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Contents

Dear colleagues and friends,

The use of imported soybean meal in poultry nutrition has been an issue since years among NGOs and government authorities, mainly in Europe. Production of soybeans for animal nutrition is considered responsible for clearance of rainforests and dislocation of indigenous people in Brazil. Energy use for processing, transport and treatment of soybeans contribute to climatic change. These arguments lead to the request to replace soybean meal by locally produced raw materials. But does Europe have land resources to produce sufficient quantities of alternative protein rich crops? Taking Germany as an example, the production of an equivalent quantity of protein from peas and lupines would require 4 to 5 Mio hectares, i.e. about 33 to 43 % of arable land. In view of the relatively low yield of legumes, production of protein per hectare would be more efficient with wheat or other grain crops. Beyond political efforts to reduce the dependence on imported soybean meal and to stimulate local production of protein rich crops, research should focus on the most efficient use of scarce resources. The first three articles in this issue focus on nutrition research around a global challenge. The next three articles focus on genetic contributions to improved efficiency and bird welfare.

Dr. Klaus Damme and co-authors present results of a recent nutrition experiment at the Bavarian Poultry Research Station in Kitzingen, which demonstrate that eggs can be produced economically without soybean meal. However, rapeseed and sunflower meal are only competitive relative to non-GMO soya. White-egg and brown-egg laying hens reacted differently to alternative feed sources.

Whatever the source of locally available protein, environmental concerns call for a reduction of dietary protein in poultry and animal feed. Supplementation of essential amino acids is common practice. Recent experiments by **Dr. Wolfgang Siegert and Prof. Markus Rodehutscord** at the University of Hohenheim have shown that further substantial reduction of total protein in broiler rations can be achieved if the non-essential amino acids serine and glycine are taken into account.

Technical treatment of diets is commercially used to improve the utilization of nutrients in poultry feed. Treatments like pelleting, extrusion and expansion can have positive and negative effects on the availability of nutrients. This complex matter is treated in detail in the review of **Dr. Terence Z. Sibanda and Dr. Isabelle Ruhnke**, University of New England, Australia.

Commercial breeders of laying hens and meet type poultry have contributed to improved feed efficiency since many years, based on measurement of individual records of pedigree stock. **Dr. Hans-Heinrich Thiele** describes how individual feed intake is measured in pedigree populations of Pekin ducks under near-commercial conditions and presents genetic parameters of feed efficiency and feeding behaviour.

Björn Andersson and co-authors reviewed the literature on causes of bone damage in laying hens and analyzed genetic differences between and within lines of commercial White Leghorns. They conclude that selection based on a palpation score may help to reduce the frequency of bone damage in the long run, while short-term reduction is more likely to come from improved equipment.

The ban of conventional cages in the EU has led to considerable changes in egg production and international trade. **Prof. Hans-Wilhelm Windhorst** shows the shift in the European egg industry in the critical years from 2010 to 2015. In contrast to predictions, the number of laying hens increased by about 10 Mio in Germany and by 20 Mio in the EU.

Prof. Dr. Dietmar K. Flock

Prof. Dr. Werner Bessei

Klaus Damme

Co-authors J. Hartmann, R. Schreiter und N. Wolff

Dr. Klaus Damme is Director of the Poultry Competence Centre of the Bavarian Institute for Agriculture, Germany. At the experimental station in Kitzingen (http://www.lfl.bayern.de/lvfz/kitzingen/index.php) he has extensively studied the use of the possibilities to replace soybean meal through alternative feedstuffs under nutritional, economical and environmental conditions. Here he and his co-authors present recent results of experiments with products derived from rape seed and sunflower.

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Egg production without soybean meal? Results of partial and total replacement of soybean meal by rapeseed and sunflower meal.

Abstract

Partial and total substitution of soybean meal by alternative sources of protein, such as sunflower meal and rape seed meal from extracted or extruded rape seed, was investigated using a white and a brown commercial layer hybrid. The control diet was a conventional layer diet containing 16% non-GMO HP soybean meal and 8% dried distillers' grain with solubles (DDGS). Three different substitution treatments were used: partial substitution using small proportions of rape seed products and sunflower flower meal (T1), total substitution of soybean meal using rape seed products (T2) and sunflower meal (T3) as main protein sources. The four treatments (control, T1, T2 and T3) were randomly assigned to the pens. Egg production and egg quality, welfare indicators and economic results were assessed for a laying period from 19 to 72 weeks of age. Despite higher mortality, LSL had higher hen-housed egg production than LB. Within lines the dietary treatments showed no significant effect on egg production, feed efficiency and mortality. Egg weight was lower in the treatments with replacement of SBM. There was no effect of treatments on skin and footpad lesions, but the control hens showed better feather condition. Income over feed cost was highest in T1 (partial substitution of soybean meal) under three different marketing scenarios. The control would have produced better economic results if cheaper GMO soybean meal had been used.

Keywords

laying hens, diet, soybean meal, rape seed meal, sunflower meal, production, welfare, economics, egg quality

Introduction

Soybean meal is the most widespread source of protein in poultry diets worldwide. Most of the soybean meal used in Europe is imported from the USA and Brazil. The use of imported soybean meal is criticized for its high environmental costs (transforming rainforest into arable land, energy use for processing and transport). Hence attempts are made to replace imported soya by locally grown alternative feedstuffs, such as peas, faba beans, lupines, rapeseed meal, sunflower meal or Dried Distillers Grains with Solubles (DDGS). The inclusion of these materials in poultry diets is however limited for their content of anti-nutritive substances, low levels of sulphur-containing amino acids, low digestibility of protein or high levels of crude fiber. Maximum recommended inclusion rates for common alternatives of soybean meal and causes of the restriction are shown in Table 1. Considering the limited levels of inclusion, at least 3 to 4 different alternative feedstuffs have to be combined should soybean meal be totally replaced. The effect of such combinations on digestibility and metabolism and thus on feed intake, egg production, health and egg quality cannot be predicted and needs to be verified in feeding experiments. The aim of the present experiment was therefore to substitute soybean meal partially or entirely with different combinations of alternative feedstuffs. Since laying hens may differ in their response to alternative diets, the experiment was carried out with a white-egg and a brown-egg commercial hybrid.

Table 1: Maximum recommended inclusion rates of alternative protein sources (Jeroch et al., 2012; Jeroch and Daenicke, 2016; Kamphues, 2014)

Feedstuff	Max. inclusion rate (%) Conventional/organic	Causes
Rapeseed extract RSE Rapeseed cake RSC	10/0 5/5	Sinapin. glucosinolates
Sunflower extract SFE/ Sunflower cake SFC	10/15	Crude fiber
Peas	20	Tannines. low in sulfuric amino acids
Sweet lupines	15	Low energy. low in sulfuric amino acids
Faba beans	10	Tannines. Lectines. Vicin. Convicin. Low in sulfuric amino acids
Destillers Dried Grain Solubles (DDGS)	10/0	NSP Low ileal digestibility of amino acids
Dehydrated grass	5/5	High level of crude fiber. low energy

Materials and methods

A total of 1320 hens, 600 Lohmann Selected Leghorn (LSL) classic and 720 Lohmann Brown (LB) classic were used. All birds were raised from day-old up to 18 weeks of age in deep litter pens at the Experimental Poultry Farm of Bavaria, Kitzingen, Germany. The birds were not beak trimmed. At 19 weeks of age the pullets were transferred to a force ventilated layer house with windows. The layer house was subdivided in 44 deep litter pens of 4.07 m^2 each. 30 birds (7.4 birds per m^2) were housed in each pen; 24 pens were stocked with LB and 20 pens with LSL. Four experimental diets, a control diet and three different substitution treatments, with 11 replicates each were randomly assigned to the pens. The control diet represented a practical diet containing 16% of HP soybean meal and 8% of DDGS as protein sources (table 2). A control diet on the basis of soybean meal only would contain 19% of soybean meal. This hypothetical diet was used as reference for the substitution of soybean meal by other components. In treatment one (T1) 52.6% of soybean meal was replaced by 15.7% of a mixture of rapeseed meal from extracted rapeseed (RSE), rapeseed expeller (RSC) and sunflower meal (SFM). In treatment 2 (T2) soybean meal was entirely replaced with sunflower meal as main component and small amounts of DDGS, RSE extract and RSC. The substitution components in treatment 3 (T3) were based on RSE and RSC. Within each treatment a four phase feeding program was established to adjust the nutrient composition to the changing requirements of the hens (Table 3). Within the treatments and feeding phases all diets were iso-caloric, iso-nitrogen and contained the same amount of minerals and vitamins. Egg production, egg quality, mortality, feather conditions, injuries of skin and toes and economic criteria and egg income over feed cost (IOFC) were determined for a full-year laying period. Data were analyzed using a two-factorial model with line and feed treatment as main effects. Within each line, differences between dietary treatments were tested using Tukey's multiple t-test. Treatment x

Table 2: Main protein components used for substitution of soybean meal (SBM) (%) in the experimental treatments

Feedstuff	Control	T1	T2	T3
Level of substitution (%)[1]	**15.7**	**52.6**	**100**	**100**
SBM HP	16.0	9.0	–	–
DDGS	8.0	8.0	1.6	4.4
RSE	–	4.0	4.0	10.0
RSC	–	4.0	4.0	6.0
SFM	–	5.0	16.0	8.0
Maize gluten	–	–	2.7	–

