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BREEDING FOR SUCCESS … TOGETHER

LOHMANN TIERZUCHT

Contents

Dear colleagues and friends,

At the current rate of growth, the world population will soon reach 8 billion, and per-capita consumption of poultry meat and eggs is expected to increase. Is this good news for the animal industry or bad news for the environment? Critical consumers wish to know where their food comes from, under which conditions it is produced and which efforts are made to improve animal welfare and to minimize environmental impact. In this issue, the authors will address several aspects of questions which have become part of the public debate in Western countries.

Chickens are the most resilient domestic animals and adapt easily to a wide range of different management systems. How many eggs they will lay depends on their genetic potential, health, nutrition and housing system. **Rudolf Preisinger** explains how genomic selection is used to improve the genetic potential. Regional consumer preferences for egg quality traits such as average egg size and shell color are taken into account in different lines, while all lines are selected for efficient egg production, shell strength and livability. Genetically improved efficiency of feed conversion helps to reduce production cost and impact on the environment. In recent years, bone strength and behavior traits, including use of nests, perches and free range have received more attention to support the adaptability to non-cage housing systems.

The trade of eggs between EU member countries affected market shares temporarily while conventional cages were replaced by enriched cages and non-cage systems. Currently the trade of eggs between countries within the EU is determined by production cost and consumer preferences for regional production and/or management system. In the second article of this issue, **Mark Williams** describes the special situation of the egg industry in the United Kingdom and how British egg producers are preparing for the expected "Brexit", hoping to benefit from it.

Traditional animal farming, which used to provide year-round work and modest income for millions of family farms, is gradually being replaced by large operations with intensive systems, focused on maximum return on investment, based on high productivity and efficient feed conversion to minimize production cost for edible meat, milk and eggs. In response to consumer demand for "healthy products from healthy animals", the EU has started a project to determine common causes of depressed productivity and develop a strategy to reduce these risks, which should also improve animal welfare. **Paul McMullin** explains the "Prohealth" concept and reports first results with poultry.

The effect of light-dark-cycles on performance and welfare of layers and broilers has been studied extensively in the past. Lighting programs have been established for the rearing and laying period, based on the perception of humans. However, the sensitivity of the chicken eye to different wave length differs from the human eye. Hence, the same light will produce different light intensity in chickens and humans. When energy-saving light sources were recently installed in chicken houses, effects on the birds were unknown and need more attention. **José Daniel Kämmerling** and co-authors are shedding some light on the characteristics of the main sources of light and light perception of chickens and turkeys.

Meat production for human consumption requires a lot of resources (energy, land and water). To limit negative effects on global warming and environmental pollution, reduction of meat consumption in industrialized countries has been suggested by environmentalists. Statistics of human meat consumption often include the meat which is used to feed the carnivorous companion animals. This aspect has been overlooked for a long time, until publications like "Time to eat the dog" drew attention to the environmental aspects of keeping dogs and cats. **Ferry Leenstra** and co-authors review effects of meat consumption on land use and carbon dioxide production for feeding dogs and cats in the USA and Europe and show that dogs and cats indeed consume a considerable amount of meat which could be used for human nutrition.

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Innovative Layer Genetics to Improve Egg production

Abstract

In commercial layer breeding, extensive gene pools are tested and selected for market requirements which must be anticipated at least five years ahead. Animal welfare and cage-free housing dominate future needs of the market. Stronger shells for longer production cycles without moulting have to be combined with stronger bones. Nesting behaviour and minimal tendency to develop feather pecking or cannibalism without beak treatment, are key trait complexes. Field results confirm a continuous positive genetic trend in egg output and better feed efficiency which can be converted into land savings.

No single big gene effect can be expected to control the multifactorial problem of feather pecking. Adjusting the shape of the beak, with a heritability of .10 to .25, can contribute to reducing the risk of severe cannibalism. For better skeletal integrity, the assessment of bone quality in pedigree birds housed in enriched cages is done by keel bone palpation or ultrasound measurement of the humerous. Both traits show similar heritabilities in the range of .15 to .30 and can be included in a balanced selection approach for performance, quality, and welfare traits. The combination of performance testing and genome-wide marker analysis, are promising tools to generate more progress for a balanced performance and behaviour profile.

Keywords

Layer breeding, balanced selection, behaviour, welfare, production efficiency

Introduction

Today's human population of more than 7 billion will grow steadily and by 2050, this will reach about 9 billion. In order to feed the growing human population, the production of food will have to be more efficient in terms of utilising the limited resources that we have. We have to produce large amounts of high quality protein with affordable prices to cover the growing demand. Production systems need to be environmentally friendly, socially responsible and economically viable. Selective breeding of farm animals can make a major contribution to this global challenge.

The demand for eggs is on a level of 75 million tons with an annual increase of 1 million tons each year. To satisfy the increasing demands, at least 50 million hens will have to be added each year, assuming management conditions to support the genetic potential for 20kg egg mass per hen, i.e. from 20 to 76 weeks of age. Current per capita egg consumption and the rate of change, differ considerably between continents and countries within continents, depending on traditions, purchasing power, and the ability of other sources of food. Europe and North America have little growth potential, while the demand in countries like China, India, Latin America and certain countries in Africa, is expected to grow considerably, especially due to changing consumer habits of educated urban people with the necessary purchasing power.

Consumer habits and preferences for specific egg characteristics like shell colour and egg size also differ between countries and between consumers within a country. Japan, for example, has maintained one of the highest levels of consumption with more than 300 eggs per capita for decades. The custom of breaking a raw egg over a bowl of rice for breakfast helps to explain the focus on egg quality: white-shelled eggs with superior internal egg quality and guaranteed freedom from Salmonella. White eggs are also preferred in North and Central America, the Middle East, India, Taiwan and the Philippines, whereas brown eggs are preferred in most countries of Latin America, Europe and China. Tinted eggs, produced from crosses between White Leghorns and brown-egg breeds, are popular in Japan and China, but seldom seen in Europe.

The layer breeding industry has gone through significant changes during the past decades and has a remarkable record to cope with new challenges. Increased egg production, improved feed efficiency and adaptation of egg quality to consumer preferences have contributed significantly to the success of the poultry industry. Without these genetic improvements and corresponding improvement of nutrition, disease control and general farm management, the poultry industry would not have achieved its current position in the global food market. While the focus has to remain on maximizing the genetic potential for producing high quality protein at competitive cost, additional requirements of the egg industry, changing consumer habits and public opinion have to be taken into account.

General layout of layer breeding

Primary breeders have to look beyond current requirements and anticipate changing needs and opportunities at least five years into the future. Close communication between breeders and distributors is necessary to introduce new varieties at the right time to benefit from growing niche markets. For the global layer business, diverse markets have to be served and each of these may prefer different performance profiles of the commercial layers. This requires extensive gene pools with large elite lines which can be combined to generate strain crosses with specific attributes to meet market needs as closely as possible. Maintaining and developing new lines, testing, selection and reproduction of primary stocks involves high fixed costs in the operation and requires superior skills in quantitative genetics as well as internal organization to keep track of the availability of different sub-lines for niche markets. Genetic development, marketing and technical support have to communicate closely with local distributors to provide the best possible service for the current market and to benefit from changing requirements. Major challenges for the layer industries are constantly high feed prices and animal welfare which is gaining more importance not only in Europe, but also in North America. Geneticists must anticipate at least five years ahead as to what the market trends will be like as well as consumer orientation. When alternative husbandry and organic egg production were introduced some years ago, no one believed that these would someday become dominant market trends. At the time when the prospect of a prohibition of beak treatment was outlined, no one would have ever imagined that it would actually happen in several European countries. The same goes for male chicks, whose culling will be prohibited and replaced by determining sex in the egg. In fact, European legislation forbidding any kind of amputation to animals has been in place for a long time now. In the next five years, the determination of sex in the egg will be a reality, or even the demand for layer nutrition where only non-GM raw materials and ingredients are to be used in the formulation. Future selection goals are geared towards extending the production period and increasing the number of saleable eggs per hen, improving shell quality, and hen liveability with consistent feather cover until the end.

Stronger shells for longer cycles without moulting have to be combined with better bones. Bone strength and breakage can be a major issue in cage-free environments. Also, the enrichment with perches can be a challenge for the skeletal integrity and bone lesions.

Housing systems vary between continents and within Europe. In Switzerland, Austria, Sweden and Germany, commercial layer cages have been banned for several years. Enriched cages, considered by poultry scientists as an acceptable compromise between demands of animal welfare organizations and the “needs” of laying hens, are installed in Europe as an alternative to conventional battery cages. Retailers and animal welfare groups in different countries, continue to lobby for a complete ban on cages in Europe. Even in

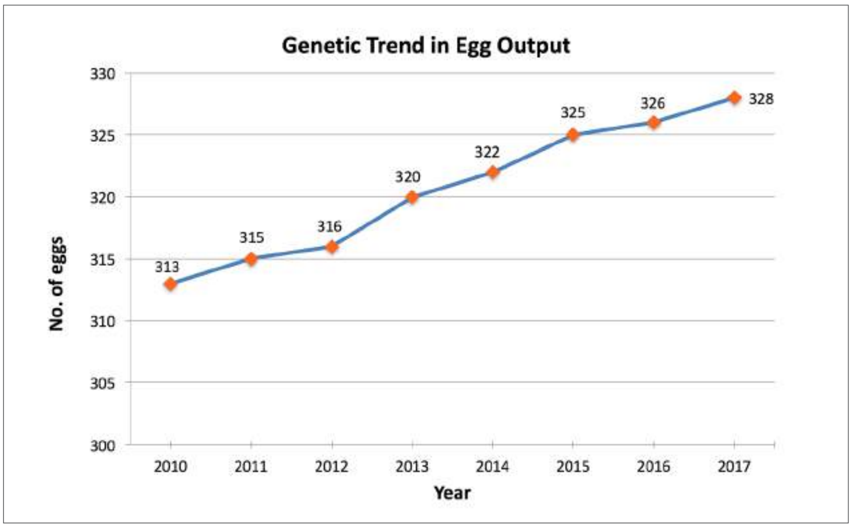

Figure 1. Recent genetic trend in egg output (field results)

North America, a change from cage systems to aviary systems is most likely within the next decade.

To supply the best possible combination for each market with specified optimal egg weight and most common housing system, every breeding company has to offer different strain crosses, which are all selected with focus on efficient egg production, but with different emphasis on individual selection traits.

For line improvement, pure-line and cross-line hens are being tested in different environments: in single, small group and family cages as well as under floor conditions with a new kind of "trap-nesting". The majority of single bird cages are enriched with perches, nests and scratching areas with the aim of creating a testing system which is as close as possible to future housing systems with more floor space and several enrichments. Daily egg production is recorded with the aid of barcode readers, various egg quality traits (mainly egg weight, shell stability, shell colour and internal egg quality) and plumage condition are recorded on a sample basis across the production cycle. Individual feed intake and daily egg mass are determined at peak production, i.e. during the time of maximum performance, so that selection for improved efficiency reflects the capacity for sufficient feed intake at a time of greatest nutrient demand.

Testing under floor conditions with trap-nesting to measure individual egg production and egg quality was practiced in the breeding program of Lohmann Tierzucht until about 1970, but was replaced by more efficient single cage and group cage testing. Almost ten years ago, testing individual performance in floor systems has been resumed, using a specially adapted transponder technique and the Weihenstephan Funnel Nest Box (Icken et al, 2012) to obtain individual information on egg production, nest acceptance and utilization of outdoor facilities (winter garden or free-range). The data are used in family selection for "number of saleable nest eggs", penalizing families with poor nest acceptance which tend to produce floor eggs. The moderate heritability of "nest eggs" recorded in these floor systems suggests that further progress can be made. However, egg producers should not expect miracles from genetic selection and must pay proper attention to rearing conditions, a timely transfer to the production house and optimal nest arrangement to minimise the number of displaced eggs. Critical are also an adequate lighting regime adjusted feed formulation and feeding.

For the foreseeable future, we can safely assume that general breeding goals such as egg number, feed efficiency and

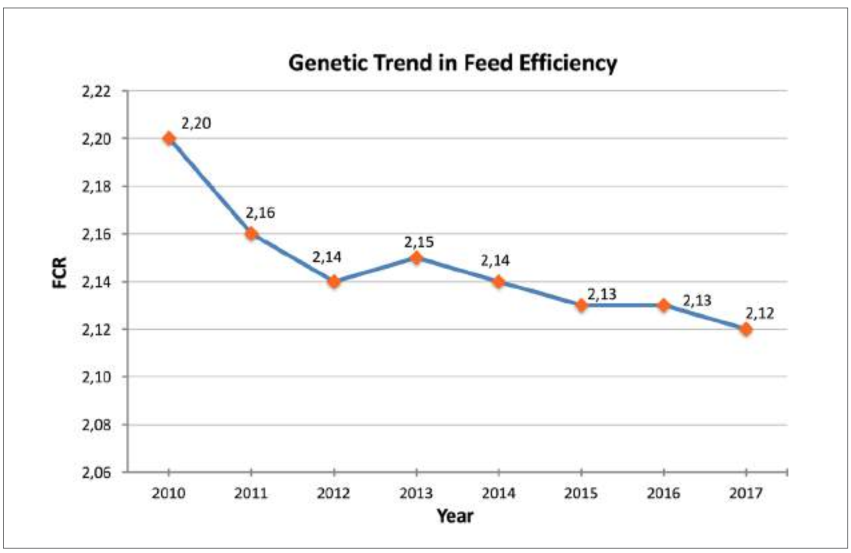

Figure 2. Recent genetic trends in feed efficiency (field results – kg Feed/kg egg mass output)

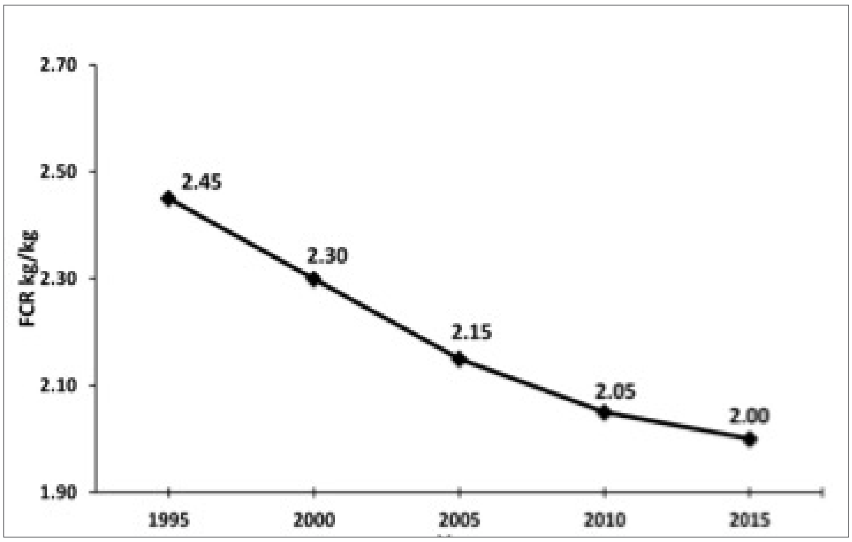

Figure 3. Trend in sustainability and feed efficiency in egg production, from a global perspective

egg quality traits will remain priorities. Behaviour patterns and especially behaviour anomalies are likely to get more attention outside the Western world. Suitability for floor housing and free-range systems has become more important, and this includes attention to a whole range of traits: acceptance of nests and free-range, persistent plumage cover to the end of lay, resistance to common diseases and minimal tendency to develop feather-pecking or cannibalism. National laws and regulations will reflect continuing attempts to define priorities and "sustainability" in terms of adequate nutrition for the growing human population, protection of the environment and natural resources, ethical standards for animal farming, and – last but not least – economics.

