	Cage (Enriched)	Barn	Free-Range	Organic	Backyard	Reference	Country
Various, mostly *C.jejuni, C.coli*	Lower			Higher			Jones et al, 2012	USA
Various, mostly *C.jejuni, C.coli*		Not sig. different	Not sig. different				Jones et al., 2015	USA
Various, mostly *C.jejuni, C.coli*	Higher		Lower				Jones et al., 2015	
Various, mostly *C.jejuni, C.coli*	Higher	Lower	Lower				Jones et al., 2015	
Various, mostly *C.jejuni, C.coli*	Lower	Lower	Higher				Jones et al., 2015	
Various, mostly *C.jejuni, C.coli*	Not sig. different	Not sig. different	Not sig. different				Jones et al., 2015	
Predominantly *C.coli*	Lower			Higher			Green et al., 2009	
Predominantly *C.jejuni*	Higher			Lower			Green et al., 2010	
Predominantly *C.jejuni* (82.8%) followed by *C.coli* (16.4%)	Not sig. different				Not sig. different		Schwaiger et al., 2008	Germany

Others

Indicator Organisms	Cage (Conventional)	Cage (Enriched)	Barn	Free-Range	Organic	Backyard	Reference	Country
*L.*monocytogenes and *L.*innocua	Not sig. different			Not sig. different			Jones et al., 2015	
Antimicrobial resistance	Higher			Lower			Schwaiger et al., 2008	Germany
Antimicrobial resistance			Not sig. different	Not sig. different	Not sig. different		Harisberger et al., 2011	Switzerland
Antimicrobial resistance	High		Highest	Low	Lowest	Lowest	Alvarez-Fernandez et al., 2012	
Lead						10- 67 lg/kg	Spliethoff et al., 2014	USA
Lead						2–477 lg/kg	Waegeneers et al. 2009a, b	Belgium
Dioxin					0.4-8.1 pg TEQ/g		Kijlstra et al., 2007	Netherlands

CAGE-FREE HOUSING SYSTEMS



Cage-free housing systems are designed to improve animal welfare by providing various features such as vertical space using perches and aviaries, but also horizontal space such as winter gardens (Rodenburg et al., 2005; Lay et al., 2011; Freire and Cowling, 2013). Common problems associated with cage-free systems include the production of overall fewer eggs, flocks not reaching the targeted breed standard, and a relatively high percentage of off-grade eggs (Aerni et al., 2005; Englmaierova et al., 2014; Golden et al., 2012; Singh et al., 2009; Tumova and Ebeid, 2003; Van Horne, 1996). A non-uniform use of resources contributes to the problem and can be observed in all cage-free (barn, free-range, organic) systems, but stress and flock size itself also increase the likelihood of misplaced or cracked eggs (De Haas et al., 2013; Sirovnik et al., 2018). Maintaining the egg shell quality is of paramount importance for non-cage systems, as the eggs produced to this standard need to be marketed and sold as whole eggs, covering the relatively higher housing costs.

Barn Housing

While barn systems do not dominate the egg market from a global perspective, it is the predominant housing system in some countries. For example, Colombia, Germany, Guatemala and The Netherlands house >60% of their hens in the barn and aviary system. Overall, the European Union (including the UK) houses 29% of their layers in the barn system, taking 119 million laying hens into account (https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/farming/documents/eggs-dashboard_en.pdf).

Ferrante et al. (2009) evaluated 4745 hens housed in commercial barns and compared their performance and egg quality with 2016 hens of the same strain housed in commercial organic/free-range systems. While the peak lay production of organic hens was superior compared to barn hens (94.5% vs 93.0%, respectively), the feed conversion ratio was worse (2.36 vs 2.20, respectively). However, significantly more eggs produced in the organic system were dirty while significantly more eggs laid in barn systems were cracked. Equivocal results have been obtained by other investigators indicating a later onset of lay or higher, equal or lower egg shell breaking strength compared to caged and/or free-range systems, as well as higher and/or lower Haugh Units *(Hidalgo et al., 2008; Jones et al. 2010; Mertens et al; 2006; Singh et al., 2009; Van Den Brand et al., 2004; Valkonen et al.,2010)*. The fact that the interior of barn systems can vary greatly between and within countries (e.g. single floor slats, single floor housing with bedding material, aviary systems, aviary systems with winter garden) makes it challenging to compare study results to one another but also highlights that the cause of reduced egg quality is mostly multifactorial *(Roberts and Chousalkar, 2009;* ***Table 2****)*.