[1] Reference diet with 19 % SBM HP as only protein component

Table 3: Composition of main nutrients in four phases

Nutrients	Phase I Special	Phase I	Phase II	Phase III
Age (weeks)	**21–28**	**29–48**	**49–64**	**65–72**
ME (MJ)	11.6	11.4	11.4	11.2
CP (%)	17.5	17.0	16.5	16.0
Lysine (%)	0.86	0.83	0.78	0.72
Methionine(%)	0.44	0.42	0.38	0.35
Calcium (%)	3.7	3.7	3.9	4.1
Sodium (%)	0.18	0.18	0.18	0.16

Table 4: Effects of partial or total substitution of soybean meal (SBM) with alternative raw materials on egg production, egg quality, welfare indicators and economics in LB classic (means on red underground worst case, on green best case and on yellow intermediate)

Criteria	Control	T1	T2	T3	Sign.
Performance					
Egg production hen housed (%)	78.6	81.4	81.1	82.5	n.s.
Feed consumption (g/hen/day)	125.4	121.5	123.3	120	*
Feed consumption (kg/ hen/year)	45.6	44.2	44.8	43.7	n.s.
Feed efficiency (kg feed/kg egg mass)	2.373	2.325	2.353	2.311	n.s.
Mortality (%)	9.3	4.0	3.3	2.8	n.s.
Egg quality					
Egg weight (g)	64.6	63.6	63.3	62.1	**
Small eggs (<53 g) (%)	2.3	2.7	3.8	4.0	**
Dirty eggs (%)	1.9	1.0	2.3	0.7	*
Cracked eggs (%)	2.2	2.4	2.1	2.1	n.s.
Breaking strength (N) 70 weeks of age	37.9	38.5	35.8	38.3	*
Welfare indicators					
Feather scores 1)	0.61	1.01	0.81	0.71	**
Birds with no skin lesions (%)	90	80	86	92	n.s.
Birds with no footpad lesions (%)	58	60	51	56	n.s.
Birds with no toe lesions (%)	100	98	95	98	n.s.
Economics					
IOFC - egg processing (€/hen)	5.37	6.59	6.39	6.79	*
IOFC - packing stations (€/hen)	10.45	11.85	11.33	12.27	*
IOFC - direct marketing (€/hen)	33.57	35.72	34.52	36.17	*

[1] Score 0 no damage; score 1 slight damages; score 3 large damages

strain interactions were not tested for statistical significance.

Results and discussion

Mean values of all criteria are shown in table 4 for LB and table 5 for LSL. LSL showed generally a higher percentage of egg production than LB with the highest egg production in T1 (89.9%). The effect of diets within lines where however, not significant. In LB hens in treatments T1 to T3 showed in tendency a higher performance then the control birds. This shows that LB hens responded more sensitively to the replacement of SBM than LSL. This is supported by the data of daily feed intake. There was a significant reduction in daily feed intake in the diets with higher proportions of rape seed products. T3 with a total of 16% of rape seed products showed the lowest daily feed intake (120 g), while T1 and T2 with 8% of rape seed products took an intermediate position between the control and T3. Why some birds dislike rape seed products and react with decreased feed intake has not been explained so far; chemical characteristics, the color, structure or taste of the feed may be involved.

Feed conversion was consistently more efficient in LSL than LB layers. Mortality varied between 2.8% and 9.3% in LB and 5.3% and 9.3% in LSL, but the differences due to treatment are not significant due to small number of replications. In LSL the main cause of mortality was toe pecking: 31 out of 48 hens which died or had to be culled for this reason. This problem occurred in all dietary treatments and may be due to the fact that the birds were not beak-treated.

In both lines, there was a significant dose response on egg weight for the level of substitution of soybean meal: egg weight decreased consistently with increasing le-

Table 5: Effects of partial or total substitition of soy bean meal with alternative raw materials on egg production, egg quality, welfare indicators and economics in LSL classic (means on red underground worst case, on green best case and on yellow intermediate)

Criteria	Control	T1	T2	T3	Sign.
Performance					
Egg production hen housed (%)	88.2	89.9	87.7	88.5	n.s.
Feed consumption (g/hen/day)	126.1	124.7	124.7	125.1	n.s.
Feed consumption (kg/ hen/year)	45.9	45.4	45.4	45.6	n.s.
Feed efficiency (kg feed/kg egg mass)	2.173	2.148	2.200	2.202	n.s.
Mortality (%)	8.9	5.6	9.3	5.3	n.s.
Egg quality					
Egg weight (g)	63.9	63.2	62.3	62.0	**
Small eggs (<53 g) (%)	3.8	3.8	5.1	5.2	**
Dirty eggs (%)	0.6	0.7	2.4	0.7	*
Cracked eggs (%)	1.1	1.1	0.7	1.1	n.s.
Breaking strength (N) 70 weeks of age	36.2	36.5	36.4	35.2	n.s.
Welfare indicators					
Feather scores 1)	0.74	0.82	0.78	0.87	**
Birds with no skin lesions (%)	90	85	84	75	n.s.
Birds with no footpad lesions (%)	12	14	13	14	n.s.
Birds with no toe lesions (%)	93	86	77	86	*
Economics					
IOFC - egg processing (€/hen)	7.3	8.1	7.5	7.6	*
IOFC - packing stations (€/hen)	13.81	14.53	13.13	13.66	*
IOFC - direct marketing (€/hen)	40.03	41.18	38.30	39.48	*

[1] Score 0 no damages; score 1 slight damages; score 3 large damages

vel of substitution of SBM. Low egg weight of 63.3 and 62.0 g was found in diets containing high levels of sunflower meal (T3) in LB and LSL respectively. Similar reduction in egg size was found in LB in T2 (63.3 g). Low levels of different substitutes (T1) showed an intermediate egg size of 63.6 and 63.2 g in LB and LSL respectively. The negative correlation between rate of lay and egg size is well known and also is found in this experiment, where the negative effect on egg weight is partially compensated by higher egg production. Differences in average daily egg mass or total hen-housed egg mass are therefore small, but have to be kept in perspective when calculating egg income over feed cost.

Due to reduced egg weight in non-soybean meal diets T2 and T3, the proportion of small eggs (S) increased substantially in the first weeks of lay and the proportion of eggs in the categories large (L) and extra large (XL) at the end of the laying period was lower. Since small eggs (below 53 g) cannot be sold as table eggs, they have to be sold at a low price to processing plants. The proportion of cracked eggs was lower in LSL than in LB hens. Egg shell strength was lower in T2 (high level of sunflower meal), but the proportion of cracked eggs was not increased in this treatment. Sunflower meal increased the percentage of dirty eggs in both lines.

Average feather scores differed significantly between feed treatments within line, but were not consistent across lines. Differences between lines could only be shown when particular areas were considered. While LSL showed more feather loss on the neck and back, more damage in the vent area was found in LB. However, most hens (93 to 79%) showed only slight feather damage (scores 0 and 1). Lower scores occurred in the control diet: only 7% of LB and 8% of LSL layers had featherless areas with more than 5 cm in diameter. In LB the highest score was found in T1 (1.01) and the lowest in the control. The deterioration of the feathers is mainly caused by vigorous feather pecking and pulling. High dietary fiber has been found to reduce the risk of feather pecking. The fiber content of diets in phase 1 feed was 2.8% in the control, 3.8% in T1, 5.8% in T2 and 4.8% in T3. The control diet had the best feather condition in both lines, although it had the lowest fiber content. Thus, a lower level of dietary fiber cannot explain feather pecking damages in the present study, but the higher feed intake of the control birds may have reduced feather pecking. Especially at the onset of lay many birds don't eat enough to fully cover their nutritional requirement, and reduced feed intake in response to the substitution of SBM may have contributed to the development of feather pecking. In line with the feather scores, skin injuries were also less frequent in the control compared to the other dietary treatments. Injuries of the skin occurred mainly in the cloacal area and in the area of the preening gland. However, differences between lines and dietary treatments where not significant. The occurrence of "bumble foot" and toe lesions is often considered as a problem of nutrition. Diets which lead to wet litter have been found to increase the risk of footpad problems. In the present study there was no significant effect of the diet. There was a tendency of better foot conditions with T1 feed in both lines. The lines differed significantly in the frequency of footpad damages. The percentage of birds with intact footpads was 56.1% in LB and only 13.3% in LSL. Similar results were found for toe injuries. The proportion of birds showing no toe damage varied between 77 and 93% in LSL and 95 and 100% in LB. The effect of dietary treatments was not significant in LB. In LSL, T2 had the lowest proportion of birds with intact toes (77%). In both lines toe conditions were best in the control (93% of intact toes in LSL and 100 % in LB). The cause of the high frequency of toe injuries in LSL when fed sunflower meal (T2) is not known, nor is it consistent with feather scores and skin injuries. Therefore it should not be concluded from these results that sunflower meal represents a special risk for cannibalism.