Genetic Trends

Continuous improvement in egg production per hen housed, is the most important selection criteria in layer breeding. Field results have confirmed the genetic trend. An annual increase of about 2 – 3 eggs per year in a 13-month production cycle, can be expected (**Figure 1**).

At the same time, feed efficiency has improved a lot. When breeding companies established a system for individual feed recording, body weight of brown layers and daily intake were reduced.

Today, an optimum body weight for white and brown layers is achieved. After 2012, the improvement in feed efficiency as shown in **Figure 2**, is mainly driven by a stable maintenance requirement and constant daily feed intake. Improved egg mass output is the major driver for a further improvement in feed efficiency. When we look from a global perspective on the sustainability and efficiency of egg production in the last 20 years, we can deduce an improvement of about 0.45 kg less feed per kg egg mass produced (**Figure 3**).

When we convert the savings in feed into resource saving in different countries and regions, we can estimate a saving of 57,000 tonnes of feed which is equivalent to 8 million hectares of land over the last 20 years of egg production for the global commercial layer population (**Table 1**).

Changing expectations of consumers in terms of animal-friendly housing systems, have put pressure on retailers. The U.S. alone, according to the United Egg Producers, have to convert up to 190 million hens from cage to cage-free production. A change in housing systems will cause an increase in production costs of about 14 to 28% due to higher space requirements, higher feed intake, increased mortality, and more downgraded eggs. With new housing systems and a small flock size, an even better egg output per hen can be achieved as compared to old, large and multiple age complexes. Flock records in **Figure 4** can be used as a typical example for the genetic potential realised in cage-free environments. Persistency in lay is one of the major drivers for further improvement in egg production in all housing systems.

Genetic potential

In order to get a better and detailed overview about the performance of each individual hen within a flock, a special recording system was established.

Table 1. Savings of feed and land in different parts of the world from better feed efficiency in the last 20 years

Region	Humans (mil.)	Layers (mil.)	Feed 1000 T	Hectares of wheat
Germany	81	48	388	55.543
Europe	508	380	3.078	439.714
USA	321	300	2.430	347.143
India	1311	195	1.579	225.643
World	7349	7035	56.983	8.140.500

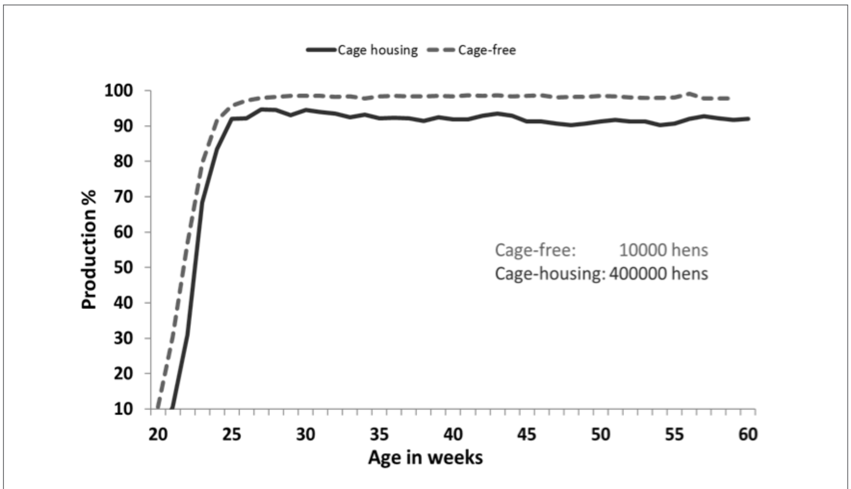

Figure 4. Comparison in egg production between stand-alone cage-free houses and multiple age cage-housing (LSL-Lite in USA)

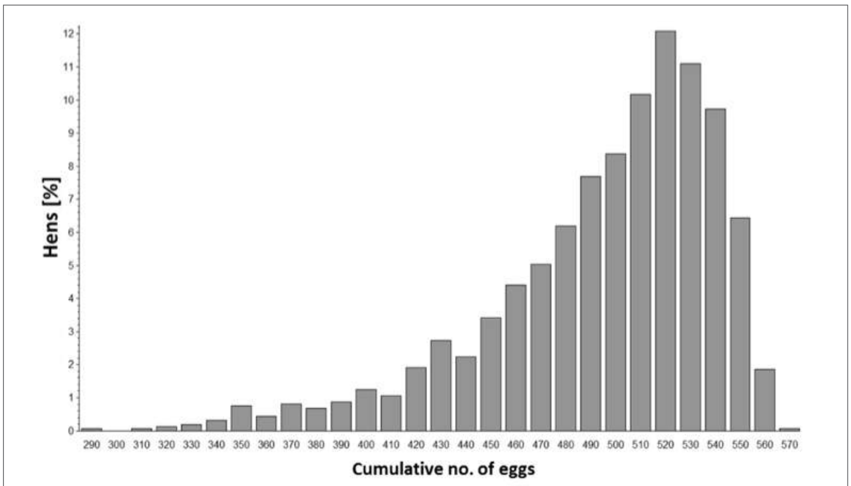

Figure 5. Distribution of the cumulative egg numbers in 574 production days

1613 hens with similar genetic background were tested individually over a period of 82 production weeks (21 to 102 weeks of age). In the 574 production days, 56% of all the hens reached the target of 500 saleable eggs. Birds need 515 to 574 days to produce 500 eggs. The maximum clutch size was up to 400 days without any breaks in between. Despite a very long clutch length of the majority of the birds, there is still a significant number of hens producing less than 400 eggs while others produce 100 or 150 eggs more at the same time **(Figure 5)**.

If we look into more details of daily egg production as demonstrated in **Table 2**, we can see a typical pattern of clutches interrupted by a break of 1 or 2 days without an egg. Clutch length does not follow a very strict pattern. In the second half of the production cycles, clutches got shorter without an extended increase in the length of the pause.

Animal behaviour

Over decades, in all parts of the world, beak trimming has been used to prevent feather-pecking in poultry. Feather-pecking is caused by a lot of factors. No single big gene effect can be expected to control this multifactorial problem **(Figure 6)**.

Increasing ethical reservations have caused a ban on beak-trimming including the infrared treatment even on day-old chicks in the hatchery. Since July 1st 2016, a ban on beak treatment was introduced for 80 million hens under the auditing system of KAT ('Kontrollierte Alternative Haltung' – Controlled Alternative Husbandry) in Germany. Branded eggs from Germany, The Netherlands, Austria, Italy and France with the quality label of KAT, represent about 80 million hens in Europe. There is a high probability that other countries and/or marketing organisations will follow this trend.

An indirect approach to reduce the risk of feather-pecking and cannibalism, can be done by means of manipulating the shape of the beak by genetic selection. Before a new trait can be introduced to a commercial breeding programme, the trait has to be measured with high accuracy and the heritability has to be estimated. Repeated measurements on the same individuals can increase the power of selection. Also progeny testing is an option to increase the number of records and the power of selection, however, progeny testing is very costly and time consuming.

A special device was developed to measure beak shape in terms of the extension of the upper beak beyond the lower beak in pedigreed hens and to evaluate the usefulness of this criterion as an additional selection criterion to reduce feather pecking. The working hypothesis was that birds with blunt beaks should be less inclined or less successful in pulling feathers from group mates or starting cannibalistic behaviour.

The heritability estimates for beak shape at 45 weeks of age range from 0.13 to 0.25 and from 0.09 to 0.26 for four lines each of the Lohmann Brown and LSL breeding programs, respectively. These genetic parameters and the high variability of the trait suggest that a reduction of beak length through genetic selection should be feasible. The heritabilities are at a similar level as for traits like plumage condition or persistency of egg production (Icken et. al, 2017). As shown in **Figure 7**, the special device to measure the upper beak length, gives a good indicator for the shape of the beak and the length of the hook.

Bone quality

With an increased production cycle length, skeletal integrity and bone fracture in layers are gaining more importance. Bone strength and shell strength are competing characteristics. Housing system, animal nutrition and genetics are two important factors (Bishop et. al 2000, Fleming et al. 2006).

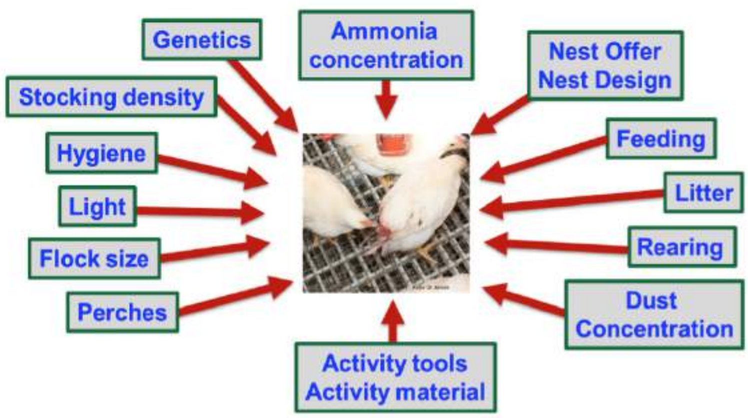

Figure 6. Factors which can cause feather-pecking and cannibalism in layers

500 eggs in 515 days	⇔	97 % egg production
		Clutch pattern
+ 3 eggs in the 1st clutch	➡	2 days off
+ 25 eggs in the 2nd clutch	➡	1 day off
+ 16 eggs in the 3rd clutch	➡	1 day off
+ 180 eggs in the 4th clutch	➡	1 day off
+ 68 eggs in the 5th clutch	➡	3 days off
+ 108 eggs in the 6th clutch	➡	1 day off
+ 31 eggs in the 7th clutch	➡	2 days off
+ 17 eggs in the 8th clutch	➡	1 day off
+ 19 eggs in the 9th clutch	➡	2 days off
+ 22 eggs in the 10th clutch	➡	1 day off
+ 11 eggs in the 11th clutch		
500 eggs in 515 days		

Table 2. Egg numbers presented in laying sequences or respectively, clutch sizes for a recording period of 515 days

Measuring bone characteristics retrospectively after the breeding hens are slaughtered at the end of the laying period, cannot be implemented efficiently in a commercial breeding programme. That means, excessive progenies have to be produced and selected on the bone characteristics of their dams.

A viable alternative for genetic selection should be based on the assessment of bone quality of the selection candidate itself. The method should be fast and accurate to screen all selection candidates for quality. Two different options have been used to score the bone quality in adult leghorn pedigree hens. Birds were housed in enriched single bird cages with a perch, nest box and a scratching area. A subjective human scoring of keel bone deformation was performed on a scale from 1 to 3 (Anderson, et al. 2017) for almost 6000 hens.

Keel bone palpation was done at 46 and 70 weeks of age. Ultrasound measurement of the humerous were taken at 64 weeks of age. In this study, both traits show reasonable heritabilities with a small advantage for the male line. Keel bone assessment can be done much faster as compared to ultrasound examination, showing similar heritabilities **(table 4)**. Future studies have to show which traits reflect the risk of bone breakage better. It can already be concluded, at this stage, that phenotypic recording of bone quality in live birds can contribute to better bone quality when it is included in the selection index. Both traits are available during selection and will be part of the balanced selection approach in commercial layers. An additional and major step forward, in bone quality, can be achieved if genetic markers for osteoporosis would be available for selection (Dunn, et. al 2007).

Figure 7. Measuring the upper beak length

Conclusion

Primary breeders will continue to invest in additional testing capacities which reflect typical field conditions in different markets. At the same time, the genetic basis of the elite lines will be expanded to accommodate the demand of growing markets, which in turn will minimise the rate of inbreeding and the risk of losing valuable genetic variation. A special program to match selected males and females at the pedigree level assures that inbreeding effects are minimized and genetic progress continues at a predictable rate.

Advances in molecular biology have contributed to new techniques for selection. Using informative genetic markers, geneticists can identify individuals and families with special characteristics early in life and thereby accelerate improvements in egg production, egg quality, behaviour and liveability. These innovations complement traditional performance testing and evaluation methods based on phenotypic selection indexes of production, efficiency and quality parameters.