Table 2.
The impact of the housing system on egg quality. All differences recorded were of statistical significance (p<0.05).

External quality	Cage (Conventional)	Cage (Enriched/colony)	Barn Aviary	Barn Single floor	Free-Range	Organic	Reference
Shape	Narrower				Broader		Van Den Brand et al., 2004
Shape index	Not sig. different				Not sig. different		Wang et al., 2009
Egg weight	Lower			Higher			Singh et al., 2009
Egg weight	Not sig. different	Not sig. different					Guesdon and Faure, 2004
Shell thickness	Not sig. different				Not sig. different		Wang et al., 2009
Shell strength	Higher	Lower					Guesdon et al., 2006
Shell strength	Not sig. different	Not sig. different			Not sig. different		Valkonen et al., 2010
Shell strength	Higher		Lower		Lower	Lower	Hidalgo et al., 2008
Shell strength	Not sig. different		Not sig. different		Not sig. different		Jones et al., 2010
Shell strength	Intermediate	Intermediate	Higher		Lower		Mertens et al., 2006
Cracked eggs	Higher	Lower					Guesdon and Faure, 2004
Cracked eggs	Higher	Higher	Lower		Lower		Mertens et al., 2006

Internal quality	Cage (Conventional)	Cage (Enriched/colony)	Barn Aviary	Barn Single floor	Free-Range	Organic	Reference
Haugh Unit	Higher		Higher		Higher	Lower	Hidalgo et al., 2008
Haugh Unit	Higher		Lower		Lower		Jones et al., 2010
Albumen height	Higher				Higher		Singh et el., 2009
Albumen & yolk weight	Lower			Higher			Singh et al., 2009
Yolk colour score	Lower			Higher			Singh et al., 2009
Overall egg quality	Not sig. different				Not sig. different		Wang et al., 2009
Overall egg quality	Not sig. different	Not sig. different					Guo et al., 2012

Free-Range Housing

Free range egg production is of increasing popularity world-wide, with certain countries such as Switzerland and the UK (57% of all hens housed free-range) leading the segment, followed by Australia (47%), Ireland (44%) and Austria (25%) *(European Union overall 16%; Australian Eggs, 2019; Windhorst et al., 2013;* ***Link****)*.

It had been demonstrated numerous times that egg taste can be influenced by feed components such as fish oil or various spices (thyme, basil, garlic, fennel, peppermint, marjoram) if added at sufficient quantities to the layers' diet *(Tserveni-Gousi, 2001; Hammershøj and Steenfeld, 2012; Richter et al., 2002)*. These quantities may be up to 15g of spice/kg diet and are such not economically viable. Ranging hens usually denude their available area from plants in relatively short periods of time, eating up to 60 g pasture/hen/day. This leads to negligible pasture intake over the duration of an entire laying period unless being provided by continuously new range areas due to rotational fencing or mobile sheds that frequently move to new grazing areas *(Singh and Cowieson, 2013; Ruhnke et al., 2015)*. The practice of mobile sheds is especially used by grain farmers, who run their flocks on harvested fields, expecting a fertiliser effect from the chicken manure as well as a cleaned-up paddock where the hens eat loose grains remaining in the stubble. Foraging in general and on lucerne in particular increases yolk colouring, adding beta-carotenes, canthaxanthins' lutein and xanthophylls such as violaxanthin to the diet which is deposited in the egg yolk *(Ahammed at al., 2014; Ferrante et al., 2009; Pavlovski et al, 2001; Golden et al, 2012)*. In contrast, naked oats fed at 800g/kg decreased yolk colour in addition to yolk flavour intensity *(Cave et al., 1992)*. Other forage material may include silages or kale with varying effects depending on the quantity consumed *(Hammershøj and Steenfeld, 2012)*. However, in most flocks where hens are housed for commercial production, the intake of additional forage material diet is negligible and therefore sensory properties of eggs are usually not affected by the production or farming system *(Mizumoto et al. 2008)*.