Economics

The economic calculation is based on the assumption that imported non-GMO HP soybean meal is replaced by locally produced DDGS, rape seed extract, rape seed expeller, sunflower meal and maize gluten. Since non-GMO HP soybean meal is very expensive, its substitution with locally grown products leads to a substantial reduction of feed cost compared to the control diet: 1€/dt in T1, 1.31 €/dt in T2 and 1.55 €/dt in T3. Taking different egg prices into account, calculations were made for three different scenarios: eggs sold (1) to an egg processing plant (lowest price), (2) to a large-scale packing station (intermediate price), and (3) directly to the consumer (highest price). The results are shown tables 4 and 5. Independent of the egg price, egg income over feed cost (IOFC) was higher for LSL than in LB layers. The economic results with different diets also differed between lines: under all marketing scenarios, LB layers produced a higher IOFC when imported non-GMO soybean meal was replaced by alternative sources of protein: the best result was found with T3, followed by T1 and T2, and the lower egg production with the control diet in LB could not be compensated by larger eggs. In LSL the best economic result was achieved in T1 under all marketing scenarios, followed by control, T3 and T2. However, it should be kept in mind that the calculation is based on the high price

Table 6: Feed prices of the different treatments; egg prices by weight category for egg processing, packing stations (Weser Ems) and direct marketing (DGS 2016)

Average feed price	
Control	27.16 €/dt
T1	27.71 €/dt
T2	27.40 €/d
T3	28.71 €/dt
Egg processing	1 € /kg egg mass
Packing station	XL: 13.75; L: 8.40; M: 8.10; S: 5.10 cts./egg
Direct marketing	XL: 20.00; L: 18.00; M: 16.00; S: 6.00 cts./egg)

of non-GMO soybean meal. With the same performance, the ranking of economic results would be reversed if ordinary GMO soybean meal were used.

Conclusions

- ➔ Total substitution of imported soybean meal with locally available sources of protein in layer diets leads to reduced daily feed intake, reduced egg weight, and more damage of feathers, skin and toes. Therefore total substitution is not recommended at present. Further experiments are required to find out whether disadvantages of alternative feedstuffs may be removed by adjusting nutrient density, composition of amino acids or feed additives which improve the digestibility of nutrients in these components.
- ➔ Genetic lines respond differently to alternative feedstuffs. Brown-egg layers like LB appear to be more sensitive than white-egg layers like LSL to substitution of soybean meal.
- ➔ High levels (16%) of sunflower meal produced more dirty eggs and toe damages than other diets.
- ➔ Partial substitution of non-GMO soybean meal by moderate levels of locally available substitutes (rape seed products, sunflower meal) showed similar performance in terms of egg mass and feed efficiency, but minor problems of welfare related characteristics.

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Relevance of glycine in crude protein-reduced broiler nutrition

Abstract

This article reviews the possibilities to reduce the crude protein concentration in feed for broiler chickens. Considering concentrations of all essential amino acids allows for a reduction of the crude protein concentration in the feed for 1 to 21 days-old broiler chickens to about 19%, without impaired growth. Considering nonessential amino acids only as their sum does not allow for a reduction any further. Instead, single nonessential amino acids need to be considered. The nonessential amino acids glycine and allow for a serine are growth-limiting in feed for broiler chickens containing less than 19% crude protein. Glycine and serine are best assessed together as glycine equivalents (Gly_{equi}) due to the equal effect of these amino acids on the growth. Adequate concentrations of Gly_{equi} allow to reduce the crude protein concentration in the feed for 1 to 21 days-old broiler chickens to about 16% without implications on the growth. The requirement for Gly_{equi} depends on the concentrations of other nutrients in the feed, such as threonine, choline, and cysteine. A reduction of the crude protein concentration below 16% is expected to be possible in the future by optimizing the Gly_{equi} concentration in the feed and the factors influencing the response to Gly_{equi}.

Keywords

broiler chickens, low protein feed, glycine, nonessential amino acids

Introduction

The increasing demand for meat and other animal products and the concomitant global limitation of arable land results in a shortage of protein-rich feedstuff to be expected. Consequences of increased crop prices have been shown to especially affect the affordability of food in developing countries. Excreted nitrogenous compounds of broiler chickens and other farm animals can have negative effects on the environment, including soil, water and atmosphere. In addition, high ammonia levels in the animal house can affect human and animal health as well as the acceptance of livestock farming by the public due to unpleasant odors. Nitrogen excretion of animals can be reduced effectively by lowering the crude protein concentration in the feed. Experiments, however, showed that feed containing a crude protein concentration of less than 19 to 20% often had undesirable effects on the performance of 1 to 21 days-old broiler chickens even though the requirement of all essential amino acids was met.

About ten years ago, several potential reasons for unfavorable effects of low crude protein feed for broiler chickens have been discussed (Aftab et al., 2006). One of those reasons is a potentially different optimal concentration of essential amino acids between standard and low crude protein feed. This aspect was targeted in numerous studies. Some studies supplemented free amino acids to low crude protein feed to raise the level of all essential amino acids above recommendations (e.g. Jiang et al., 2005). This consistently did not overcome the reduced growth induced by low crude protein feed. In other studies, the concentrations of single essential amino acids or combinations of essential amino acid were varied (e.g. Si et al., 2004). This had no effect on the growth in most cases. Few studies reported an increased growth compared to the low crude protein feed. However, the growth of standard crude protein feed has not been met in any of the studies.

The effect of nonspecific nonessential amino-nitrogen was evaluated by investigating the effects of different combinations or levels of nonessential amino acids in the feed (e.g. Namroud et al., 2010). This had no effect on the growth in some studies. In other studies, a growth-increasing effect compared to the low crude protein feed was reported, but the level of growth of standard crude protein feed has not been achieved. Considering the sum of nonessential amino acids probably is not sufficient because specific metabolic processes can become limiting. This leads to the implication that single nonessential amino acids are important to avoid unfavorable effects of low crude protein feed on the growth of broiler chickens.

Glycine in nutrition of broiler chickens

Single nonessential amino acids have been supplemented to low crude protein feed in several studies. Supplementing free glutamic acid, aspartic acid, proline, and alanine consistently did not prevent from reduced growth caused by feeding low crude protein feed (Corzo et al., 2005; Dean et al., 2006). However, growth-increasing effects were determined when free glycine was supplemented. Two studies showed that supplementing feed with a crude protein concentration of 16% with free glycine to the level of about 22% crude protein control feed prevented reduction of growth compared to the control feed (Dean et al., 2006; Awad et al., 2015).

However, the concentration of glycine in nutrition of broiler chickens cannot be considered alone because studies revealed that serine in the feed has the same effect on the growth as glycine (Sugahara and Kandatsu, 1976). Animals can convert glycine into serine and vice versa. This interconversion seems to be not limited in poultry. The analogue effect of glycine and serine often is taken into account by calculating the sum of the concentrations of glycine and serine (Gly+Ser). However, this neglects the fact that glycine and serine in the feed are equally effective only when the same molar amount of those amino acids is considered. Therefore, Dean et al. (2006) proposed calculating the glycine equivalent (Gly_{equi}) as the sum of glycine and the molar glycine equivalent of serine, calculated as follows:

Gly_{equi} *(g/kg) = glycine (g/kg) + [0.7143 × serine (g/kg)]*

where 0.7143 is the ratio of the molar weight between glycine and serine. Formulating feed using Gly_{equi} is more appropriate than using Gly+Ser and its calculation is easy. Therefore, using Gly_{equi} is recommended for future industry applications. Once calculated for the feedstuffs, Gly_{equi} can be handled like any other single amino acid in feed formulation.

Glycine and serine are incorporated in almost all body proteins. Collagen and elastin are amongst the proteins richest in glycine. Keratin, which is mainly present in feathers and claws, contains high proportions of both glycine and serine. This might explain why a deficiency of glycine and serine in feed has been described to cause low skin strength (Christensen et al., 1994) and impaired feather development (Robel, 1977). Thus, supplying broiler chickens deficiently with Gly_{equi} may cause economic implications in addition to the consequences of the low growth.

Meanwhile, it is widely accepted that Gly_{equi} is the first-limiting nonessential amino acid in feed for broiler chickens (Ospina-Rojas et al., 2012). Waguespack et al. (2009) considered Gly_{equi} to be the fourth-limiting of all proteinogenic amino acids after methionine, lysine, and threonine in feed based on corn and soybean meal for broiler chickens from 1 to 18 days. This was basically confirmed by Ospina-Rojas et al. (2014), who described valine and Gly_{equi} as equally limiting after methionine+cysteine, lysine and threonine in corn-soybean meal-based feed for broiler chickens from 1 to 21 days.