Combining all available performance records from relatives in several generations, locations and housing systems, requires powerful computer programs, but assures that the best males and females are selected and mated to generate the next generation. Additional information based on DNA analysis is combined with traditional breeding values to select males at an earlier age and to differentiate among full brothers, which used to have identical breeding values from sib testing before DNA information became available. The combination of performance testing as described above and genome wide analysis is a promising tool for developing new strain crosses with a performance profile tailored to specific requirements.

The current rate of genetic progress for total efficiency of egg production appears to be even greater than it was 20 years ago. An improved structure and increased size of breeding populations, the application of new testing and recording technologies and more powerful computer systems for breeding value estimation have contributed to more efficient use of existing genetic variation. The application of high throughput DNA screening using dense genome-wide SNP markers, is very valuable for selective breeding by so-called 'genomic selection'. In genomic selection, the focus is not to estimate the effect of some specific genomic regions, but to use the combined effects of thousands of genome-wide SNP markers to estimate the breeding values of the pure line chickens more reliably in both sexes. In the future, when costs for commercially available SNP would be further reduced, genomic selection will play an even greater role in improving the rate of genetic progress for layers used in conventional and non-cage environments. All selection candidates can be screened even in the rearing period before any phenotypic data are available.

Table 3. Heritability for beak length in LSL and Lohmann Brown pure lines

Line	LSL	LB
A	0.21	0.21
B	0.24	0.25
C	0.09	0.13
D	0.12	0.16

Table 4. Heritability for keel bone examination and ultrasound examination of the humerous in LSL pure lines

Trait	Male line	Female line
Keel bone assesment*	0.30	0.15
Ultrasound examination	0.20	0.17

Subjective human scoring of keel bone deformation (scale 1-3)   Reference: Anderson et al. 2017

Finally, we should realize that increased genetic potential needs to be "translated" into reality in commercial practice. Disease control, farm management and nutrition have to keep pace with genetic improvements, and more efficient production is no guarantee for a sustainable farm income should the markets be oversupplied.

In the coming years, the prosperity of the egg industry will be driven by genetic progress and adjusted husbandry systems. Animal welfare will play a major role. Key indicators will be general liveability, good feather cover until the end of the production cycle, and strong bones. Breeders have to focus on a balanced breeding goal to cover the demand of the growing human population for high quality protein.

Accurate data recording in different environments, combined with genomic data, will make selection faster and more accurate, and enhance progress in persistency in rate of lay and late shell quality. The ultimate target will be increased cycle length in order to boost lifetime egg production per hen housed.

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The British Egg Industry - preparing for the Brexit

Abstract

The British egg industry is an excellent example of how an agricultural sector can innovate and embrace technology to become increasingly efficient, and to be reactive to consumer demand. It also employs the highest standards of food safety through the industry's Lion Quality assurance scheme. The key influences on the industry include: continuing to meet supply/demand, with demand having led to the UK being the largest producer of free range eggs in the EU; ensuring that eggs are produced to the highest standards of food safety via the Lion Code of Practice; protecting and promoting high standards of animal welfare; ensuring animal health by protecting birds from disease challenge; protecting the environment and ensuring that international trade agreements recognise the UK's high standards. The decision of the UK to leave the EU ("Brexit") is going to have significant implications for individual businesses, as well as the country in general. For the egg industry, there will be both challenges and opportunities. Some of these include the need for continued access to labour; ensuring future trade agreements do not allow lower standard imports; avoiding an excessive legislative burden. The egg industry in the UK has just enjoyed its 12th continuous year of growth, which is a huge achievement. But it is always alert to emerging issues and will take action to prevent them becoming a crisis.

Keywords

Egg Production, Lion Quality, Brexit

Introduction

The British egg industry is an excellent example of how an agricultural sector can innovate and embrace technology to become increasingly efficient, and to be reactive to consumer demand. It also employs the highest standards of food safety through the industry's Lion Quality assurance scheme. How did the industry get to where it is today? Part of the answer probably lies in having been subject to the so-called 'light' regime of the

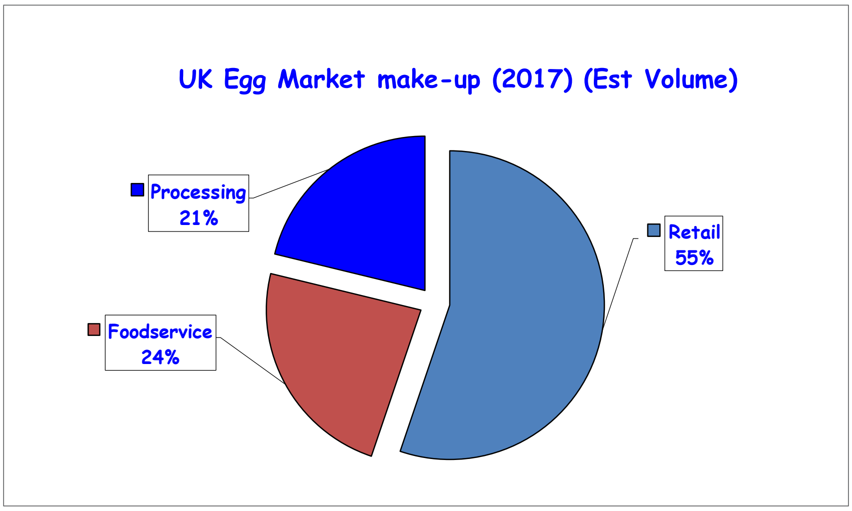

Figure 1: UK egg market by market segment (2017). (Source: BEIC)

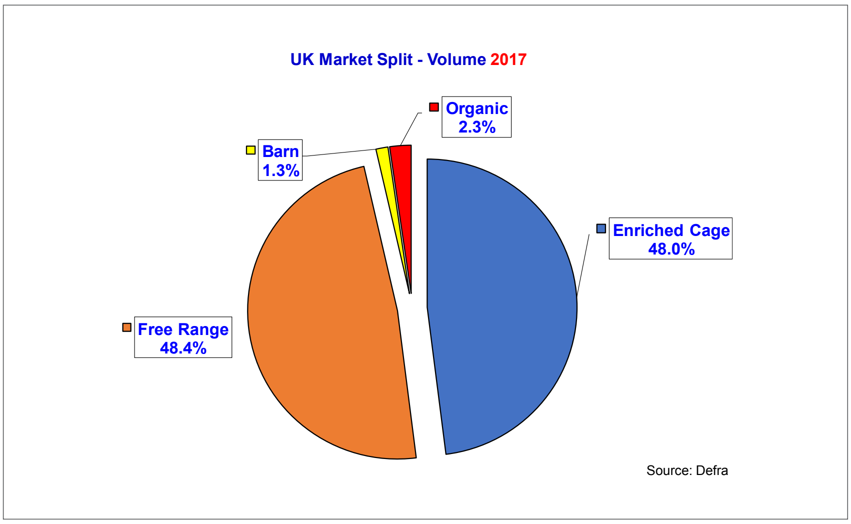

Figure 2: UK egg production by egg type through packing stations (2017). (Source: Defra)

European Union's Common Agriculture Policy, which has meant it has not received production support, leading to its focus on market orientation. Secondly, the 'Salmonella in eggs' crisis of the late 1980s and early 1990s when the then Junior Minister of Health stated that '"sadly, most egg production in the UK is now infected with Salmonella" had a major impact. This sparked a crisis, with sales falling by more than 50% overnight with many businesses failing over the following months and years. Even during the 1990s eggs were blamed for any food poisoning case, guilty or not. Consumer confidence ebbed away and consumption continued to fall by up to 8% year on year.

Realising that something had to be done, the forward-thinking members of the British Egg Industry Council undertook a major consumer research programme to identify how it could address falling sales and restore consumer confidence. Two major developments were put in place. The first was a complete revision of the Lion Code of Practice to: introduce compulsory vaccination of hens against Salmonella; to improve hygiene standards on farms and to ensure that rodents were properly controlled. The second was the first major advertising campaign for 20 years, with a £4 million television campaign promoting eggs and the British Lion mark.

The success of the scheme can be seen in the massive reduction in Salmonella in British laying flocks, as well as in humans. This has been recognised over the years by government, customers and consumers, and culminated last autumn in the British Food Standards Agency revising its long standing advice (effectively a health warning) on eggs to enable vulnerable groups (pregnant women, babies, and elderly people) to be able to eat runny Lion eggs again. This removes the final negative which surrounds eggs and we anticipate that this will lead to a further increase in egg consumption.

In 2017, egg consumption further increased to 197 eggs per capita, and self-sufficiency rose to 86%. Today, the industry has expanded to 40 million hens, making it the 5th largest producer in the EU.

Figure 1 shows that 55% of eggs were sold at retail level, with a further 24% sold in shell at food service level. 21% are processed into various egg products.

Figure 2 shows that the key production types are free range and enriched colony cages, with barn and organic making up the balance. In fact, of the 54 million free range hens in the EU, 22 million are to be found in the UK.

The key influences on the industry include: continuing to meet supply/demand (the market); ensuring that eggs are produced

[1] *Based on an invited paper, presented at the EggMeat Symposium of the WPSA 2017 in Edinburgh*

to the highest standards of food safety; protecting and promoting high standards of animal welfare; ensuring animal health by protecting birds from disease challenge; protecting the environment and ensuring that international trade agreements recognise the UK's high standards.

The decision by the UK to leave the EU (Brexit) is going to have significant implications for individual businesses, as well as the country in general. For the egg industry, there will be both challenges and opportunities. Some of these include;

- ➔ The need for continued access to labour
- ➔ Ensuring future trade agreements do not allow lower standard imports
- ➔ Avoiding an excessive legislative burden

Taking each in turn:

The need for continued access to labour. At present approximately 30% of workers in egg packing centres and on farms are from other EU member states. With UK unemployment at just 4.4% (December 2017), its lowest level for many years, this is already presenting particular challenges, with many companies struggling to retain staff due to competition from other sectors. Some non-UK nationals are returning home as the devaluation of Sterling has meant that it is no longer as financially attractive to work in the UK. As a result, the egg industry is seeking to retain existing and attract new staff by actively promoting career opportunities to UK workers at farm, packing and managerial level. The BEIC has also launched the Lion Training Passport, designed to both attract and retain staff. The industry remains of the view that government must allow businesses access to labour from outside the UK, year-round.

Future trade agreements. Successive UK governments have traditionally been supporters of free trade. However, with the threat of food price inflation following the fall in the value of Sterling, it could be attractive for the government to pursue a 'cheap food' policy to reverse this trend. We believe that a 'fair trade', rather than 'free trade', policy should be pursued to avoid damaging the UK industry from eggs/egg product imports which are produced to lower standards.

Legislation The industry is proud of its high standards of animal welfare and environmental protection and does not wish to see these weakened following Brexit. In the past, UK governments have been guilty of 'gold-plating' legislation, by going beyond the minimum, which has led to competitiveness issues. We support further improvements to standards, but these must be based on research and sound science.

In July 2017, the House of Lords Energy and Environment Sub-Committee inquiry into Brexit: (farm animal welfare) concluded; "Government will have to choose between 2 approaches post Brexit, either to become a low-tariff, competitive New Zealand-style economy, open to free trade in order to bring down food prices accepting that high-quality food and welfare standards will be difficult to enforce, or to continue to be a country that demands high welfare standards, high-quality food and looks to protect our hill farmers".

1.**'Cage-free'.** In 2016, most retailers and some food service companies announced that they would be moving to a 'cage-free' policy by 2025. This will be challenging for the industry, especially as it invested some £400m to comply with EU Council Directive 1999/74, which banned conventional cages across the EU from 2012. The question now being discussed is: 'what will this look like? Will it be barn or free range?'

Avian Influenza. The threat of Avian Influenza is likely to remain in the near future, and, as such, serves to remind producers of the importance of implementing and maintaining high standards of biosecurity on farms. Just like many other European countries, the UK was affected by H5N8 Highly Pathogenic AI during winter 2017 through to spring 2018, albeit the UK saw fewer cases in poultry flocks.

The industry rose to the challenge by providing timely reminders of the importance of separating poultry flocks from wild birds. The requirement to house free range birds from December 2016 to April 2017 came with its challenges, especially the need for producers to provide additional management measures for their birds which had been used to ranging outside. Industry lobbying at EU level led to an amendment of the EU egg marketing legislation in November 2017 to allow free range hens to maintain their marketing status for up to 16 weeks (previously 12 weeks) should they be required to be housed under veterinary instruction. A working partnership between government and industry meant that cases were identified and dealt with quickly, which enabled infected farms to get back into production, as well as regaining 'country freedom' from HPAI status, therefore reopening international markets.

On the research front, industry funded a risk assessment supporting a review of the requirements for secondary cleansing and disinfection which was published in April 2017. This showed that complex equipment that does not come into contact with birds does not need to be dismantled to be cleansed and disinfected. What this means in practice to a site infected by AI is that the time taken to conduct secondary cleansing and disinfection will be shorter and therefore the cost to the producer will be lower.

Northern Europe has seen findings of H5N6 HPAI in wild birds, rather than poultry flocks this winter, but the industry has not become complacent.

Although we are seeing occasional findings in wild birds, something we expect to see continue, the UK industry is well placed to deal with any threat to commercial poultry. The industry's Lion Code of Practice has been amended to further improve biosecurity, this along, with the industry's structure means that we are confident that any protective measures would be taken quickly and effectively to avoid major issues.

From the dark days of the Salmonella crisis to where it is today, the industry has made huge progress principally via the Lion Quality scheme and its high standards. It operates some of the most modern systems in the world, providing high quality, safe, affordable eggs and egg products to consumers. Consumer confidence has been restored via the Lion Quality mark and we have seen retail sales rise year on year by more than 5%. Encouragingly, this growth is being driven by younger consumers who see eggs as a natural healthy choice.