Soil intake during range use can also significantly impact egg quality, challenging food safety. Of special concern are fat soluble heavy metals such as dioxin or lead, which will be covered in the section "organic housing systems"; further below, as organic hens seem to be significantly more often affected, most likely due to smaller flock sizes which is known to correlate positive with range use.

It has previously been proposed that, due to the greater physical activity of free-range hens, increased bone strength may occur, leading to a better calcium deposition which would then be available for egg shell production later in life *(Miao et al., 2005)*. While early range access has been linked to increased hen body weight and egg production, an impact on bone quality could not be seen. This was most likely due to the provision of an aviary system in the shed during rearing and lay, which encourages hens to jump vertically which would have diminished any potential beneficial effect of horizontal range use on bone quality *(Kolakshyapati et al., 2019a; Sibanda et al., 2018; Sibanda et al., 2020a)*. The diversity of non-uniform hen behaviours and their impact on the hen's physiology and health status, and subsequently egg performance, is even greater in free-range farming systems compared to barn housed chickens. Range use allows for UV-light exposure in addition to the photo stimulation provided by the artificial light provided in the hen house and therefore further increases the variation of ovulation rate and calcium deposition *(Coletta et al., 2012; England and Ruhnke, 2020; Fanatico, 2006; Kolakshyapati et al., 2020; Lewis and Gous, 2009; Siopes and Wilson; 1980)*. The fact that some hens rarely or never leave the shed while others range daily, reduced body weight uniformity and inconsistent egg production may occur *(Gebhardt-Henrich et al. 2014a,b; Gilani et al., 2014; Sibanda et al., 2019)*.

Investigating the effects of range use allows egg producers an in-depth understanding of their flock and subsequently improved decision making resulting in increased egg production *(Gocsik et al., 2014; Wolc et al., 2011)*. Icken et al. (2008) investigated winter garden use and laying performance and detected a low negative correlation between laying performance and the frequency as well as the duration of winter garden use (). The authors investigated hen movement and nest box usage daily for one laying cycle. They suggested that hens that often accessed the winter garden area may have not returned to the nest boxes for laying. Unfortunately, the authors did not collect floor eggs and as such were not able to correlate those eggs with a hen's movement patterns. A similar approach was used by Sibanda et al (2020b), who tracked individual hens to determine the differences in laying rate and egg quality of flock sub-populations with different range use during early age (18-21 weeks of age). While Icken et al. (2008) investigated 272 Lohmann Silver hens in experimental facilities, Sibanda et al investigated 15625 Lohmann Brown hens being part of 5 commercial flocks. A limitation of Sibanda et al was that the hens were monitored for their range use from 18-21 weeks of age and based on this range use grouped into "stayers" (hens that spent most of their time in the shed), "roamers" (hens that accessed the range infrequently) and "rangers" (hens that spent most of their time on the range). All of these groups continued to have access to the commercial facilities including an aviary system and, as such, eggs from these individual groups could not be collected daily (and therefore hen/house production not be determined for the entire laying period), but were collected in 10-weekly intervals. Significant differences were noted for hen-day production at different hen ages: At 22 weeks of age, rangers and stayers had a laying performance of 88.0 % and 78.2%, respectively, but at 72 weeks of age the peaks had shifted and rangers laid about 10% fewer eggs compared to stayers (laying performance of rangers and stayers was 85.1% and 95.5%, respectively (all P <0.05; **Figure 3**). However, there was no overall effect of early range use on laying performance. These results lead to the suspicion that the previously reported reduced laying performance of free-range flocks may be attributed to a lower performance of flock sub-populations rather than the housing system as such and supports findings where free-range flocks perform equally or exceed the performance of caged hens. In addition, range use did not significantly affect the egg quality (**Figure 4, 5, 6, and 7**). The fact that range use had no negative impact on egg quality suggests no reasons to be concerned about range use from this point of view. However, the impact of range use on hen heath and mortalities and subsequently total egg outputs needs further investigation.