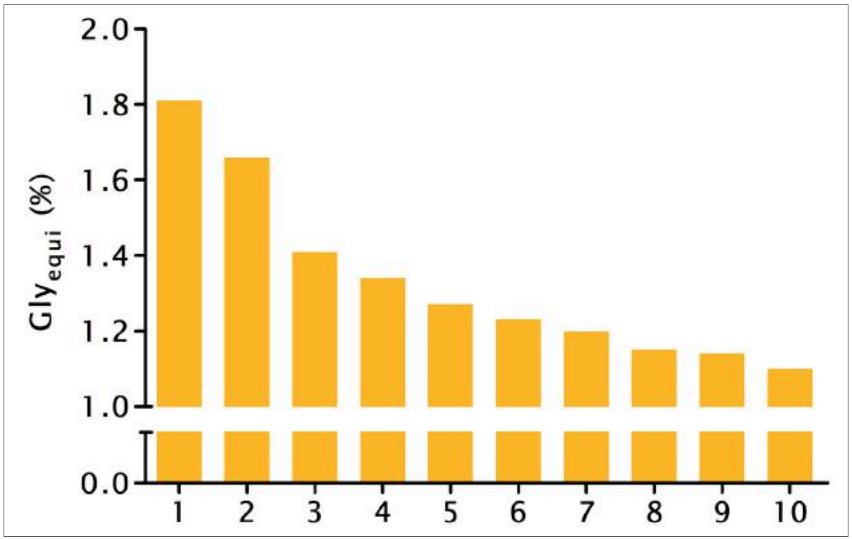

Figure 1: Gly_{equi} concentration in the feed needed to achieve 95% of the maximum gain to feed ratio in ten separate broiler studies (Siegert et al., 2015a).

Growth response to Gly_{equi}

Several dose-response studies investigating the effect of Gly_{equi} in feed were published. A compilation of some studies shows that the growth response to incremental dietary Gly_{equi} was inconsistent (Figure 1). This indicates that the response to Gly_{equi} is influenced by other dietary factors.

The metabolic formation of cysteine from methionine dissipates Gly_{equi} (Figure 2a) (Powell et al., 2011). This is especially important in low crude protein feed because a targeted methionine+cysteine concentration usually is achieved by adding DL-methionine or analogue supplements, whereas free cysteine usually is not added. The meta-analysis by Siegert et al. (2015a) showed that the cysteine concentration in the feed has a substantial impact on the gain to feed (G:F) response to Gly_{equi} even though the methionine+cysteine concentration did not vary considerably (Figure 3). Fulfilling the requirement of broiler chickens for both methionine and cysteine reduces the necessity to convert methionine to cysteine and, therefore, reduces the requirement for Gly_{equi}.

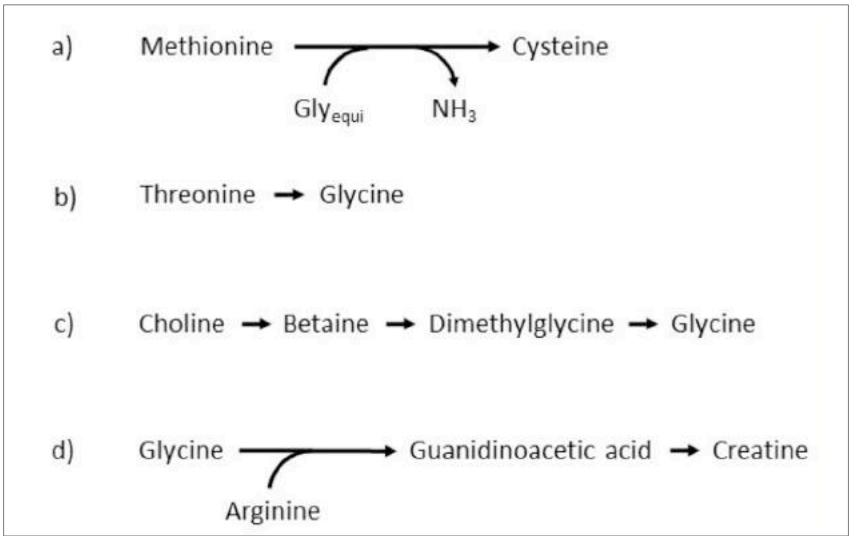

Figure 2: Scheme of selected metabolic pathways involving glycine.

Glycine and serine are nonessential amino acids and, therefore, can be produced to some extent by the metabolism of the birds. Several substances can be metabolized to glycine or serine out of which threonine and choline are the quantitatively most important (Meléndez-Hevia et al., 2009). Threonine can be metabolized directly to glycine (Figure 2b), and choline can be metabolized to glycine with betaine and dimethylglycine as intermediate steps (Figure 2c). The study of Siegert et al. (2015b) showed that the response to Gly_{equi} depended considerably on the threonine concentration in the feed (Figure 4). An increase in the threonine concentration reduced the Gly_{equi} concentration required to achieve certain response levels. The same study also revealed that the choline concentration influenced the response to Gly_{equi} and threonine. Therefore, concentrations of Gly_{equi}, threonine, and choline need to be considered together in feed formulation. The observed potential of reducing the Gly_{equi} concentration in feed by increasing the threonine and choline concentrations exceeded the theoretically possible replacement that can be explained by endogenous conversion processes. In consequence, the results shown in Figure 4 do not allow for the conclusion that adding threonine above recommendations prevents comprehensively from undesirable effects initiated by Gly_{equi} deficiency. Reasons for that are currently unknown and should be investigated before recommendations are made that can be applied by feed formulators.

There are further possible but scarcely investigated influencing factors on the response to dietary Gly_{equi}. One of them is arginine which, together with glycine, is a precursor of guanidino acetic acid. Guanidino acetic acid then reacts to form creatine (Figure 2d), a compound that is involved in the energy supply of animal cells including the muscles. Interaction effects for guanidino acetic acid and arginine on the growth were reported for broiler chickens in several studies (e.g. Dilger et al., 2013). However, little is known about the effect of Gly_{equi} on the growth response to arginine and guanidine acetic acid in the feed.

Gly_{equi} concentration in feedstuffs

The concentration of Gly_{equi} varies considerably between and within types of feedstuffs (Table 1). However, the variation in the Gly_{equi} concentration of the protein is low. It ranges in most cereals, cereal byproducts, brewery byproducts, oil seeds, and pulses between 7.3 and 8.3 g/100 g crude protein. Compared to vegetable feedstuffs, the variation of the ratio of Gly_{equi} to crude protein is higher in animal byproducts. While it is low in fish meal, the ratio is very high in meat meal and particularly in meat and bone meal.

Because the Gly_{equi} concentration in vegetable proteins is low, using only vegetable ingredients in feed formulation restricts the possibility to increase or decrease the ratio of Gly_{equi} in crude protein of plant-based feed. In consequence, formulating feed with Gly_{equi} concentrations that avoid undesirable effects on the growth using plant-based feedstuffs only leads to an excessive supply of the animals with other amino acids. This can be avoided by feeding animal-derived proteins to poultry but those are prohibited in some countries. Feed additives suitable for elevating the Gly_{equi} concentration in feed are free glycine and L-serine, which are not approved in some countries at this time.

In countries where animal-derived proteins are prohibited and free glycine and L-serine are not approved, an adequate Gly_{equi} supply can only be achieved by a surplus supply with crude protein. Environmental and possible downsides need to be accepted if this strategy is pursued. A deficient Gly_{equi} supply in low crude protein feed might be reduced by a surplus supply of endogenous precursors like threonine and choline. Betaine and dimethylglycine as intermediate steps when glycine is formed from choline might also be suitable endogenous precursors. However, these

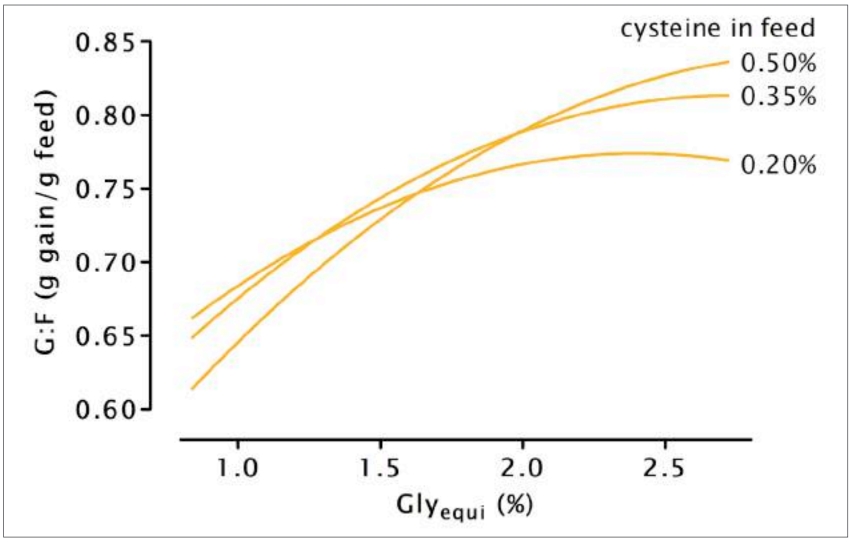

Figure 3: Response of G:F to different dietary concentrations of Gly_{equi} dependent on the level of Cys determined in a meta-analysis using 10 published studies that investigated the response of 1 to 21 days old broiler chickens (Siegert et al., 2015a).