Backed by some innovative marketing campaigns using influencers from Olympic athletes such as gold-medal winner, Max Whitlock, to reality TV stars, the BEIC's marketing campaigns have ensured that consumers now think of eggs as a 'superfood'. Our recent campaigns have been more visual, increasingly using video to demonstrate how quick, easy and convenient creating an egg-based meal is.

The recently revised Food Standards Agency advice is also re-opening markets such as in Care Homes which had previously avoided runny eggs and the BEIC is now actively encouraging them to get eggs back on the menu.

Outlook

Coming from an industry where sales were falling by 8% to one which has just enjoyed its 12th continuous year of growth is a huge achievement and the industry can be proud of its achievements. But we are always alert to emerging issues and will take action to prevent them becoming a crisis.

By way of background, the BEIC is the inter-professional trade association representing the interests of egg sector organisations and businesses in the UK. Its members are 11 egg industry organisations. It has three roles: to represent the UK industry on political/lobbying issues; it owns and administers the Lion Quality scheme for eggs, which currently accounts for more than 90% of UK egg production; it funds and runs the British Egg Information Service, whose role it is to promote Lion Quality eggs and egg products via advertising and promotion campaigns; and it funds research and development.

Paul McMullin

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The Prohealth Project: A review of some of the findings of relevance to the poultry industry

Abstract

The EU-funded Prohealth project aims to improve the health of conventionally farmed poultry and pigs by a wide-ranging programme of research into the causation of so-called "production diseases". The project consortium includes a broad range of skills and interests, including experts on research on consumer attitudes. Here we review the general background to the project and then consider results in the area of consumer perception, biosecurity assessment and establishment of normal gut flora in young birds. The project web-site includes newsletters and references to other project areas also of interest to poultry producers.

Keywords

egg, egg consumption, microbiology, production disease, microbiome, biosecurity, farm hygiene, hatching egg sanitation

Introduction

In 2012 the EU Commission announced its intention to fund research under Framework Programme 7 on **Sustainable animal production: an integrated and multi-factorial Approach.** The aim of this was to contribute to our understanding of the multi-factorial dimension (infectious agents, genetics, nutrition, and management factors) of diseases of poultry and pigs "linked to the intensification of production, so-called 'production diseases'", and so to help us to arrive at effective control strategies and reduce the impact on animal health and welfare. I was asked to help a consortium of 22 partners led by the University of Newcastle and one of our first tasks was to define what a 'production disease' is (the term had previously been applied mainly to metabolic diseases of ruminants). The definition we proposed was

"Diseases which tend to persist in animal production systems and, typically, become more prevalent or severe, in proportion to the potential productivity of the system". Our bid was successful and the Prohealth project started in December 2013 and will run until November 2018. Our consortium includes a broad range of partners including academic institutions, breeding companies, and small and medium enterprises relevant to the project objectives. They are active in 10 different EU member states and one associated country and have, collectively, a good geographic spread and involvement in poultry and pig production.

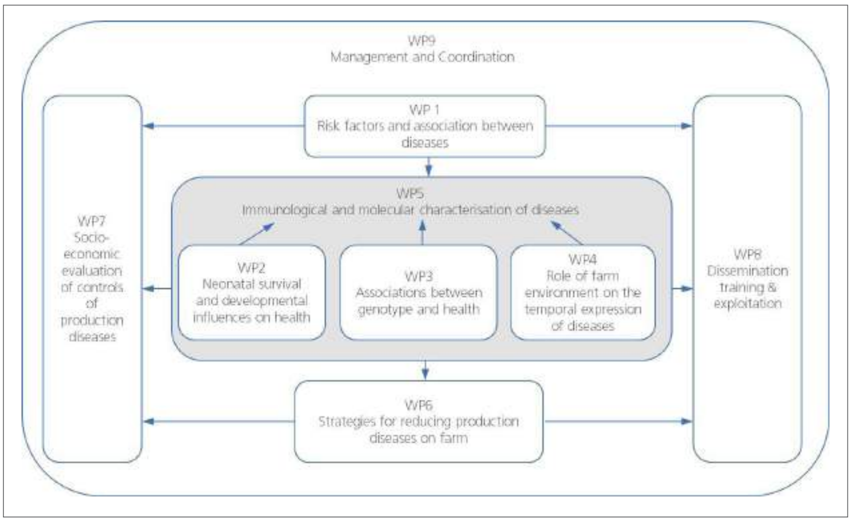

Figure 1 Project Overview

The project has a broad ranging and ambitious set of objectives to:

- identify the risk factors for production diseases and establish associations between diseases;
- explore the role of genetic and environmental factors on neonatal survival and in exerting longer-term developmental influences on health;
- evaluate the effects of genetic selection for productive traits on susceptibility and identify strategies to mitigate these;
- determine the role of variation in farm environment on the temporal expression of production diseases;
- characterize the microbio-immunological changes and identify pathological changes at the molecular level which take place during production diseases in order to develop diagnostic tools;
- synthesize strategies to reduce the impact of production diseases on a farm and assess the efficacy of improvement strategies in reducing disease prevalence or severity; and
- identify economically viable and socially acceptable ways to control pathologies, with emphasis on animal welfare implications.

Much more detail is available on the project web-site http://www.fp7-prohealth.eu .

The work has been organised in a series of work packages to target a range of issues in the areas outlined below. Much has been achieved on the basic characterisation of production diseases and their risk factors in poultry. Work is currently ongoing on some selected interventions based on these findings and this will be reported in due course. Here we will briefly review some of the completed work which is likely to be relevant to poultry production now and in the future.

Social Science and Economics

Clark et al (2017) have published the findings of their detailed meta-analysis of consumer attitudes to farm animal welfare and identified a gap in relation to the control of production diseases in livestock. They did find quite a lot of variability in attitudes to modern farming but they also identified willingness to pay a small premium for products associated with improved disease control and welfare. They found that consumers mostly view modern production systems negatively and tend to voice concerns about naturalness and humane treatment. Many they also tended to be focussed on human health concerns. Most consumers had little knowledge about production diseases and how they are controlled, though they did tend to refer to antibiotic use. The same research group have gone on to carry out a large survey of consumer attitudes in 5 European countries. A range of possible interventions were presented and, for layers, the order of preference found was as shown in **Table 1**. Considering that the consumer claims to have little technical knowledge about the topic they appear to have chosen quite sensibly those topics which might be grouped as 'good management' as their preferred approach. Given the identified low premium that they are willing to pay, some of these approaches may not always be economically viable. However, broadly speaking, this work supports the approach the layer industry has been taking for many years, of focussing on controlling any egg-associated human health risks and offering products produced in different systems. This work also helps us focus on specific disease control mechanisms which have consumer acceptance and emphasises that 'do nothing' is the least favoured approach.

Biosecurity

Although biosecurity was not included as a specific intervention in table 1, it is a significant component of the number 1 choice, “Enhanced hygiene and disease prevention measures”. It is, of course, high on our list of priorities currently because the unusually high numbers of avian influenza outbreaks in both wild birds and poultry over the past few years. Colleagues at the University of Ghent have developed detailed questionnaires to help poultry producers assess their biosecurity practice and also applied these independently on farms of different types. It only takes about 20 minutes to carry out the survey and the system immediately gives a report with suggestions for areas of improvement. Separate biosecurity surveys are freely available for broilers and layers :

Layers: https://www.survey.ugent.be/lime/index.php/519199/lang-en

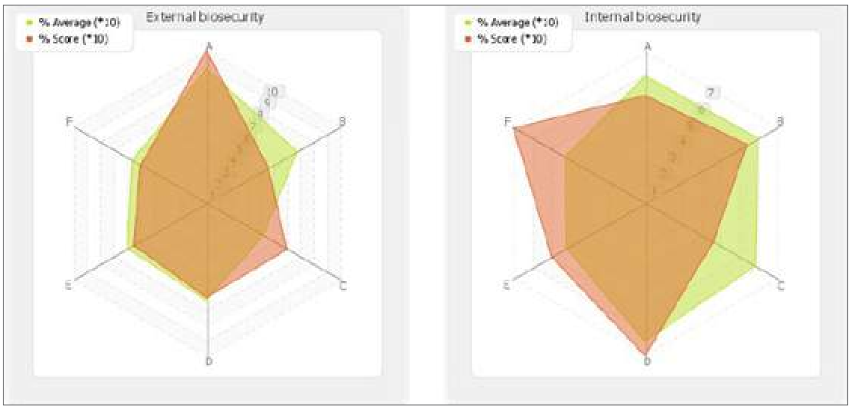

Figure 2 Biocheck Graphic output

Broilers: https://www.survey.ugent.be/lime/index.php/981521/lang-en

The graphic output is intended to allow each user to see how he is doing for both ‘external’ biosecurity (between the farm and the rest of the environment) and ‘internal’ (within farm). Perfection would be 100% in all categories (and would be shown as a red hexagon with the maximum score all way around). The red hexagon represents the score of the respondent and the green the average of all respondents. The developers point out the benefit of repeating the survey after having done improvements to see the effect on scores. A total of 124 layer farms were visited for assessment of biosecurity in 3 countries (T. van Limbergen, pers.comm.). These included enriched cages, deep litter and perchery systems. Internal scores were, on average 71% whereas external scores were 62%. The best scores were those relating to egg management (88%) whereas the poorest related to the entry of staff and visitors (41%). This points to some relatively simple and inexpensive opportunities for improvement, by focussing on procedures and systems for the entry of staff and visitors.

Farm Hygiene Assessment

A key aspect of within-farm biosecurity is effective cleaning and disinfection between successive flocks in the same farm and building. With increasing regulatory focus on the approval of biocides and protection of the health of workers it is important to carefully monitor these processes. Visual assessment is an important component of this but does need microbiological assessment for confirmation.

Table 1. Consumer preferences with respect to disease control interventions in laying chickens

Order	Intervention
1	Enhanced hygiene and disease prevention measures
2	Housing that allows birds greater freedom to move
3	Providing materials and an environment where animals can perform natural behaviours
4	Reducing the number of animals in a given area
5	Improvements in housing design
6	Enhanced maintenance of the quality of the bedding
7	Housing that protects the animals from adverse natural conditions
8	Providing a price premium that encourages enhanced animal health
9	Enhanced control of air movement in the houses
10	Adjustments to feed or diet composition
11	Changes in the amount and time of light provision
12	Adjustments to the quantity of feed available
13	The use of vaccination
14	Using antibiotics and medicines to treat sick animals
15	Use of feed supplements e.g. probiotics
16	The preventative use of veterinary drugs including antibiotics
17	Doing nothing

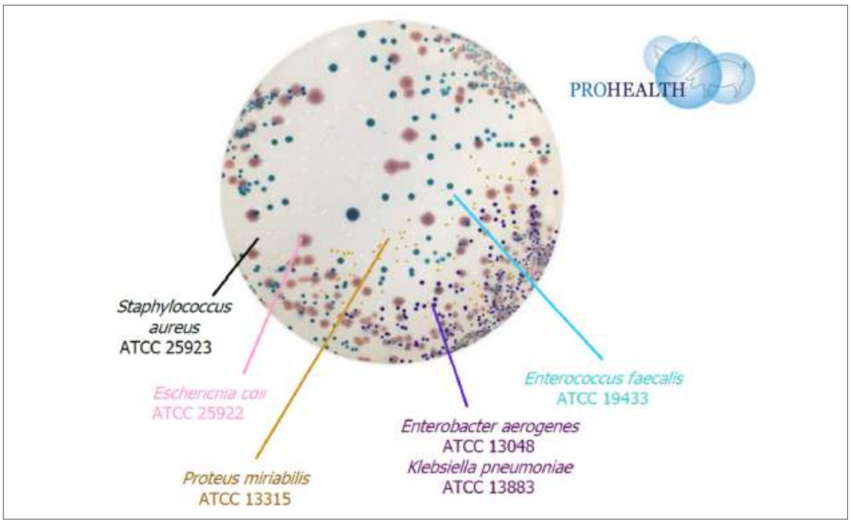

Figure 3. Colony colour and morphology on UTIC agar – similar formulations are available from different suppliers.

Many assurance schemes require specific measures such as absence of Salmonella sp, or Total Viable count on hygiene swabs. Absence of Salmonella is very important but tells little about the efficacy of disinfection against other flora, whether pathogenic or beneficial. We developed a simple protocol to semi-quantitatively assess the microbiology of environmental and post-placement samples. Post-placement samples were, mainly, boot swabs but also included dusts, chick-papers etc. These were in varying proportions among the types of birds examined in accordance with the types of samples normally submitted for other purposes. Briefly, the method involves a peptone pre-enrichment (so that we are focusing on microbes which favour body temperatures, and also reduce variability associated with intervals from sampling to testing). The broths are then diluted and swabbed and streaked on a chromogenic medium developed for human urinary tract infections (UTIC), and separate media to detect lactobaccili, pseudomonads, and staphylococci. Scores are logarithmic and take into account dilution where appropriate. The novelty of the technique lies in the use of a single chromogenic agar allowing identification of major classes of bacteria (Figure 3), and the use of an enrichment to provide more consistent results and favour pathogens.

Over 2500 poultry-origin samples were examined by this method over a 15 month period. The mean scores obtained on post cleaning and disinfecting samples from pullet and layer farms are shown in table 2. The rough spectrum of "patho-potential" runs from low on the left to high on the right, and the areas are sorted by the combined E.coli + Staphylococci score. The mean scores are generally satisfactory, and Lactobacilli and enterococci are commonly present. Higher scores of pathogens in this series were more common from water tanks and drinkers, walls and floors.

This relatively low-tech approach may be helpful in addressing the challenge of controlling production-related disease and maintaining productivity with reduced use of anti-microbials.