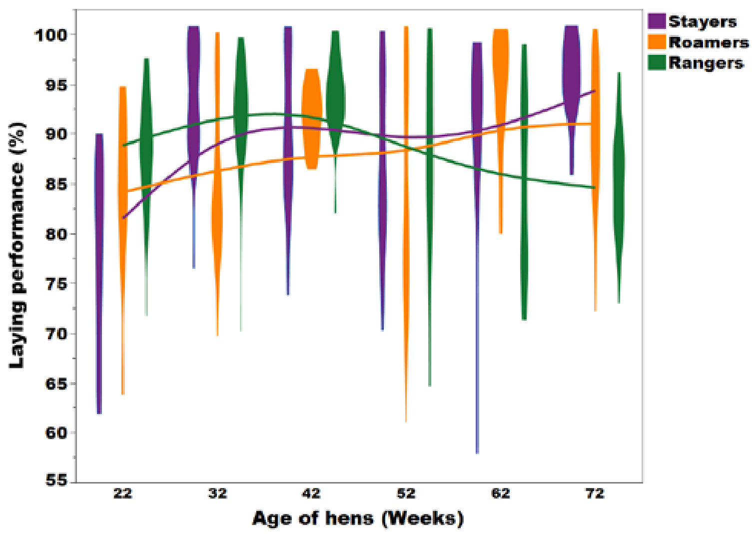


Figure 3.
A violin plot with an overlay of smooth spline (lambda = 3.5) representing the distribution and the laying performance trend of stayers (purple), roamers (orange) and rangers (green) at 22, 32, 42, 52, 62, and 72 weeks of age per day in commercial free-range laying hens. The time-age interaction can be seen at 52 weeks of age (Figure adapted from Sibanda et al., 2020b). This figure has been published in Feedmgazine /Kraftfutter, Dec. 2023.

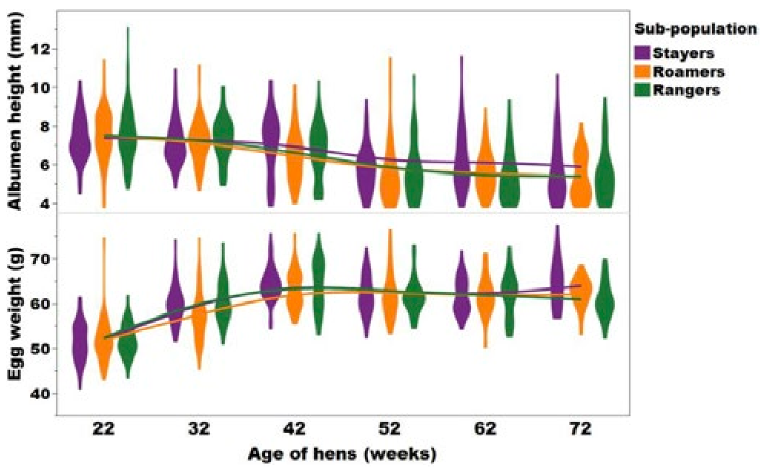


Figure 4.
A violin plot with an overlay of smooth spline (lambda = 3.5) representing the trends and distribution between the egg weight and albumen height of stayers (purple), roamers (orange), and rangers (green) at 22, 32, 42, 52, 62 and 72 weeks of age (Figure adapted from Sibanda et al., 2020b).

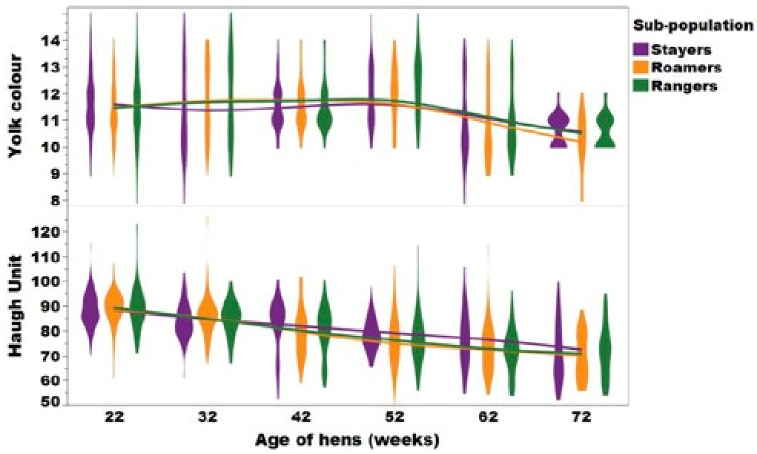
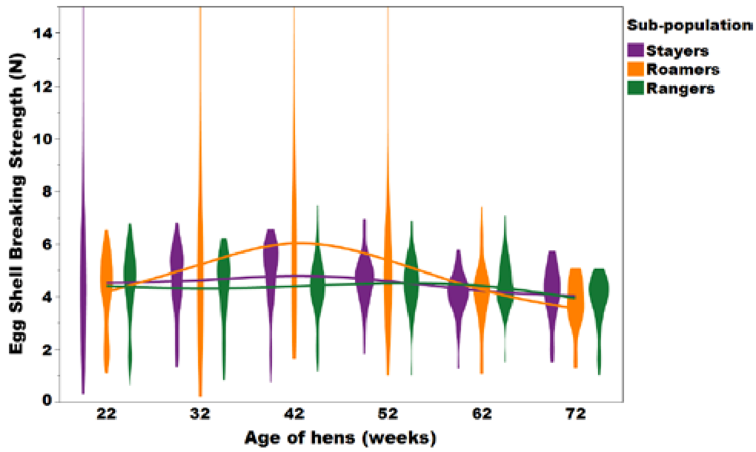