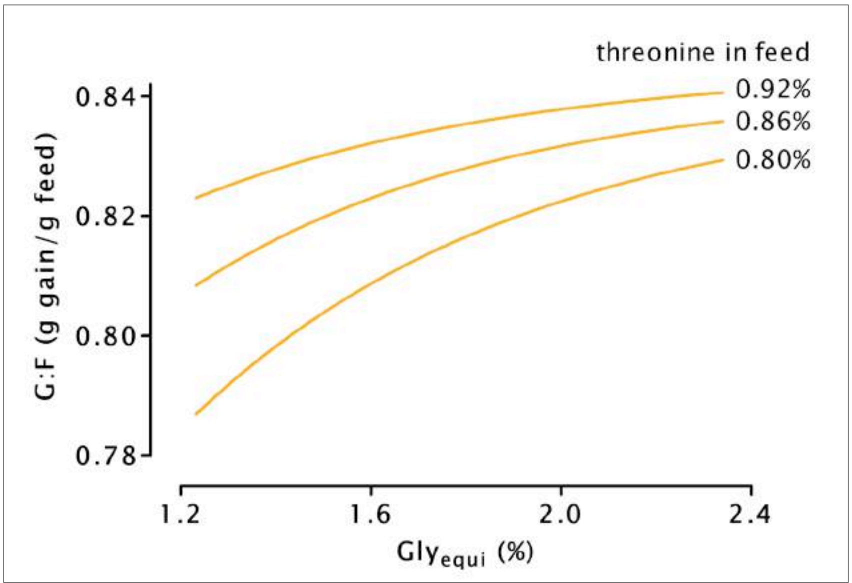

Figure 4: Gly_{equi} concentration in feed necessary to achieve 95% of maximum G:F responses of 7 to 21 days old broiler chickens depending on the threonine concentration in feed (modified from Siegert et al., 2015b).

Table 1: Concentrations of Gly_{equ}i and ratio of Gly_{equi} in crude protein of selected feedstuffs relevant for animal feeding based on nutrient concentrations extracted from AMINOdat® 5.0 (2016).

Feedstuffs		Gly_{equi} (g/kg dry matter)	Gly_{equi} (g/100g crude protein)
Cereals	Winter wheat	8.3	7.4
	Durum	11.1	7.0
	Corn	6.6	7.3
	Triticale	9.5	7.3
	Oats	8.8	7.3
Oil seeds	Rapeseed meal	31.7	7.9
	Soybean meal	41.6	7.8
	Sunflower expeller	44.4	8.3
Pulses	Field beans	21.6	7.4
	Field peas	18.5	7.6
	Lupins	30.4	7.4
Non-animal byproducts	Corn gluten feed	17.1	7.5
	Wheat bran	11.4	8.2
	Distillers dried grains with solubles (wheat)	22.5	7.2
	Brewer's dried yeast	35.3	7.8
Animal byproducts	Fish meal	64.3	6.4
	Feather meal	130.1	14.7
	Meat meal	11.4	14.8
	Meat and bone meal	14.9	17.7

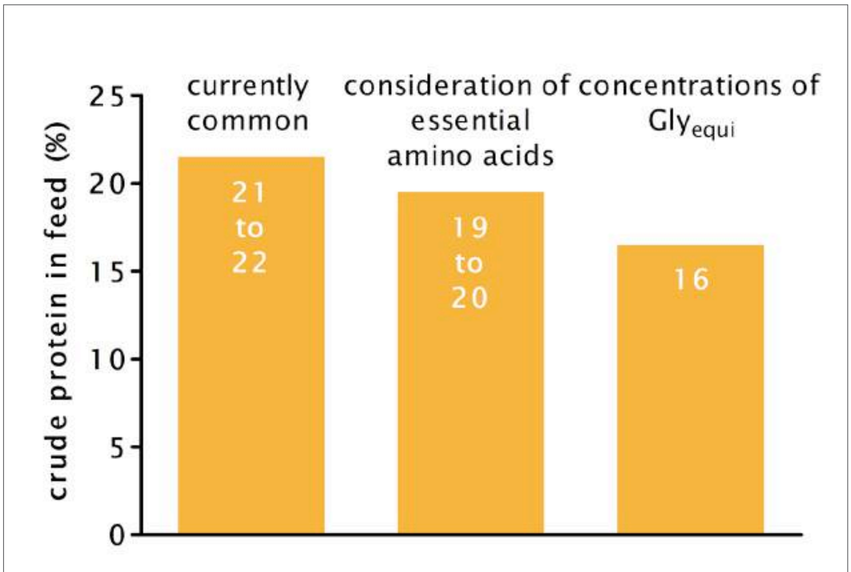

Figure 5: Currently common crude protein concentration in feed for 1 to 21 days old broiler chickens and concentrations to which level the crude protein in feed can be reduced without affecting growth by considering the concentrations of essential amino acids and Gly_{equi}.

possibilities need to better investigated before the relevance of endogenous precursors of Gly_{equi} in Gly_{equi}-deficient feed can be better evaluated.

Current status and perspectives of crude protein reduction

During the past decades the crude protein concentrations have been lowered basically because of knowledge of the requirements for essential amino acids. This enabled diminishing safety margins of crude protein supply but still ensured an adequate supply of essential amino acids. Current research continues to search for ways to reduce the crude protein concentration in feed without compromising growth (e.g. Corzo et al., 2005; Dean et al., 2006). Currently common crude protein concentrations in feed for broiler chickens from 1 to 21 days are about 21 to 22% (Figure 5). Dean et al. (2006) summarized that the growth of broiler chickens fed with feed containing less than 19 to 20% crude protein was reduced even when the requirement for essential amino acids was met. Considering additionally Gly_{equi} enables to reduce the crude protein concentration in the feed considerably without undesirable effects on the growth. Several studies showed that the growth of broiler chickens from 1 to 21 days fed with feed containing 16% crude protein was at the level of feed with more than 20% crude protein if the Gly_{equi} concentration was adequate (Figure 5) (Corzo et al., 2004; Dean et al., 2006; Siegert et al., 2015a).

Factors influencing the response to Gly_{equi} such as those mentioned before were suboptimal in most published dose-response studies with Gly_{equi}. Optimizing both the Gly_{equi} concentration in the feed and the factors influencing the response to Gly_{equi} should enable to reduce the crude protein concentration in the feed even further. The level to which the crude protein concentration in the feed with optimized concentrations of Gly_{equi} and of the factors influencing the response to Gly_{equi} has not been identified so far.

Glycine and serine are the first nonessential amino acids of which experimentally verified requirement values are available. To our knowledge, experimentally verified requirement values for other nonessential amino acids than glycine and serine are not available. It can be expected that the crude protein concentration in the feed can be reduced below 16% without adverse effects on the performance when the role of other nonessential amino acids needs is better understood and experimentally verified requirement values are available.

Conclusions

Gly_{equi} usually is growth-limiting when the crude protein concentration in feed for broiler chickens from 1 to 21 days is below 19%. Considering of the concentration of Gly_{equi} in feed enables to reduce the crude protein concentration in for broiler chickens to about 16%. The requirement for Gly_{equi} depends on the concentrations of other nutrients in feed like threonine, choline, and cysteine. It can be expected on the long term that the crude protein concentration in feed for broiler chickens can be reduced below 16% without adverse effects on the growth when the requirement of other non essential amino acids is assessed.

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NOTES

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The impact of feed treatment on the performance of broilers: A review

Abstract

Commonly used treatments of poultry feed, such as pelleting, expanding or extrusion increase the physical density of the feed and lead to increased feed intake, reduced time spent feeding, improved growth rate and improved feed to gain ratio. Subsequently, improved feed conversion and better performance can often be observed when feeding processed diets compared to mash. Other benefits of thermal treatment include the ease of handling the finished product, improved hygienic status of the feed, and reduced anti-nutritional factors. Besides the mechanic forces of processing, feed is also exposed to heat and steam as conditioning procedures. The amount and duration of heat and moisture applied while processing feed can have a significant effect on the availability of crude protein, amino acids, starch, fat, vitamins and feed additives. The effectiveness of feed processing on nutrient digestibility is also determined by the ingredients and their thermolability. There is a tradeoff between the control of feed borne diseases and digestibility of nutrients. Treatment conditions which reliably reduce harmful micro-organisms may have an adverse effect on digestibility and performance. Short time exposure of the feed to high temperature improves the hygienic status of the feed with limited impact on nutrient digestibility.

Keywords

Broilers, nutrition, feed treatment, pelleting, extrusion, expansion, digestibility, performance, micro-organisms

Introduction

Commonly, poultry is fed a complete diet composed of all ingredients required for balanced nutrition. Depending on the production type and management system used, the macrostructure of mash feed is modified to a pellet, expandate, or extrudate. While laying hens are commonly fed mash, broilers are mostly provided with pellets. Several factors (particle size, particle number, particle shape, flowability, moisture content, etc.) affect demixing of a diet and allow for feed selection by the animal (Amerah et al., 2008; Axe, 1995; Löwe and Mohrig, 2013). Therefore, the beneficial effects of compaction and uniformity of the mixture are of great impact to the poultry industry. Furthermore, thermal treatment of the feed results in modification of proteins and starch, diminishes microbial contamination, reduces dust exposure in the processing plant and in the poultry houses and decreases feed wastage (Maciorowski et al., 2004; Lundblad et al., 2011; Behnke 2001; Peisker, 2006). The physical and thermal effects are confounded when the effect of pelleting and other mechanic procedures are compared under practical conditions. While poultry feed can be heat treated to increase its value by improving nutrient digestibility or by inactivating specific anti-nutritional factors, the nutritional value of some feed ingredients can also be lowered by the heating process (Jia and Slominski, 2010; Kilburn and Edwards, 2001; Moritz et al., 2002).