We went on to compare pre-placement hygiene and post-placement (boot swab) samples evaluated with the same technique in over 800 samples from broiler

Table 2. Scores for post-cleaning and disinfection environmental swabs

Source	Tested	Lactobacilli	Enterococci	Coliforms	Proteus	Pseudomonas	Staphylococci	E.coli
Water Tank	66	2.33	1.73	0.88	0.76	0.32	2.14	1.29
Walls	93	1.90	1.39	0.97	0.16	0.56	1.74	1.42
Drinkers	93	1.98	1.24	0.98	0.18	0.42	1.67	1.44
Floor	93	2.11	1.16	0.90	0.16	0.47	1.58	1.53
Air inlets	109	2.28	1.43	0.82	0.34	0.55	1.98	1.12
Feeder	57	2.07	1.21	0.70	0.12	0.21	1.74	1.21
Fan(s)	83	2.12	1.04	1.04	0.11	0.54	1.48	1.36
Feed Bins	48	1.94	1.06	0.50	0.06	0.04	1.60	0.92
Service area	48	1.92	0.92	0.96	0.17	0.17	1.60	0.90

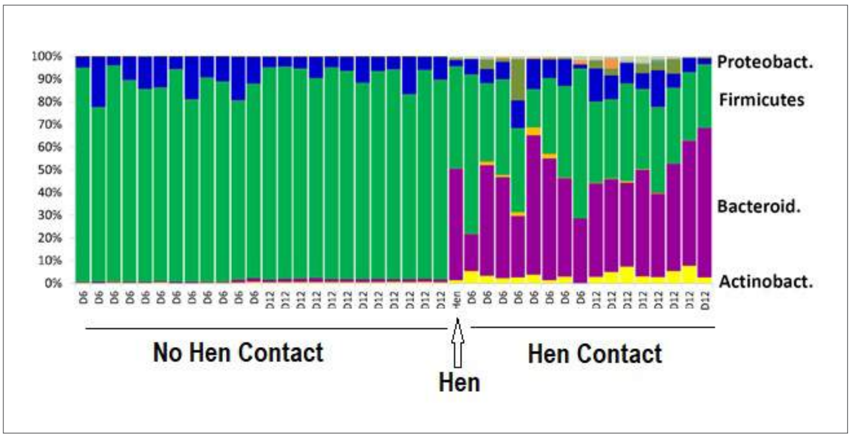

Figure 4. Caecal microbiome assessment of individual layer type chicks at 6 and 12 days of age, with and without direct exposure to an adult hen (with the pattern of the hen shown in the middle of the chart).

chickens and to evaluate associations with health and processing reject parameters (McMullin et al 2017). It was possible to identify clear differences in microbial profiles between samples and sample types. Residual bacterial contamination of farm environments showed clear positive and negative associations with particular flock traits relevant to production disease. There were also significant associations between specific genera in boot swabs samples and relevant flock traits. The analysis supports the need for intervention strategies which focus broadly on the relationship between pathogen and beneficial organisms along the lines of the "Weed/Seed/Feed"-type strategies which are being used increasingly in the poultry industry.

Hatching Egg Sanitation

Colleagues in Denmark and Cyprus have recently published the results of their studies on egg sanitation (Olsen et al. 2017). This work is particularly interesting because there is wish to develop alternatives to formaldehyde in egg fumigation. It demonstrated that repeated treatments can substantially reduce microbial loading of egg surfaces and went on to study the detailed microbiome of egg surfaces. The authors rightly point out that conventional microbiology will only identify culturable bacteria and that 16S RNA sequencing will allow identification of all bacterial species colonizing the eggshell of hatching eggs, but it will not distinguish between live or dead bacteria.

There may be a role for the use of the enhanced hygiene monitoring protocol in routine checks of egg sanitation to help focus on viable organisms of key pathogenic classes, supplemented by molecular techniques where more detail is required.

Establishment of normal intestinal flora

Our colleagues in the Institute of Veterinary Research at Brno provided support to various parts of this project, especially in relation to the composition of intestinal and caecal flora using sequencing of 16s RNA products to classify bacteria regardless of culturability. A nice example of this (Rychlik, 2016) was a series of experiments in which one group of layer chicks were reared from day of age with an adult hen, the other without. Exposure to the hen resulted in a much more diverse and adult-like flora as early as 6 days of age **(Figure 4)**. They have repeated this study on a number of occasions with similar results giving them confidence in the repeatability of this phenomenon. Separate work has demonstrated that establishment of an adult-like flora can take 4-16 weeks in conventionally reared chickens.

Rearing commercial pullets along with adult chickens would be likely to have unintended adverse consequences, by, for example, increasing spread of pathogens and heat-stressing the hens. However this work emphasises the potential benefit of using defined or undefined adult flora administration in very early life to help replicate the flora maturation which would occur naturally through exposure to adults. This approach has been widely applied to reduce risk of colonisation with Salmonella sp for over 30 years (Wierup et al, 1987). Recently in-hatchery administration of such products has begun to be widely applied as an alternative to "starter" medication with antimicrobials.

The same group (Varmuzova et al 2015) have gone on to use a Salmonella Enteritidis challenge model to demonstrate a very obvious activation of inflammatory markers **(Figure 5)** at day 4 after infection, which was declining by day 14 post infection. The inclusion of 2 plant extracts in the feed markedly reduced this response. However detailed examination of the microbiota showed that the combination of SE challenge and plant extract supplementation resulted in the greatest deviation of flora from the normal pattern. So far this experiment has only conducted once so these findings should be interpreted with caution. While Salmonella Enteritidis is becoming a rare occurrence in most European countries, other pathogens may well interact with the immune system, the microbiota and use of nutritional supplements to destabilise gut flora.

Gene markers and disease

The team at the University of Nottingham veterinary school, has been conducting wide-ranging research on gene-activation associated with disease in poultry, including, in particular coccidiosis and clostridial infection. They are particularly interested in a case of leg weakness in 10 week-old brown-egg layer strain pullets with a histopathological diagnosis of lymphoplasmacytic neuritis. They analysed lymphocyte expression and found that the CD72 gene was up-regulated in these birds. The preliminary findings suggests that while CD8-type cell numbers may be increased, they may not function properly. It is possible that this work will help improve our understanding of so-called B-type Marek's lesions and/or idiopathic peripheral neuropathy.

Other activities

Here we have reviewed only a small proportion of the work carried out under the Prohealth project relevant to poultry. Both the topics discussed and much other useful work carried out in a range of areas will be of interest to the industry. A scientific conference is planned to take place on November 27th/28th 2018 in Ghent, Belgium. Various publications are planned and the web site(http://www.fp7-prohealth.eu) is a good way of following these developments.

Finally, readers may find the recently-launched "Online Poultry Journal" of interest. This initiative by the consortium provides a consolidated news feed from different sources on topics relevant to poultry and pig health.

This 'Online Poultry Journal' may be accessed at: http://www.fp7-prohealth.eu/knowledge-platform/online-poultry-journal/

PROHEALTH

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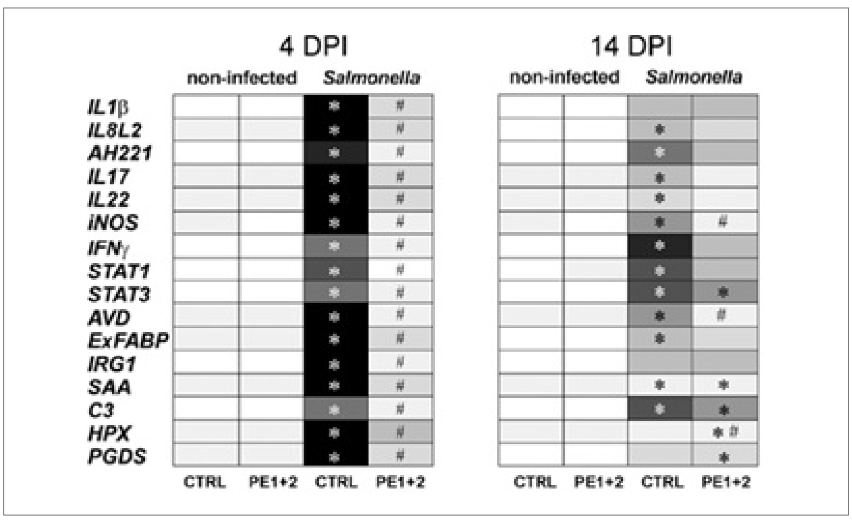

Figure 5. Expression of cytokines and acute phase genes in chickens after S. Enteritidis infection. CTRL = Chickens fed control diet; PE1+2 = Chickens fed control diet supplemented with plant extracts. Darker shading indicates higher expression level.

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Lighting of Poultry Houses to Meet the Needs of Bird Eyes

Abstract

Bird eyes generally differ from human eyes, especially within spectral sensitivity and their ability to resolve temporally varying stimuli. Up to now, measurements of light in poultry houses and assessment of illuminants are still based on parameters developed for human perception of light. Differences in the anatomy and physiology of human and avian eyes should be taken into account in order to optimize the lighting conditions in poultry houses. It can be assumed that natural daylight corresponds most closely to the requirements of a bird. Suitable illuminants should cover the whole spectrum contributing to the reception of light, including UV-A light. Spectral data can be compared with reference values for chickens and turkeys, based on their natural habitats. The emitted light frequency should be at least 120 Hz. As a precaution it is advisable to strive for flicker rates in lighting systems including a buffer-range. The comparison of different illuminants offered for poultry houses indicate a need for more research and development to improve the light quality in poultry houses. Furthermore procedures for testing light intensity must be developed which will show the brightness perceived by commercial poultry. Light intensity in poultry houses are commonly measured with lux meters, which cannot detect UV-A light, even though these ultraviolet wavelengths contribute to brightness perception in birds. As a practical approach, tests of light intensity in functional areas of non-cage systems (e.g. feeder and rest area) are recommended, corresponding to varying preferences for different functions.

Keywords

artificial lighting, photometric units, daylight wavelength, UV-A, animal welfare.

Introduction

Light plays a critical role in the development of feather pecking and cannibalism (Kjaer and Vestergaard, 1999; Kjaer and Sørensen, 2000). The risk and prevention of these misbehaviors is a major challenge if pullets are not beak-treated and laying hens kept in cage-free systems. Good management practice for poultry kept in closed houses must therefore pay special attention to lighting. First of all, it must be understood that the anatomy and physiology of the bird's eye differs from the human eye (Reese et al., 2009).

Light affects poultry by two biological mechanisms: visual perception and effects on the physiology of the birds. The visual perception enables the bird to see pictures. Inside the eye is the retina, an epithelial layer with photosensitive receptors, including cones for (photoptic) seeing of daylight and rods for (skotoptic) seeing of nightlight. Physiological effects of light are important e.g. for endocrine functions, the circadian rhythm and sexual behavior (Lewis and Morris, 2000). Light also affects the hypothalamus and controls the release of sex hormones from the gonads via the gonadotropin releasing hormone (GnRH). Physiological effects of light are used in poultry production, for example, to control the onset of lay or to induce a molt.

Measurement of the bird's perception of light is essential and a major challenge in developing optimal lighting programs. Parameters describing the quality of light reflect the perception of humans (light intensity in Lux; light color in Kelvin). The commonly used criteria to describe the light environment (e.g. Lux and Kelvin) should be adjusted to the differences between human and bird's eyes.

Visual perception

The visual perception can be reduced to two basic patterns, "shape" and "color", which are used by animals to differentiate between objects which are relevant for their survival. The ability to determine which feed is edible and non-edible and to differentiate aggressors/enemies from possible mates assure the survival of a species. Birds have to cope with a special challenge, because they have to recognize dangers or feed from a distance. It is easier to differentiate distant objects on the basis of "color" than on "shape"; therefore, color vision is important for birds.

Physiology of the eye

The eye contains two functional units: The refracting structures, including tear fluid, cornea, anterior chamber, lenses and vitreous body, concentrate the light waves on the retina (Loeffler and Gäbel 2009). The retina contains the photoreceptor cells of the eye, the rods and cones (Engelhardt et al. 2010). The rods and cones contain photo pigments which change their structure when exposed to light. A cascade of reactions follows, leading to an electric signal. Bipolar cells, ganglia cells, amacrinal cells and horizontal cells in the retina are involved in the connection and transmission via the optic nerve to the brain. The transmission of the signal is electric, as a sequence of action potential (Loeffler and Gäbel 2009). A picture of the environment is generated in the brain. The visual perception of pictures is subjective and an individually learned process (Engelhardt et al. 2010). In humans more than 200 million sensory cells and billions of nerve cells in the brain participate in this process (Frings and Müller 2014). The rods react to mimimal light stimuli (a single photon). However, they cannot detect color and are therefore only able to differentiate between light and dark (skotopic seeing). The cones allow color vision and need a certain light intensity to be activated. The photo pigments of the cones absorb only certain wave lengths of the light, depending on the type of cones (Loeffler and Gäbel 2009). The retina of the human eye contains three kinds of cones, which can be identified on the basis of maximal absorption. The three absorption maxima are long (red), middle (green) or short (blue) waves (Deeg 2009). The wave length of the light is not transmitted directly to the brain. The cones always react in the same way to the corresponding wave lengths (Engelhardt et al. 2010). The strength of the signal depends on the wave length of the light. In order to generate the same strength of signal in green-sensitive cones with long wave (red) light, the intensity of long wave light must be much higher (Frings und Müller 2014).

The visual system of birds

The avian vision is highly developed. The special importance of the eyesight for birds may be related to their weight: in fowl-like birds, a pair of eyes typically weighs 7-8.5 % of total body mass, in humans only 1 % (König und Bragulla 2009). The basic structure of the avian eye is similar to the mammalian eye, but displays some additional features (König and Bragulla 2009).