Figure 5.
A violin plot with an overlay of smooth spline (lambda = 3.5) representing the trends and distribution between the egg yolk colour and Haugh unit of the stayers (purple), roamers (orange), and rangers (green) at 22, 32, 42, 52, 62, and 72 weeks of age (Figure adapted from Sibanda et al., 2020b).

Figure 6.
A violin plot with an overlay of smooth spline (lambda = 3.5 representing the trends, interaction and distribution between the eggshell breaking strength of the stayers (purple), roamers (orange) and rangers (green) at 22, 32, 42, 52, 62, and 72 weeks of age (Figure adapted from Sibanda et al., 2020b).



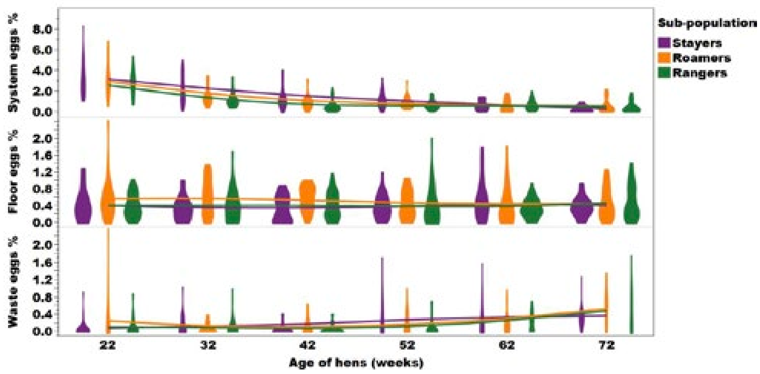


Figure 7.
A violin plot with an overlay of smooth spline (lambda = 3.5) representing the trends of system, floor and waste eggs collected from the various flock sub-populations at 22, 32, 42, 52, 62, and 72 weeks of age (Figure adapted from Sibanda et al., 2020b). This figure has been published in Feedmagazine / Kraftfutter, Dec. 2023.

Barnett et al., (1992) provided evidence that fear of humans was a factor that was negatively correlated with peak hen day production, coming into effect when birds were exposed to unfamiliar environments. With stayers being more fearful than rangers, the higher blood cortisol levels in combination with reduced UV light exposure in stayers may explain the lower egg performance and it would be interesting to investigate further effects on egg shell colour, for example, as shell colour has been found to be paler in free-range flocks compared to barn or caged eggs *(Campbell et al., 2016; Hartcher et al., 2016; Kolakshyapati et al., 2019b; Mahboub et al., 2004; Lewis and Gous, 2009; Siopes and Wilson; 1980; Roberts and Chousalkar, 2009).* The increased fearfulness of stayers may have also been a reason for the increased presence of system eggs (e.g. eggs laid in areas of the aviary system that were not nest boxes; **Figure 7**). System and floor eggs increase not only the labor associated with egg collection, but affect egg shell hygiene, preventing these eggs from being sold as whole in some countries such as member states of the European Union and therefore presenting a significant financial loss to the producer *(Van den Brand et al., 2004; Michel and Huonnic, 2003; Jones et al; 2015; Villanueva et al., 2017).*

Range use did not impact egg shell breaking strength and, at 72 weeks of age, the breaking strength remained comparable to that at the beginning of lay, indicating the ability to house hens beyond the commonly practiced 72 weeks of age *(Bain et al., 2016).*