The following techniques for thermal treatment are most common in the poultry industry:

Pelleting

Pelleting of feed involves a mechanical process, where the application of moist, heat and pressure results in the agglomeration of individual particles into a product of defined shape, size and durability. Commonly, (steam) pressure is applied to the mash feed particles (conditioning), which is then moved into the heated pelleting chamber (Figure 1a; 1b). Once the feed enters the pelleting chamber, it is forced to leave the pelleting press through a metal die of various diameters. During this pellet formation, the feed can be exposed to high friction temperatures (Fairfield, 2003). Depending on the size of the blending screen, the pressure of around 10–20 N results in a final feed temperature of 80–90°C. The heated product exits the pelleting press in long strands, and is then cut to length, cooled and dried.

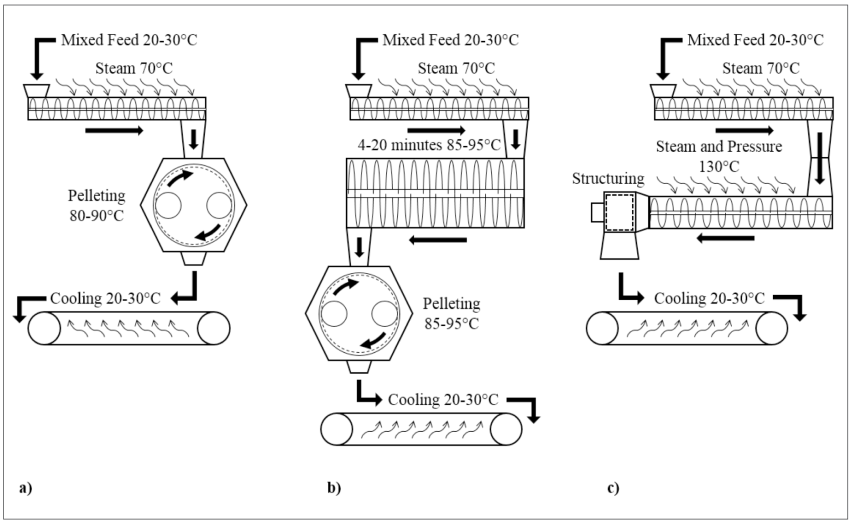

Figure 1: Scheme of pelleting: a) conventional, b) with long term conditioning, c) Scheme of expanding

The physical quality of the pellet is significantly affected by the cooling process, the length of cuts, temperature applied in the pelleting chamber, steam pressure and duration of conditioning, feed ingredients and diet formulation (Arshadi, et al., 2008; Fairfield, 2003; Lemme at al., 2006; Liu et al., 2013b). It has been estimate that the feed formulation and particle size determine up to 40% and 20 % the pellet quality; hence the major parameters of physical quality are already determined before the feed enters the pelleting machine (Behnke, 2001; Figure 2). Wheat as a major feed ingredient is thought to be beneficial for pellet quality due to its relatively high protein and gluten content, while being relatively low in fat compared to corn (Arshadi, et al., 2008; Denstadli et al., 2010). Pellet durability is predominantly influenced by steam added into the conditioner. Steam pressure, steam saturation and steam temperature are the major parameters of this treatment (García-Maraver et al., 2011; Jensen, 2000). Physical advantages of pelleting include ease of handling, reduced ingredient segregation, reduced feed wastage, and increased nutrient density (García-Maraver et al., 2011; Moritz et al., 2002).

The nutritional quality of pellets can be significantly influenced by the duration and temperature of heat exposure. In general, pelleting is used to improve nutrient digestibility, feed palatability and feed conversion ratio (García-Maraver et al., 2011; Jensen, 2000). Further details are outlined in the sections below "the impact of thermal treatment on nutrient digestibility". Increase in the average daily gain of broilers by 32% and feed to gain ration by 3% compared to mash feed have been reported by Jiménez-Moreno et al. (2016) and Engberg et al. (2002). Nutrient excretion can be decreased by 25%, depending upon pellet quality (Hancock and Behnke, 2001) Higher physical density of the pelleted feed enables higher feed intake and reduces time spent feeding. This leads to improved weight gain and feed efficiency. Therefore, an improved performance is common when broiler chickens are given pelleted diets (Abdollahi et al., 2013; Hamilton and Proudfoot, 1995; Lemme et al., 2006). With regard to the digestibility of the nutrients, the effect of pelleting can be highly variable and depends on many different factors which will be dealt with in the following section.

Figure 2: Factors influencing pellet quality include diet formulation, particle size, conditioning, die specifications, and cooling and the drying process. The pellet quality is evaluated by the pellet durability (ability to remain intact when handled), pellet hardness (maximum crushing load that a pellet can withstand without cracking), and the bulk density (biomass/volume). (Source picture: https://pixabay.com/photo-2615928/)

Standard short-term conditioning for feed preparing before pressing (70°C)

Short term conditioning is used in nearly every method of feed compacting. Figure 1a demonstrates the schematic construction of a pelleting press with short term conditioning. The moisture of ingredients needs to be increased to form durable pellets. Steam applied in the conditioner provides a sufficient amount and quality of moist bridges between the feed particles and subsequently allows for binding mechanisms. The amount of saturated steam used to enhance the available moist varies between 1–13%. The use of saturated steam allows for simple temperature difference measurements: A moisture addition of 0.6–0.7% results in a temperature increase of the feed by 10°C. For example, if the starting temperature of 20°C is assumed, conditioning with 3% saturated steam will result in a feed temperature of 70°C in the press.

Long term conditioning (85-95°C)

One possibility to improve the hygienic status of the feed and the durability of the pellet is by applying long term conditioning. While short term conditioning allows mash to be exposed to 60–90°C for several seconds, long term conditioning can last more than 20 minutes (Fairfield, 2003). After the feed has been conditioned under standard procedures (short term conditioning), long term conditioning follows (Figure 1b). The most common steam condition temperatures range from 85–95°C. The mash is usually exposed to these temperatures between 4–20 minutes while being transported with an auger that allows homogenous mixing and subsequently uniform treatment of the feed (e.g. uniform steam injection, uniform heating of the conditioner, continuous speed of the auger). A continuously feed flow as well as any avoidance of clearance volume is essential for an acceptable product quality.

Steam conditioning significantly reduces the fine particle fraction, and increases pellet durability (Skoch et al, 1981). Due to the effect of heat and steam on various feed components such as non-starch polysaccharides (NSP) and subsequently the viscosity of final feed product, the impact of conditioning varies with the feed ingredients used. For example, it has been shown that increasing conditioning temperatures decrease the body-weight gain and feed intake in broilers fed wheat-based diets (Abdollahi et al., 2010; 2011). Similarly, the negative impact of increased conditioning using temperatures above 80–90°C has been demonstrated by Cowieson (2005), when the production of pellets increased the viscosity of the diets. However, broilers fed corn-based diets conditioned at 60°C and 90°C had higher body-weight gain and feed intake than those fed on the diet conditioned at 75°C (Abdollahi et al., 2010). In agreement with these findings, broilers fed with corn-soybean meal pellets conditioned at 93°C significantly increased their feed intake, live weight gain and improved their feed conversion ratio (Cutlip et al, 2008).

Expanding

Comparable to the pelleting process, the expander forces pre-conditioned mash feed through a die sieve of various diameters (figure 1 c). However, while the feed is subject to a shorter treatment time with a maximum dwell time of 3 seconds in the expanding chamber, the temperature that the feed is exposed to while being forced through the expanding chamber is comparably higher and reaches up to 130°C. Expanding combines hydrothermal exposure with mechanical shearing forces. Due to the more intense preconditioning status of the mash feed and the ability of adding steam and fluids directly into the expanding chamber, additional shearing forces push the feed through the machine (Abd El-Khalek and Janssens, 2010; Kaliyan and Morey, 2009). The following exposure to the ambient pressure results in additional shearing forces, reduction of the product moisture due to reactive flash volatilization, and cooling of the product to <100°C.

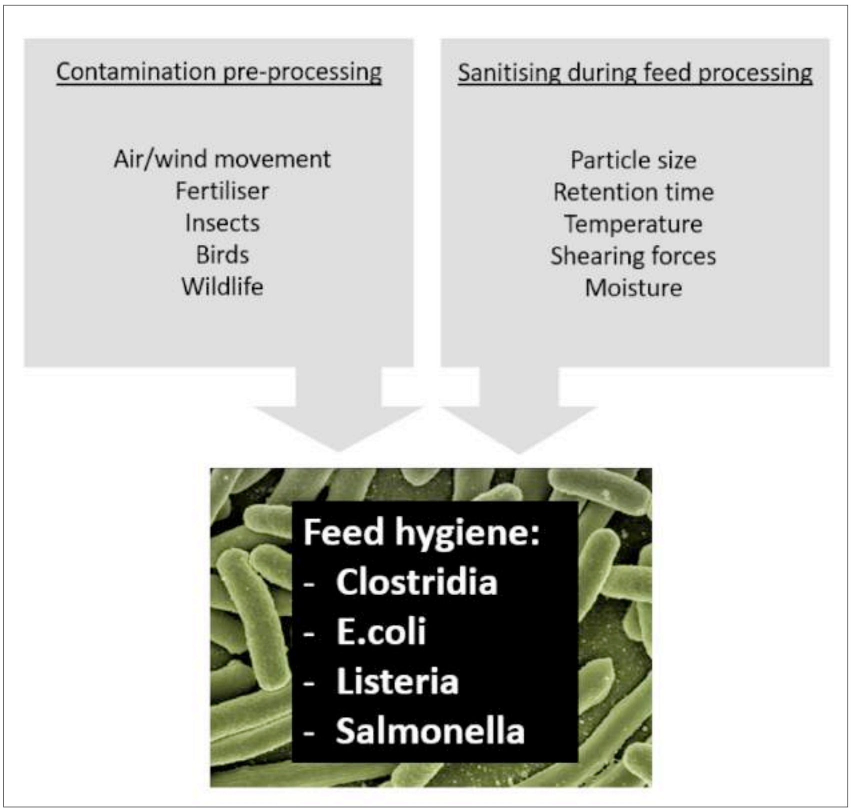

Figure 3: Factors influencing the hygienic status of feed
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Therefore, the structure of the resulting final product breaks up when leaving the expander and the expandate is characterised by a porous surface and lower density, compared to firmly pressed pellets (Kaliyan and Morey, 2009). While the unformed product needs to be cooled, an additional drying process in not required. The expandate can be fed directly or further be processed and served as crumbs, pellet, or granulated pourable feed.