- ➔ Due to the large eyeball and the relatively large retina surface, the vision and optical resolution are stronger in birds than in humans (Nickel et al. 2004).
- ➔ The tear fluids, cornea, anterior eye chamber with fluid, lenses and vitreous body are involved in the refraction of light. Most of the light refraction occurs between the air and tear fluid on the cornea (Deeg 2009, Löffler und Gäbler 2009; Moyes and Schulte 2008).
- ➔ In contrast to humans, birds have four kinds of cones. The absorption maxima

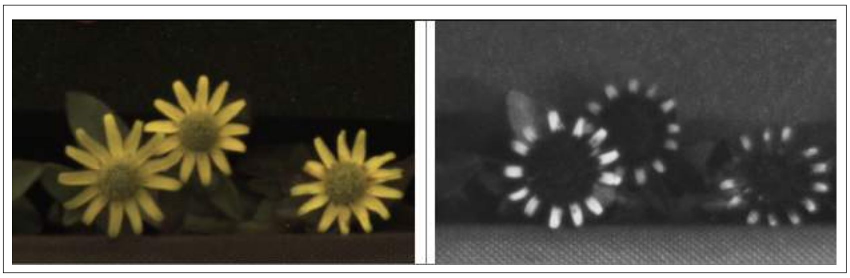

Figure 1: left: Regular photo with RGB camera; right: same object as seen by UV-A camera with integrated VIS filter under UV-A light

λmax of the different cones of chickens are as follows: 419 nm (UVS/VS), 455 nm (SWS), 508 nm (MWS), and 570 nm (LWS) (Bowmaker et al. 1997). The UVS pigment in birds appears in two variates: VS pigment with an absorption maximum λmax between 402 nm and 426 nm and UVS pigment with an absorption maximum λmax between 360 nm and 373 nm (Hart 2001). Lind et al. (2013) published an absorption maximum of 418 nm for the VS pigment. Birds also have double cones with an absorption maximum λmax around 580 nm (Hart 2001; Kram et al. 2010). The double cones are assumed to be responsible for seeing movements (Barber and Daly 2013; Kram et al. 2010). For comparison, the absorption maxima of the three cones in the human eye are about 420 nm (blue), 534 nm (green) and 564 nm (red) (Deeg 2009).

- ➔ The cones of the human eye recognize only light waves between 380 and 780 nm length (Baer et al. 2016; Ris 2015), while birds can see a much wider color spectrum, including UV light (Barber and Daly 2013; Lewis and Morris 2006; Reese et al. 2009). The figures published for avian vision differ considerably between authors: Prescott and Wathes (1999) reported spectral sensitivity up to 740 nm. According to Hart et al. (1999), chickens can see wave lengths above 330 nm. Slightly higher values of 350 to 360 nm were found by Lewis and Morris (2006), Prescott and Wathes (1999) and Saunders et al. (2008). In the most recent reference, Deeg (2009) concludes that the spectral vision has a range from 320 to 680 nm.
- ➔ Birds have a sharper vision than mammals, which is explained by the smaller number of cones per transmitting nerve cell. The avian cones also contain oily droplets (Bowmaker 1977; Maier 1994; Reese et al. 2009) which reduce the specific absorption range of individual cones (König and Bragulla 2009). This enables birds to see more clearly and to differentiate wave lengths or shades of color.
- ➔ The ratio of cones to rods is opposite between human and avian eyes: 5:95 % in humans (Curcio, 1990) vs. 85:15 % in chickens (Morris, 1970). The actual numbers are 4.6 million cones and 92 million rods in the human eye compared to 7.5 million cones and 1.3 million rods in chicken eyes (Cebulla et al. 2012).
- ➔ Depending on light intensity or luminance, color vision (photopic), twilight vision (mesoptic) or night vision (scotopic) takes place. According to Lindsey et al. (2011) the receptor sensitivity of the optical nerve cells of chickens is > 14 cd/m^2 (8 Lux) for photopic vision and < 0.8 cd/m^2 (0.5 Lux) for scotopic vision. Baer et al. (2016) consider > 30 cd/m^2 (20 Lux) as limit for photopic vision and < 0.01 cd/m^2 for scotopic vision of the human eye.
- ➔ Birds have a higher temporal resolution, i.e. they recognize more pictures per second than humans. The critical Flicker Frequency (CFF) is the frequency at which a series of light stimuli is seen as continuous light. CFF depends on the surrounding brightness (Lisney et al. 2012). Several research groups estimated the CFF for chickens based on behavior tests (Nuboer et al. 1992, Jarvis et al. 2002, Railton et al. 2009, Lisney et al. 2011) and found values between 71.5 and 105 Hz. Based on electroretinogram measurements, Lisney et al. (2012) found a higher CFF of 119 Hz.
- ➔ Due to the lateral position of their eyes,

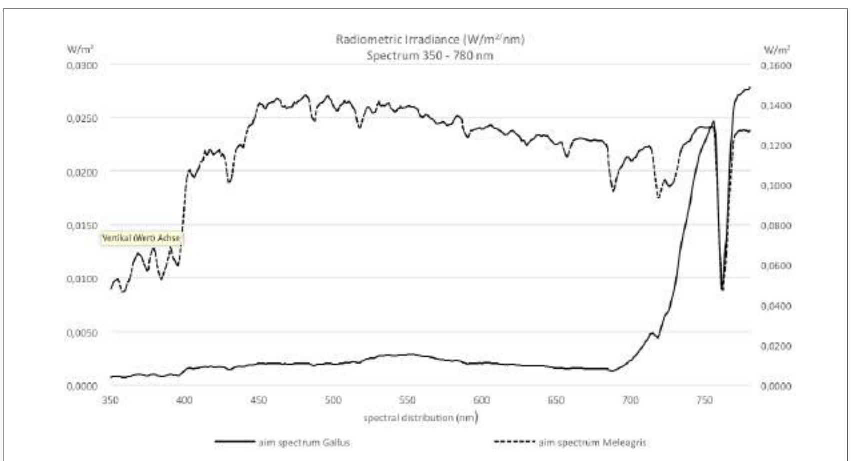

Figure 2: Target spectra for chickens and turkeys: Average values of source data in W/m2 for each wave length (based on 434 turkeys and 88 chickens)

birds (excepts owls) have a monocular visual field which can reach 360° (König and Bragulla 2009). Their binocular visual field is only 26°, compared to 120° for humans (Engelhardt et al. 2010, Barber and Daly 2013). The spatial resolution of birds is therefore poorer than by humans. The limited muscling and lateral position of the eyes is largely compensated in birds by a very flexible head (König and Bragulla 2009).

- ➔ Avian eyes are able to adapt more quickly to changing lights (light-dark) than mammalian eyes. This is possible with deliberate movement of skeletal muscles of the iris (König and Bragulla 2009).
- ➔ Another peculiarity of avian eyes is that birds can process two different pictures simultaneously, e.g. to use one eye to search for feed while the other is watching for potential enemies (Barber and Daly 2013).

Spectral composition

The color of light emitted by a source is measured in terms of temperature, using a black object for reference (Ris 2015). The object changes its color depending on the temperature and is measured in Kelvin (K) to classify the light spectrum for humans. The European standard EN 12464 defines the temperature of a light source in three categories: daylight white (>5.300K), neutral white (3.300 - 5.300K) and warm white (< 3.300 K). This scale of light color is one-dimensional. Rotscholl and Neumann (2015) point out that the parameter temperature of color can easily lead to misinterpretation whenever small differences in color are to be described. The one-dimensional scale (Kelvin) is also inadequate to describe the quality of light for the complex vision of the avian eye. The ability of birds to see UVA light, becomes obvious when photos of an object with standard camera vs. UVA camera are compared **(Figure 1)**. The petals appear monochrome in the "color picture" and show a color gradient in the UVA shot.

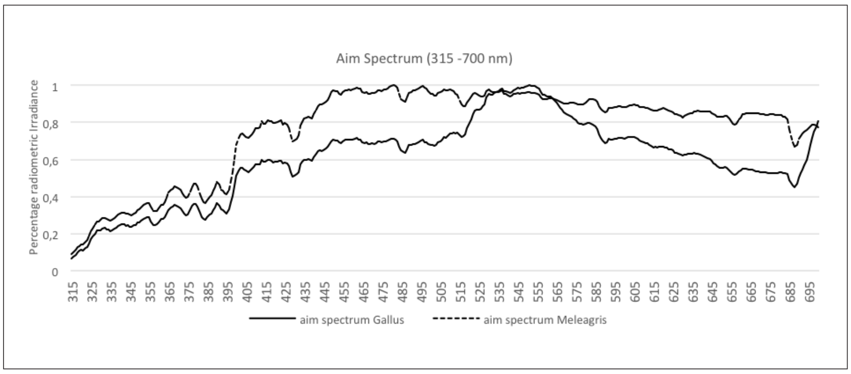

Figure 3: Target spectra for chickens and turkeys: relative values of radio-metrically measured irradiance in % (based on 434 turkeys and 88 chickens)

Instead of the simple parameter "light color" found in commercial illuminants, the complete spectral quality of illuminants needs to be taken into account. The Spectrum should include all areas which are relevant for poultry, including parts in the UV-A range (350–400 nm). Even though the peculiarities of the avian eye and its physiology are known, precise recommendations for optimal illumination of poultry houses are not yet possible. Natural daylight may be used as a reference until more information about artificial light becomes available.

In an earlier publication (Kämmerling et al. 2017) we reported the results of spectral radiometric measurements of the composition of daylight throughout a year at four different locations, characterized as open sky, outskirts of a forest, shrubbery and inside a forest. The natural habitats of different species of domestic poultry differ. Birds which prefer a habitat under the shade of leaves have other requirements for the spectral color range (including UV-A light) than birds preferring to live under open sky. Domestic chickens (Gallus gallus domesticus) are descendants of the Bankiva hen (Gallus gallus). This wild bird lives mainly in the shade of trees and shrubs in the tropical and subtropical jungles of Southeastern Asia. De Castro (2000) described the spectral composition of light in the jungle of Puerto Rico (Central America). The composition is very similar to what we find in our forests. The ancestors of our turkeys (Meleagris gallopavo) are mainly found in steppes, outskirts of forests and open forests in Northern and Southern America.

Based on our measurements of daylight, we calculated targets for the light spectrum for chickens and turkeys (Fig.2) corresponding to the natural habitats of these species. For chickens we used the values measured during the summer in the forest and in shrubs. For turkeys we used the measurements throughout the year under clear sky, outskirts of forest and open forest, because the wild species is also exposed to seasonal variation of daylight and steppe conditions with little shade.

The radiometric irradiance shows significant differences between the two target levels. In order to illustrate both curves in one graph, double Y scales were used, which differ by a factor of 10: the target for chickens on the left side, for turkeys on the right side of **Figure 2.** The curve of **Figure**

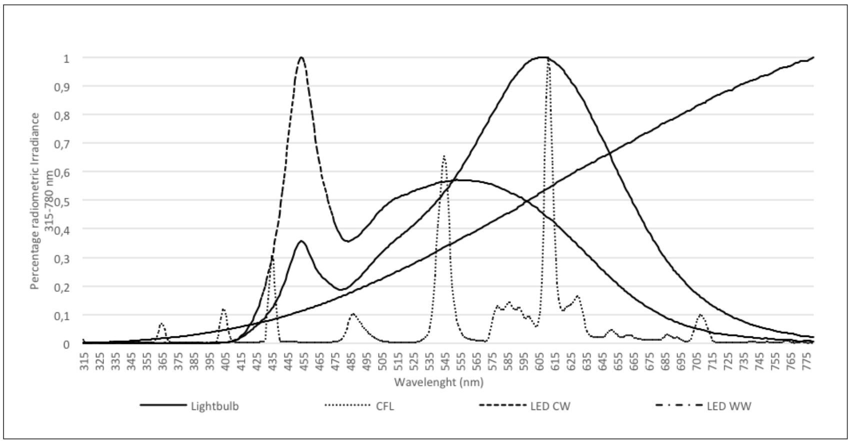

Figure 4: Spectral composition of common illuminants

3 is only shown to 700 nm to the spectra between 315 and 700 nm.

The relative target values were calculated from the pigment content given in Table 1. The long wave (red) spectrum was subdivided into two areas (I and II) to take the wide range into account. The area "red II" represents the largest part. The absorption maximum for the corresponding red-sensitive cones of chickens is about 570 nm, but above 650 nm the absorption curve tends toward zero (Wilby et al. 2015). An open question is whether the cones would need a higher absorption capacity at this high intensity or whether the content is of little importance due to the limited absorption capacity of the cones.

Different reference values can be seen especially for UV-A light: 2.5 % for chickens vs. 5.8 % for turkeys, which corresponds to the natural habitat of turkeys (steppes and open forests, with little shade of vegetation). Turkeys are also more sensitive to UV-A light than other poultry species (Barber et al. 2006).

The spectral composition of common illuminants (light bulb; fluorescent lamp (CFL); LED cool white; LED warm white) differs considerably, as shown in Figure 4.

None of these illuminants meets the estimated needs of poultry.

Typical illuminants are compared with the reference values.

- Light bulb: Light is generated by a Wolfram wire glowing at a temperature of about 2400-2700 °C (Baer et al. 2016). The majority of the generated radiation is in the infrared region. In the visible range, the light bulb showed high emissions in the deep red area (red II) and low emissions in the UV-A and purple area.
- CFL: Compact fluorescent lamps function with low pressure discharge. The gas contained in the glass cylinder consists mainly of mercury vapor, which is made to shine with a cathode. Coating of the lamp converts the resulting ultraviolet radiation (253.7 nm) to visible light (Baer et al. 2016). The sample CFL we analyzed showed a very heterogeneous distribution within different wave lengths. On the one hand, we found sufficient emission in the UV-A und violet area relative to the reference values; on the other hand, some colors like green and orange were prominent.
- LED CW und LED WW: depending on their structural property, light emitting diodes can produce visible light with different semiconductors. The most common structure is a combination of a blue LED-Chip and one or more luminescent substances which convert the emitted blue light into longer waves (green, yellow and red light). Depending on the luminescent substance used, the blue LED emits in warm white (WW) or cold white (CW) (Baer et al. 2016). The LEDs analyzed (CW, WW) emitted very little in the UV-A or violet area. LED CW emitted mainly in the blue-green range, LED WW mainly in the orange and red (Red I) range.