Soil ingestion from the range can result in the accumulation of elevated dioxin-like compounds where free-range eggs have higher and polychlorinated biphenyl levels than conventional cage eggs *(Schoeters and Hoogenboom, 2006).*

Organic Housing

Organic egg production is the least sustainable housing or farming system, taking ammonia emissions from manure, reduced number of eggs produced per hen per year and higher feed conversion ratio into account when conducting life cycle assessments (Aarnik et al., 2006; Dekker et al., 2009; Nijdam et al., 2012; Williams et al., 2006). While the increased use of food and land resources have a major impact on the carbon footprint of the industry, the sector is rapidly growing in many countries and eggs are usually sold at a premium, allowing this sector to have the highest profit margin. Therefore, the organic sector has a relatively high potential to increase its sustainability and efficiency by producing more eggs/hen, resulting at the same time in the highest financial reward when being able to sell more egg outputs at a relatively high price (Australian Eggs, 2019). The definition and underlying legislation vary largely world-wide, but common challenges affecting the quality of organic eggs include unintentional impacts of the environment such as contaminated soil ingestion. Vincevica-Gaile et al. (2013) investigated various trace elements in eggs obtained from different housing or farming systems and eggs derived from organic farms had the highest concentrations of most elements. While this is not of general concern, the unwanted exposure to contaminants becomes critical when affecting food safety. Kiljstra et al (2007) investigated 34 organic farms in Europe of which 9 (nearly 10% of the investigated farms) exceeded the legal limit of 3 pg of toxic equivalence/g of egg fat. With dioxin being ubiquitously present in the soil of many industrialized countries, its presence in eggs seems to be positively correlated to decreasing flock size and as such affecting organic flocks which are commonly smaller more often than larger free-range flocks (Kiljstra et al., 2007). Flock size significantly affects the percentage of hens that access the range, increasing the exposure time of the ranging hens to the contaminated environment and the amount of soil uptake (Harnly et al., 2000; Hegelund et al., 2005). Thus, it is not surprising that organic farms worldwide have been affected by dioxin-like compounds such as polychlorinated dibenzo-p-dioxins (PCDD), polychlorinated dibenzofurans (PCDF) and polychlorinated biphenyls (Harnly et al., 2000). Similarly, pesticides and heavy metal contamination of the environment such as dichlorodiphenyltrichloroethane (DDT) or lead can be frequently elevated. Eggs obtained from backyard flocks in Belgium had 2-6 times higher concentrations of lead, mercury, cobalt and thallium than those obtained from commercial farms (Spliethoff et al., 2014; Van Overmeire et al., 2006; Waegeneers et al. 2009a, b). Despite the fact that the interaction of hens with the living environment such as rodents, insects, wild birds and mammals is theoretically higher in free-range and organic housing or farming systems, the incidence of biological contamination with food borne pathogens such as Salmonella enteritidis, Listeria monocytogenes or various Campylobacter species is not necessarily higher than in caged farming systems (Schwaiger et al., 2008; Van Hoorebeke et al., 2010; Wales et al., 2007). As mentioned above, resistance rates of bacterial isolates from cage farming systems have higher values than those from organic ones (Alvarez-Fernandez et al., 2012; Schwaiger et al., 2008). These results show that biosecurity challenges in free-range and organic systems can be effectively addressed, reducing inter-flock and organic material transmission to insignificant levels.

Conclusion and implications

Housing or farming system have no impact on egg shape but inconsistent information has been obtained on egg weight, egg shell breaking strength, shell thickness, cracked eggs and dirty eggs. An impact on shell colour could be observed where free-range hens had lighter shell colour compared to barn and caged hens. The production or farming system may affect food safety and egg quality especially due to ingestion of dioxin and lead contaminated soil, but does not necessarily impact the Salmonella prevalence as all farming systems are able to be managed to produce eggs of superior external and internal quality. Nest box management is of highest impact as its design and management determine the hen's access time as well as dust exposure. While egg production differs with range usage, egg quality between ranging and non-ranging hens is of minor relevance. Awareness of the typical pitfalls associated with the different production or farming systems and their impact on egg quality allows for prevention and preparedness, resulting in the reliable outcome of immaculate and safe eggs with minimal losses and hence improved sustainability of the industry.

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