The interaction between conditioning temperature and steam pressure and its influence on feed quality affects broiler performance directly. Due to the lower energy density of expandate and subsequently reduced feed intake, increased FCR and lower body weight has been observed in broilers (Smith at al., 1995; Lundblad et al., 2011). However, other studies show no significant differences in bird performance when comparing overall body weight and FCR of broilers and layers fed pellets and expandate (Boorojeni, 2014b; Peisker, 2006; Ruhnke et al., 2014).

Extrusion

Similar to pelleting and expanding, an extruder forces conditioned mash feed through a die of various sizes. Depending on the shape, diameters and distance of the feed delivering augers, the conditioned mash is exposed to various mixing and cutting forces. While higher levels of moisture, pressure, and heat are used for extruding, the end-product is of higher energy density and pressed into firm structures (Fancher et al., 1996; Heidenreich and Michaelsen, 1995). The use of multiple screw extruders is primarily of importance in the food industry and is capable of the production of specialised items, such as highly viscous foods (e.g. chewing gums, fatty products). Therefore, this method is relatively expensive and primarily used in the pet food or fish feed industry. However, extrusion has been shown to be extremely valuable in decreasing anti-nutritional factors in various legumes including lupines, fava beans, and peas, subsequently improving body weight gain, feed intake and feed conversion ratio in broilers (Hejdysz et al., 2015; Hejdysz et al., 2016; Rutkowski et al., 2016).

The impact of thermal treatment on feed hygiene (microbiota)

Poultry feed ingredients can serve as a carrier for a wide variety of microorganisms. Common modes of feed contamination include the transfer of soil by air movement, rain, mechanical agitation (use of manure as fertilizer, or insects). Temperatures above 71°C used for pelleting are known to reduce the bacteria load. Bacteria of concern to the poultry industry include Clostridia perfringens, Cl. botulinum, Listeria spp. Escherichia coli, and Salmonella spp.. The consequences of these pathogens on bird health and humans due to its potential of causing food-borne illness can be severe. For example, Cl. perfringens causes necrotic enteritis of the intestinal tissue, resulting in growth depression of affected birds and an estimated global economic loss of >2 billion US$ annually (Timbermont et al., 2011; Van der Sluis, 2000). The high prevalence of Cl. perfringens in broiler flocks can be explained by the high heat tolerance of its spores, surviving pelleting temperatures unaffected (Greenham et al., 1987). Salmonella spp. are one of the most common causes of human food borne illness (Tauxe, 2002). The amount of pathogens present in poultry feed, such as Salmonella enteriditis or E.coli, declines with increasing time of exposure to heat. The thermal death rate of salmonella in poultry feed can be predicted at varying time, temperature, and moisture (Himathongkham et al., 1996). For example, thermal treatment of feed with 93°C and 15% moisture for 90 seconds causes a 10,000- fold reduction of viable Salmonella spp. in vivo studies performed in broilers demonstrated that animals fed with pellets had significantly lower Salmonella spp. In their gizzards ($P < 0.01$) and caeca ($P < 0.05$), compared to broilers fed mash (Huang et al., 2006). Similarly, pellet-fed broilers of a different study had larger numbers of coliform bacteria and enterococci in the ileum but reduced number of C. perfringens and lactobacilli in the distal end of the digestive tract (caeca and rectum) compared birds fed with mash (Engberg et al., 2002). In agreement, increased feed processing temperature during pelleting, long term-conditioning and expanding led to an increase of lactobacilli in the crop and ileum of broilers, whereas clostridia and enterobacteria were unaffected (Boorojeni et al., 2014a). However, short term conditioning alone with subsequent pelleting has only shown to reduce the numbers, not to kill all pathogens reliably (Jones, 2011). The antimicrobial effect of pelleting needs to be homogenous and due to the uneven distribution of pathogens in the feed pelleting is not a reliable method to reduce the number of bacterial sufficiently (Jones & Richardson, 2004; Maciorowski et al., 2004). The antibacterial effect can be improved by using a higher mechanical force, such as a double press. In contrast, the short term but very intensive shearing forces in combination with the very high temperatures as provided by the expander results in a reliable profound hygienic status of the feed (Fancher et al., 1996; Maciorowski et al., 2004). Using the expander and various temperatures revealed that temperatures of at least 103°C are insufficient to kill pathogen bacteria and relevant spores reliably. Due to the very short duration that the feed is exposed to the high temperatures, only temperatures of 115–125°C result in a sufficient decontamination of the product by 10^5 to 10^6 colony-forming units (Fancher et al., 1996).

In summary, it can be concluded, that pelleting without any additional treatment is not a reliable method to improve the hygienic status of the feed while expanding feed at temperatures of >115°C can be considered as adequate. The success of thermal treatment depends on the on the intensity (temperature and moist), the duration of the treatment (retention time), as well as the mechanical shearing forces.

The impact of thermal treatment on nutrient digestibility

The impact of thermal treatment on nutrient digestibility of individual feed ingredients has been subject of many research studies. In general, hydrothermic or hydrothermic-mechanic feed treatment allows for a modification of nutrient digestibility including proteins, amino acids, and carbohydrates (Selle et al., 2012; Newkirk et al., 2003). The optimised application of thermal energy on the major feed ingredients is subsequently of highest importance for the feed quality and bird performance. While thermal treatment frequently improves digestibility of the nutrients, the heat application can result in chemical reactions such as the Maillard reaction between the aldehyde group of reducing sugars and the amino acids which significantly impairs nutrient availability (Lundblad et al., 2011, Amezcua and Parsons, 2007; Newkirk et al., 2003). The extend of the Maillard reaction reduces commonly the digestibility of heat labile amino acids such as lysine, arginine and threonine (Newkirk at al., 2003). Feed ingredients with high content of thermolabile amino acids such as canola meal should hence be heat treated with caution. Furthermore, it is known that heat treatment of feed can have a significant impact on digesta viscosity due to the varying amount of water soluble non-starch polysaccharides in various grains such as wheat and barley (Annison, et.al, 1991; Lundblad et al., 2011). The reduced protein availability can result in a depressed growth, reduced meat yield and increased mortality in broiler production (Amezcua and Parsons, 2007; Newkirk and Classen, 2002).

The impact of thermal treatment on crude protein and amino acid digestibility

In general, denaturised proteins are more exposed to digestive enzymes than proteins with an intact structure (Camire et al., 1990). Increasing conditioning temperatures from 65–80 and 95°C significantly enhances digestibility coefficients of amino acids in the proximal ileum and distal ileum in broilers diets (Anderson-Hafermann et al., 1992; Lui et al.; 2013a). However, these effects are mostly attributed to the physical denaturation of the intact protein, allowing its full exposure to enzymes, or the heat inactivation of anti-nutritive factors associated with protein inhibition (Abdollahi et al., 2013; Camire et al., 1990). So while moderate temperatures and short-term treatment showed beneficial or no effects, intensive thermal treatment significantly reduces amino acid availability due to a destroyed secondary structure and therefore diminishes the beneficial effects of protein digestibility seen at seen at lower temperatures (Panigrahi et al., 1996; Amezcua and Parsons, 2007). For example, autoclaving of diets for 40-60 min at 121°C and pressure of 105 kPa reduced amino acid digestibility and subsequently led to lower growth performance (Achinewhu and Hewitt, 1979; Fernandez et al., 1994). In another study, heat treatment of feed (85°C for 3 minutes) resulted in significantly reduced ileal nutrient digestibility of crude protein and amino acids in broilers compared to pellets or expandates (110°C for 3–5 seconds; 130°C for 3–5 seconds) (Boorojeni et al., 2014). The effect of heat treatment on crude protein and amino acid digestibility is also greatly influence by the type of crop, conditioning temperature and feed form which can be linked to the concentration and availability of disulfide bonds and sulfhydryl groups in the diet (Abdollahi, 2011; Selle et al. 2012). For example, increasing conditioning temperature decreased digestible protein and AME intakes in wheat-based diets but not in corn based diets (Adbollahi et al., 2010).