In order to evaluate the suitability of an illuminant for poultry houses, the spectrum must include the UVA area, which is essential for birds. If areas contributing to the visual spectrum are missing, objects will be seen in different (wrong) colors (Steigerwald 2006). The light environment should be comparable throughout the life cycle of chickens or turkeys. The chicks or poults learn within a given light environment to associate colours with water, feed, other individuals in the group and caretakers. Changes in the spectrum, e.g. when pullets are transferred to the laying unit, may lead to difficulties, because the learned association (feed, water, mates etc.) no longer corresponds to the new environment. Similar problems can occur, when the color and shape of feeder or drinker equipment change at transfer from rearing to production houses.

Frequency

Illuminants emit light with different frequencies, which are expressed in Hertz (Hz). Studies of the flicker fusion frequency of poultry show a range between 20 and 119 Hz (Nuboer et al. 1992, Jarvis et al.

Table 1: Spectral percentages for natural habitat of chickens and turkeys (means, minima and maxima as calculated of the pigment contents)

Color-ratio	Habitat Spectrum Gallus Gallus			Habitat Spectrum Meleagris gallopavo		
	MW	Min	Max	MW	Min	Max
% UV-A (315-380 nm)	2.5	0.0	5.2	5.8	0.0	14.0
% violet (381-436 nm)	4.3	0.5	8.7	10.3	2.7	19.1
% blue (437-495 nm)	6.3	0.8	14.3	15.7	3.6	24.4
% green (496-566 nm)	9.6	3.1	16.0	18.9	6.5	21.0
% yellow (567-589 nm)	2.9	1.0	4.3	5.8	1.9	6.2
% orange (590-627 nm)	4.1	1.2	6.5	9.3	2.4	10.1
% red I (628-688 nm)	5.3	0.2	9.4	14.2	0.2	16.8
% red II (689-780 nm)	65.0	43.6	91.9	20.0	9.7	78.2

2002, Railton et al. 2009, Lisney et al. 2011). The flicker fusion frequency also depends on the light environment.

The differences in light intensity can be documented with a high speed camera (5000 pictures/second); an example is shown in **Figure 3**. The light intensity fluctuates (modulates) to a significantly different degree in different illuminants.

The frequency of an illuminant may also be analyzed with an oscilloscope and a photodiode **(Tab. 4)**
The frequency of an illuminant may be influenced by the operating mode used. Depending on the control gear and driver, dim level etc., the same illuminant may emit different frequencies. In order to assess the critical flicker frequency (CFF) of an illuminant, the whole installation, including power supply, technical control and illuminant, must be analyzed using Fast Fourier Transform technique (FFT).

The frequency of the lighting system in poultry houses should be at least 120 Hz. Taking individual variation of resolving capacity as well the lighting systems in poultry houses should provide for frequencies of more than 120 Hz.

Light intensity

Light intensity is measured in LUX. 1 LUX = 1 Lumen/m^2. The light intensity doesn`t describe the brightness perception of the eye. Luminance (cd/m^2), on the other hand, describes the brightness impression of the eye. When the actual light intensity is measured, e.g. to check compliance with animal welfare regulations, a lux meter is commonly used. However, this device only yields a photometric value which takes the spectral sensitivity of the human eye into account. The unit lux or lumen is meaningful for the human eye, but birds have a different spectral sensitivity and require different specifications of light, including UV-A light. The units for such measurements are called "Galli-Lux", "Clux" or "Light index for Poultry". Photometric values of Light intensity for chickens may be calculated with the following formula (Gall 2007):

$$X_v = K_m \int_{380\,nm}^{780\,nm} X_e\lambda * v(\lambda) * d\lambda$$

where

- Km is a constant, in lm/m2 units. Depending on the kind of vision (scotopic, mesopic, photopic), different values are used
- Xeλ is the measured intensity of radiation in W/m^2 relative to the sum (∫) of radiation of all wave lengths der in the visible area (380-780 nm for humans; 350-780 nm for poultry)
- v(λ) is the spectral light sensitivity, which differs between humans and poultry (Lewis and Morris 2006)
- dλ is the resolution of the measured intensity of radiation (dλ = 1, if a value is available for each wave length)

If all factors are known, the light intensity (Xv) can be measured as a photometric unit and expressed in lux. However, the formula is only meant for the human eye and not for the avian eye. The V(λ) values published by Lewis and Morris (2006) refer only to photopic vision of birds, while values for scotopic vision of birds are not yet available. Borderline situations between scotopic and photopic vision should also be taken into account.

The constant (Km) for photopic vision refers to the absolute light intensity which is sensed, but for application the differences between human and avian vision must be taken into account. This question has to be answered before poultry specific values like "Gallilux", "Clux" or "Light Index for

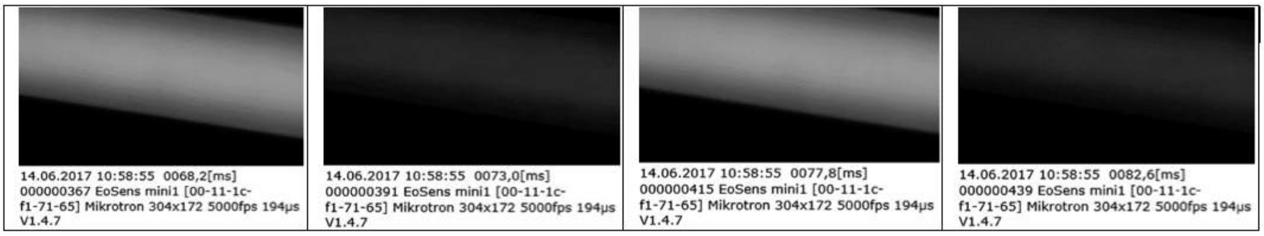

Table2: Changing light intensity of an illuminant (LED) during an observation period (4.8 milliseconds between pictures)

Poultry" can be compared with photometric units in LUX.

The distribution of light intensity in a poultry house is important. Light spreads simultaneously from a source in all directions, and the light intensity at any distance is inversely proportional to the squared distance. If the light cone has a given angle, the light will spread out in a larger cross-sectional area: at twice the distance, four times the area will be illuminated, and light intensity per cm^2 will be reduced accordingly. There will always be differences in light intensity **(Fig.5)**, depending on the angle and distance from the illuminant.

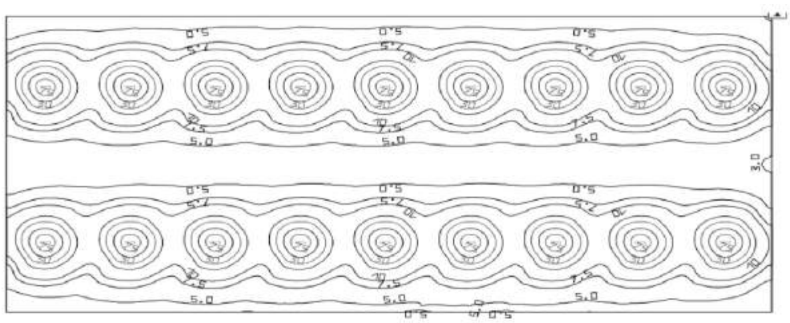

Figure 5: Distribution of light intensity in a poultry house (40 x 100 m) in LUX, calculated with Relux Software

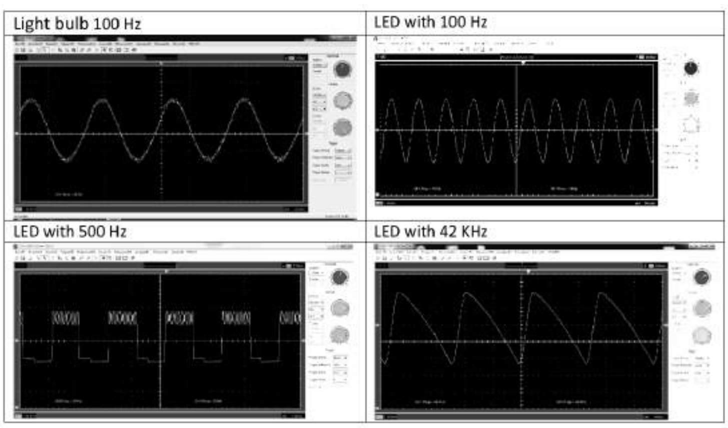

Table 3: Frequencies of different illuminants

A specific ilumination oft the barn, differentiate to functional areas, may be of interest.

Summary and Conclusions

Up to now, measurements of light in poultry houses and assessment of illuminants are still based on parameters developed for human perception of light. Differences in the anatomy and physiology of human and avian eyes should be taken into account in order to optimize the lighting conditions in poultry houses. Commonly used criteria (e.g. Lux and Kelvin) must be adjusted accordingly. Illuminants for poultry houses should include spectrum, frequency and light intensity (distribution of brightness). The light color (Kelvin) appears to be inadequate for the assessment of the spectrum, because it only reflects the wave length with maximal intensity. Suitable illuminants should cover the whole spectrum contributing to the reception of light, including UV-A light. Spectral data can be compared with reference values for chickens and turkeys, based on their natural habitats.

In order to assess the critical flicker fusion frequency of illuminants, the higher resolution of avian eyes has to be taken into account. The emitted light frequency should be at least 120 Hz. A generous additional safety margin is highly recommended, because individuals may vary in their flicker fusion frequency. Light intensity in poultry houses is commonly measured with lux meters, which cannot detect

UV-A light. Birds are therefore likely to see their environment brighter than the measurement suggests. Procedures for testing must be developed which will show the brightness perceived by commercial poultry. As a practical approach, preference tests of light intensity in functional areas of non-cage systems (e.g. feeder and rest area) are recommended. The comparison of different commercial illuminants for poultry houses indicate a need for more research and development to improve the light quality in poultry houses.

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NOTES

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Environmental footprint of meat consumption of cats and dogs

Abstract

Dogs and cats have traditionally been kept on farms and other households and were fed offal from human consumption. Dogs were used as guards or for hunting; cats had an important role to play in the control of rodents. In industrialized countries, dogs and cats are nowadays kept mainly as companion animals and fed on high quality commercially produced feed. As carnivorous animals by nature their diet contains high amounts of materials of animal origin which could be suitable for human consumption. This raises the question of the impact of dog and cat feed from animal origin on the use of scarce resources and the environment. It was the aim of the present study to estimate feed consumption, land use and carbon dioxide equivalents (CO_2e) for dogs and cats as the most frequent carnivorous companion animals in the USA, EU and selected European countries from available statistics. The total number of dogs and cats is similar in the USA and in the EU. However, the number of dogs and cats per capita is higher in the USA than in the EU and any selected European country. Annual feed intake was estimated 98 kg (23kg dry matter) per cat and 211 kg (76.5 kg dry matter) per dog. The fraction of materials of animal origin is 50 % for cats and 45 % for dogs. Land use for feed production was about 1000 m^2 per cat and 2000 m^2 per dog. Annual CO_2e for cats and dogs was 411 and 840 kg respectively. Arable land required for the production of feed for cats and dogs varied between 10 and 20 % of the national land resources. The CO_2e for dog and cat feed is about 1 – 2 % of the countries' total CO_2e production, but equals about 10 % (for a cat) to 20% (for a dog) of the CO_2e for feeding their owner. The contribution of feed for dogs and cats on the overall production of greenhouse gases may be overestimated in the public discussion, but cannot be neglected if food consumption is considered.

Introduction

Keeping animals for meat production and meat consumption is being criticized for various reasons. Ethical concern is raised on the prevailing husbandry systems of intensive livestock production, transport of animals to the slaughter house and the large number of animals which are being killed for meat production. Another important point in the public discussion is the impact of livestock production on the environment. Emissions from intensive livestock farming are considered to deteriorate the environment through emission of ammonia, nitrate, phosphate and greenhouse gases, such as CO_2, methane, and nitrous oxide. Manure from concentrated production units represents a risk of increased nitrate in the ground water and accumulation of phosphorous in the soil. Clearing the rain forest in tropical countries to satisfy the increasing demand for feedstuff, mainly soybeans, is a further negative environmental effect of intensive livestock production. In fact, livestock production and especially of ruminants has been estimated to contribute considerably to the worldwide production of greenhouse gases. Besides all livestock production is an important factor in land use for feed production. This is insofar difficult to justify because the meat consumption of the population in industrial countries exceeds the demand for protein and energy of the urban population. Furthermore overconsumption of meat is considered to represent a serious health hazard for humans. Associations of vegetarian or vegan nutrition recommend to completely stopping meat consumption.

A reduction of meat consumption by 50 % is suggested by Governmental authorities and by NGOs in Germany with the aim to reduce the emissions of greenhouse gases (BUND, 2018). On the worldwide level McMichael et al. (2007) recommend a per caput meat consumption in industrial countries to 90 g per day (33 kg/year). Considering the present consumption of 200 to 250 g per capita and day (73 – 91 kg/year) in industrial countries the use of meat should be reduced by about one third. Experts in human nutrition, in contrast, underline the importance of food of animal origin for humans as omnivorous beings (Biesalski et al., 2017).

In the debate on meat consumption of the human population the role of companion animals has received little attention. Indeed most statistics on per caput meat consumption include not only losses during processing and storage but also the use for feed of carnivorous companion animals, mainly dogs and cats. It is generally assumed that dog and cat feed is based on slaughter offal which is not suited for human consumption. There is, however, not sufficient slaughter offal to satisfy the demand for commercial dog and cat feed. Hence parts of slaughtered animals with low preference by human consumers, such as tripe, liver, kidney, fat, etc. are used. Some of these components, such as liver, contain important amounts of essential amino acids, micro-nutrients and essential fatty acids. Others are even culinary specialties in Europe and overseas. Chicken and duck feet for example, which are not considered as edible product in European countries are highly appreciated in Asian countries and imported in large quantities. To some extent Europe imports meat from game animals, such as springbok from Africa and kangaroo from Australia to be used as pet food. There is increasing interest to quantify the share these companion animals take in meat consumption and related environmental criteria. The

Table 1 Population of humans, dogs and cats in the USA, EU and selected EU countries

Country	Human population in Mio	No. dogs in Mio	No. cats in Mio	Cats per 1000 inhabitants	Dogs per 1000 inhabitants
USA	324.00	69.93	74.06	229	216
EU	508.00	68.00	74.00	146	134
UK	66.00	9.00	8.00	121	136
France	65.00	7.57	11.48	177	116
Poland	38.00	7.31	5.55	146	192
Italy	59.00	7.00	7.40	125	119
Germany	82.00	5.30	8.20	100	65
Spain	46.00	4.72	3.39	74	103
Netherlands	17.00	1.50	2.88	169	88

Table 2: Composition and recommended daily intake per dog (25 kg) of two types of dry and wet dog feed (Leenstra and Vellinga, 2011)

	Dry feed 1	Dry feed 2	Wet feed 1	Wet feed 2
Recommended intake (g/day)	323	390	1375	1400
Crude protein	25	23	6.4	8
Crude fat	14	10	4.1	5
Crude fibre	1.2	3	0.3	0.4
Raw ash	5.6	6.5	1.2	2.5
Water	8	Not provided	76	80
Main ingredients of dry feed: Cereals, meat and animal products and of wet feeds meat and animal products followed by cereals				

Table 3: Composition and recommended daily intake per cat (4 kg) and for two types of dry and wet cat feed (Leenstra and Vellinga, 2011)

	Dry feed 1	Dry feed 2	Wet feed 1	Wet feed 2
Recommended intake (g/day)	55	80	255	300
Crude protein	25	23	6.4	8
Crude protein	32	32	12	10
Crude fat	15	12	2.8	3.5
Crude fibre	4.2	2.5	0.6	0.3
Raw ash	6.8	7.5	1.7	2.5
Water	Not provided	Not provided	76	80
Main ingredients of dry feed: Cereals, meat and animal products and of wet feeds meat and animal products followed by cereals				

present study aims at calculating the impact of food for carnivorous companion animals, such as dogs and cats.

Number of dogs and cats in relation to the human population

The number of dogs and cats is almost the same in the USA and in the EU (Table 1). However, there is a higher number of dogs and cats per capita in the USA than in Europe (216 and 229 dogs and cats per 1000 persons for the USA and 134 and 146 for the EU). There is a wide variation between the European countries. With regards to the number of cats per 1000 inhabitants in the selected countries France shows the highest (177) and Spain the lowest (74) density. For dogs the highest number per 1000 inhabitants exists in Poland (192) and the lowest in Germany (65).

Food of animal origin and related environmental criteria

Dogs and cats which are kept in households of industrialized countries are mainly fed specialized commercial food of animal and plant origin. The ratio of animal derived components is higher for cats than for dogs. Dogs are able to utilize plant components more efficiently than cats. Quantified ingredient lists for dog and cat feed are not available, but the declaration on packed dog and cat feed gives some information. Results of a study on the nutrient composition of dog and cat feed are shown in Tables 2 and 3. Crude protein content of dry dog feed (> 90 % dry matter) varies between 23 to 25 % and wet feed (about 20 % dry matter) between 6.4 to 8 %. Cat feed is higher in crude protein: 32 % in dry feed and 10 – 12 % in wet feed. This is within the span of the NRC recommendations for dog and cat feed. The diets contain a large variety of raw materials. The percentages of the individual ingredients are, however, not declared. Hence it is not possible to exact-

Table 4: Basic data of feed consumption and CO2 equivalents (CO_2e) for dogs and cats, based on 50/50 animal and plant products in cat feed and 45/55 animal and plant products in dog feed.

Criteria	Unit	Cats	Dogs
Live weight	kg	4	13.5
Energy requirement (NRC)	kcal/day	280	922
Energy content feed	kcal/kg DM	4400	4400
Total feed intake*	DM kg/year	23	76.5
Feed of animal origin	DM kg/year	11.5	34.4
Feed of plant origin	DM kg/year	11.5	42.1
CO_2e for feed of animal origin **	kg/ kg DM	287.5	862.5

*Feed intake/year is in dry matter: 80% moisture in wet feed and about 90 %in dry feed.
** CO_2e Is estimated on a mix of meat (Pork, poultry, beef and other animals (Lasar,2016)

ly determine the share of animal and plant based feedstuff. In the USA the fraction of energy in dog and cat feed derived from animal products varies between 24 and 47 %, with minor difference between dog and cat feed (Okin, 2017). We assume that the fraction of animal derived materials in cats feed is 50 % and in dog feed 45 % (Leenstra and Vellinga, 2011). The basic data and the estimate of feed intake, land use and carbon dioxide equivalents derived from feed of plant and animal sources is shown in Table 4. Taking feed from both animal and plant origin a medium sized dog (13.5 kg) consumes 76.5 kg dry matter annually (about 82 kg if only dry feed would be given and 383 kg for only wet feed) and a cat of 4 kg mean weight consumes 23 kg dry matter annually (about 25 kg if only dry feed would be given and 115 kg for only wet feed). With regard to the high variation of raw materials of plant and animal origin used in pet food it is not possible to get an exact calculation of land use and CO_2 equivalents (CO_2e). Land use given in Table 4 is based on LCA studies of Williams et al. (2006). The annual land requirement for one cat is estimated at1000 m^2 and for a dog at 2000 m^2. The plant fraction in the diets represents less than 10 % of total land use. These figures are based on high crop yields from North-West European conditions. More land may be required under less favorable climatic and soil conditions. Since the animal derived components of dog and cat food is based on animal products which might be suitable for human consumption, we used data from human diets. According to Lasar (2018) a mix of animal derived products results in 5.49 kg of CO_2e per kg product. The CO_2e per kg of the vegetarian diets is by the factor 1.5 to 2.0 lower than animal based diets (Reijnders and Soret, 2003). Table 4 shows that the CO_2e emission per kg dry matter of dog feed is 863 and that of cat feed is 288 kg CO_2e per year.

Annual feed consumption in selected countries

Dog and cat food contains relatively high fractions of components from animal origin. Therefore the fraction of dog and cat food of animal origin is shown in relation to the total meat production by country in Table 5. Since water contents differ widely in dry and wet feed, all data are calculated on dry matter (DM) basis, assuming a mean dry matter level of 25 % for meat derived products. Dogs and cats consume about the same amount of animal feed in the USA and in the EU (3.23 and 3.16 Mio to DM/year respectively for the sum of dog and cat food). The proportion of dog and cat food of total meat production is highest in the UK followed by the USA and Italy. Germany, Spain and The Netherlands show the lowest proportion ranging from about 10 to 12 % and France and Poland take an intermediate position of about 24 %. The high proportion of dog and cat food in the UK and Italy is obviously due to the relatively low national meat production (1.02 and 1.03 Mio to). The high level of feed of animal origin for dogs and cats from our calculation may seems surprising. However, other authors report similar results. According to Weiler (2016) the consumption of meat products of dogs and cats in Germany was 1.43 Mio to fresh weight. This corresponds to 0.358 Mio to dry matter, which is higher than our estimate (0.27 Mio to). The difference is obviously based on a higher number of dogs and cats assumed in Weiler´s calculation. For The Netherlands, Luske and Blonk (2009) estimated that half of the category

Table 5 Total feed intake (in Mio to DM/year) of dogs and cats of animal origin in the USA, EU and selected European countries (estimated annual feed intake per cat 11.5 and per dog 34.4.kg DM) in relation to meat production in these countries

Country	Dogs animal feed	Cats animal feed	Dogs and cats animal feed	Total Meat production dry matter	Dogs and cats animal feed in % of total meat production
USA	2.38	0.85	3.23	10.25	31.52
EU	2.31	0.85	3.16	12.79	24.73
UK	0.31	0.09	0.40	1.02	39.21
France	0.26	0.13	0.39	1.58	24.61
Poland	0.25	0.06	0.31	1.29	24.17
Italy	0.24	0.09	0.32	1.03	31.45
Germany	0.18	0.09	0.27	2.16	12.69
Spain	0.16	0.04	0.20	1.74	11.48
Netherlands	0.05	0.03	0.08	0.85	9.89

3 animal products (e.g. products which are suitable for human consumption) are used in pet food. Leenstra and Vellinga (2011) estimated that total feed energy requirement of one human equals the requirement of 3 dogs and 10 cats, which is 33 and 10 % respectively. Since many dogs and cats are overfed, data on feed consumption may be underestimated.

There is a rapid increase of meat consumption in countries which are on the way of industrialization (Windhorst, 2011) and it is expected that more pet animals will be kept. This will lead to an increase of the use of animal products for pet animals worldwide.

Land use

The use of arable land for pet food is based on calculations of Williams et al. (2006). The authors differentiate between "fish and meat" and "byproducts". Since animal based ingredients for pet food compete with human consumption (as explained before) the values of "fish and meat" have been used by Leenstra and Vellinga (2011) and for the present study. The higher average land use for dogs (about 2000 m2) as compared to cats (1000 m2) reflects the higher feed intake of dogs compared to cats. 24.1 Million ha of arable land are required both in the USA and in Europe to produce feed for both species of companion animals (Table 4). This represents 13.4 % (USA) and 19.8 % (EU) of total arable land. The share of land use for dog and cat feed varies widely among European countries with the highest values in the UK, Netherlands and Italy (42.6; 33.3 and 30.4). But even in the lower land use category more than 10 % of arable land is required to produce food for pet animals. Williams et al. (2006) reported an average land requirement of 12500 m^2 per head and year for food of humans. Hence cats use 8 and dogs 18 % of the land requirement of humans for food production. Vale and Vale (2009) reported considerably higher values for land use of dogs and cats (11000 and 1500 m^2 respectively). The higher land use estimates may be due to the assumption of feed production under less favorable soil quality and climatic conditions. The authors also not only consider space required for feed production but also for other inputs.

Green house gases

Feed production is the main component of production and emission of greenhouse gases in animal production. Therefore, the present study focusses on the effect of dog and cat food of animal origin on emission of CO_2e. There is no reliable statistical information on the quantity and only vague reports on the type of raw materials used in dog and cat food. The producers claim that all ingredients stem from sources which are suitable for human consumption, in particularly those of animal origin. Hence we used the estimate of a mix of different meat products (pork, poultry, beef and others) for the calculation of CO_2e (Lasar, 2017). According to this information the CO_2e is 5.49 kg per kg of fresh meat. Considering an average dry matter content of 25 % for meat the correspondent value is 21.72 kg CO_2e per kg dry matter. The CO_2e emissions per country from the animal part in dog and cat food are shown in Table 7. The CO_2e values follow directly the amount of food consumed by dogs and cats. Here again the figures for the USA and EU are similar (52.83 and 51.37 Mio. to annually for dogs; 18.70 and 18.85 Mio to for cats). The estimates

Table 6 Surface needed to feed the dogs and cats (based on 1000m2/cat, 2000m2/dog) and total surface of agricultural land in million ha

Country	Dogs	Cats	Arable land available
USA	14	7.4	160.0
EU	14	7.4	108.3
UK	1.8	0.8	6.1
France	1.5	1.1	21.5
Poland	1.4	0.6	11.3
Italy	1.4	0.7	6.9
Germany	1.1	0.8	12.2
Spain	0.9	0.8	12.6
Netherlands	0.3	0.3	1.8

Table 7 CO_2 equivalent (CO_2e) production (in Mio to/year) of animal origin of dogs and cats in the USA, EU and selected European countries (estimated annual feed intake per cat 11.5kg DM and per dog 34.4 kg DM)

Country	Dog feed of animal origin	Cat feed of animal origin	Dog and Cat feed of animal origin
USA	52.83	18.70	71.53
EU	51.37	18.48	69.85
UK	6.80	2.00	8.80
France	5.72	2.87	8.59
Poland	5.52	1.39	6.91
Italy	5.29	1.85	7.14
Germany	4.00	2.05	6.05
Spain	3.57	0.85	4.41
Netherlands	1.13	0.72	1.85

for the USA are lower than those of Okin (2017), who reported CO_2e for the feed of dogs and cats of animal origin of 64 Mio to annually. Since the Standard Deviation was high (+16 Mio to) our estimate is still within the range of Okin`s result. The higher CO_2e emissions in Okin (2016) may also be due to the fact that a higher weight for dogs was used (22 kg vs. 12.5 kg in our study). Considering total CO_2e emissions in the USA and the EU of 6870 and 3527Mio annually the CO_2e for feed of dogs and cats of (71.53 Mio to in the USA and 69.85 Mio to in the EU) represent 1.9 and 1.0 % of total CO_2e emissions respectively. The ratios of CO_2e to total CO_2e production in the other countries are in a similar range. However, if only CO_2e from food is considered, cats and dogs require a higher proportion: about 2-5%.

Restricting the number of companion animals, keeping smaller dogs and feeding cats and dogs vegetarian diets, as recommended by Okin (2007) and Vale and Vale (2009), will not have a significant impact on global environmental problems, although current environmental impact of dogs and cats is of a similar magnitude as Meatless Monday or Veggy Day for the human population.

Conclusions

Meat consumption by humans has been discussed extensively with regard to its negative effect on the use of natural resources and emission of greenhouse gases. Recent publicity has called attention to the fact that dogs and cats compete for human food of animal origin and land use. Emissions of greenhouse gases of these animals have been considered as a serious cause of global warming. The present study shows that dogs and cats indeed use a considerable percentage of animal derived products which could be used in human nutrition and land required for the production of dog and cat food represents 10 to 20 % of arable land in the USA and EU countries.

However, relative to the total emission of greenhouse gases (CO_2e) the fraction which can be attributed to dog and cat food is low.. The impact of dogs and cats on the environment as discussed by Vale and Vale (2009) and Okin (2017) seems to be overestimated. Reduction of the number of dogs and cats, or keeping smaller animals on vegetarian diets will not contribute significantly to the reduction of global environmental emission problems.

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NOTES

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