The impact of thermal treatment on carbohydrate digestibility

High processing temperature causes the destruction of the crystalline structure of starch granules which is called gelatinisation. Starch gelatinisation significantly improves carbohydrate digestibility especially in young animals which are lacking endogenous amylase activity (Bjorck et al., 2000; Holm et al., 1988; Kishida et al., 2001). Steam-pelleted diets have frequently shown to increase significantly starch digestibility coefficients in the proximal jejunum of broilers (Adbollahi et al., 2011; Selle et al., 2012). The extent of starch gelatinisation is widely influenced by temperature, shear force and the amount of moisture during feed processing. Starch gelatinisation occurs at 45–90°C and the temperature needed to initiate starch gelatinisation is inversely correlated with the water content of the feed. Moderate pelleting temperatures (65–85°C) results in gelatinisation of starch and cell wall destruction, both of which improve the availability of nutrients (Pickford, 1992; Svihus et al., 2005). When dry heat treatment (< 30%) is applied, more heat is needed to gelatinise starch. (Lund, 1984). Altering processing temperature and water availability has a significant impact in starch gelatinisation concomitantly with starch digestibility (Lundblad et al., 2011). However, prolonged heat treatment insignificantly reduces starch digestibility. Furthermore, the heating temperature at which starch will gelatinise is also influenced by the type of the crop. Starch in wheat will gelatinise at temperature range of 59–68°C while starch in corn will gelatinise at a temperature range of 63–72°C (Ingrid, 1997). For example, in wheat-based diets, increasing conditioning temperature decreased the ileal digestibility of nitrogen and starch while in corn based diets starch digestibility was unaffected (Adbollahi et al., 2010). Similarly, steam-pelleting at a conditioning temperature of 90°C improved significantly starch digestibility in red and yellow sorghum-based diets, but not in white sorghum-based diets. (Liu et al., 2013b). When comparing feed processed by various thermal treatments including pelleting, expanding, and extruding for broiler chickens, hydro-thermal processing increased total apparent starch digestibility, but due to reduced feed intake of the expanded and in particular of the extruded diets, only pelleting improved growth rate and feed utilisation (Lundblad et al., 2011). The reduced bulk density of expanded and extruded feed was held responsible for these effects. Additionally, extruded feed had the highest extract viscosity (Lundblad et al., 2011). Excess of starch gelatinisation can increase the solubility of the NSP which then increases the viscosity of the chyme in the gastrointestinal tract and lowering overall nutrient digestibility (de Vries et al., 2012). At high conditioning temperatures, wheat and barley have been shown to solubilize NSP and increase gut viscosity thus reducing broiler performance compared to maize and sorghum (Cowieson et al., 2005). As a consequence the addition of exogenous enzymes targeting NSP's can be up to six times more beneficial when applied to a thermal treated diet compared to mash (de Vries et al, 2012).

The impact of thermal treatment on fat digestibility

Fat in poultry diets is not only a source of energy but have other advantages including reduces dustiness and improvement of palatability. Feed processing methods such as expansion at 110- and 130°C, short and long-term pelleting have no significant effect on fat digestibility in broilers or layers (Boroojeni et al, 2014; Ruhnke et al., 2015). In contrast, oxidation of fat over time can affect odour and acceptance of a diet and the rancidity of fat can be influenced by the thermal treatment. For example, rice bran and full fat soy bean meal have antinutritional endogenous lipase and peroxidase enzymes that oxidize fats and oils. Heat processing of rice bran at 130–140°C immediately after milling and retaining the temperature at 97-99°C before cooling has been reported to stabilize oil for 30–60 days (Randall, 1985). Steam flaking of cereals can cause lipid oxidation. Oxidized fatty acid can react with certain amino acids and vitamins, making them inaccessible to the animal for digestion. Crystalline amino acids such as methionine and tryptophan are particularly susceptible to react with oxidized fatty acids.

The impact of thermal treatment on vitamins

Feed processing reduces the stability of vitamins which in turn reduces vitamin bioavailability. While all vitamins are heat labile, vitamin A, vitamin B7 (biotin) and vitamin B9 (folic acid) are the most sensitive to heat (Gadient and Fenster, 1994). Heat and steam accelerate most of the vitamin denaturing, with steam having the most influence. The influence of expander treatment on vitamins is significantly lower than pelleting (Kostadinovic et al, 2014; Jubero, 1999, Marchetti et al, 1999). The impact on vitamins due to expanding can therefore be neglected (Schai et al., 1991). This is summarised in Table 1. However, in order to protect vitamin E from the effects of unfavorable storing conditions (60°C and 80% humidity), pelleting and expanding seems to be more appropriate than no heat treatment, even though losses of 46–53% have been detected (Kostadinović et al., 2013). However, when investigating the stability of vitamin A in feed, its concentration decreased by 60–70% in untreated feed, while pelleted diets maintained 39–50% of their vitamin A content during a three month storage period (Kostadinović et al., 2014). Coating allows vitamins to be protected during the pelleting process (Gadient, 1994). If uncoated vitamins are used, an oversupply of vitamins should be integrated into the feed formulation to balance the expected losses (Broz and Ward, 2007).

Table 1: Vitamin losses (%) during pelleting and expanding

Vitamins	Pelleting (70°C)	Pelleting (90°C)	Expander (101-105°C)	Expander (111-115°C)
Biotin (B_7)	10	35	6	9
Choline	5	5	1	2
Folic acid (B_9)	5-20	45	6	9
Niacin	5	10	7	11
Pantothenic acid	10	20	5	8
Vitamin A	10	30-40	3	5
Vitamin C	40	85	2	4
Vitamin D_3	15	35	2	4
Vitamin E	10	15	3	5
Vitamin K_3	20	40	18	22
Vitamin B_1	15	50	4	8
Vitamin B_2	10	15	8	12
Vitamin B_6	10	30	6	9

Source: Charlton and Ewing 2007; Coelho, 1996 (Extracts)

The impact of thermal treatment on anti-nutritional factors

Thermal treatment is one of the most common methods of reducing the adverse effects of anti-nutritional factors in feed including enzyme inhibitors, haemagglutinins, plant enzymes, cyanogenic glycosides, goitrogens, phyto-oestrogens, saponins, gossypol, tannins, amino acid analogues, alkaloids, mineral- and vitamin binders.

Enzyme inhibitors occur naturally in plant ingredients such as trypsin and chymotrypsin inhibitors, amylase and elastase inhibitors, xylanase and plasmin inhibitors. Chymotrypsin activity in soy beans can be eliminated after 40 min at 80°C, 20 min at 90°C or 10 min at 100 °C, while trypsin inhibiting activity was abolished only after 90 min at 100°C (Armour et al., 1998). At 90°C, significant levels of trypsin activity persisted after 40 min of treatment, and the beans had to be heated for 90 min to eliminate any remaining inhibitory activity. Moderate pelleting temperature (65-85°C) deactivates enzyme inhibitors in cereals thereby increases enzyme activity (Saunders, 1975). Plant enzymes such as trypsin and urease activity are correlated to body weight and feed conversion ratio and can be destroyed by heat treatment of the feed (Ruiz et al., 2004; Foltyn et al., 2013; Anderson-Haferman et al., 1992). Especially legumes are rich in enzyme inhibitors, but also haemagglutinins and tannins. Traditional cooking, but also extrusion are reliable methods to decrease the activity of trypsin, chymotrypsin, α-amylase inhibitors and haemagglutinins significantly without reducing protein digestibility (Alonso et al., 2000). Soy beans and lucerne contain saponins which cause a bitter taste, foaming, and erythrocytolysis. In monogastric animals, such as pig and poultry, depressed growth, mainly due to reduced feed intake can be observed (Cheeke and Shull, 1985; Shqueir et al., 1989). Furthermore, unheated soyabeans contains heat-labile anti-vitamin factors that increases the requirement for vitamin B12 and others (Liener, 1980). Dehulling of the legumes decreased even further the tannin and polyphenol levels, allowing the extrusion process to be the most effective and reliable method (Alonso et al. 2000). Gossypol is known to be tolerated by poultry in high levels, but its adverse effects on egg yolk colour discourages its commercial use in layers and limited the inclusion rate (Aletor and Onibi, 1990; Aletor, 1993). Similarly, the presence of sinapine in rapeseed used to limit the use of this feed ingredient for the layer industry, as sinapine levels were associated with a fishy taint of the eggs, reduced feed intake, and reduced egg production. Studies on rapeseed involving a combination of chemical and hydrothermal processing with subsequent expansion and drying has demonstrated that it is feasible to decrease the sinapine content from 6152 mg/ kg rapeseed to < 50 mg/kg, and glucosinolate concentration, from 13.8 mmol per kg to 1.4 mmol per kg (Jeroch et al., 2001). Nevertheless, the inclusion of more than 22.5% untreated or treated rapeseeds significantly impaired egg production, feed conversion ratio, and egg weight (Jeroch et al., 2001). Other anti-nutritional factors such as cyanogenic glycosides, glycoalkaloids, coumarins, and amino acid analogues are of limited relevance in poultry, as their presence occurs predominantly in potatoes, solanum spp., sweet clover (Melilotus officinales), and other pastures which are usually not subject to a poultry diet.

The impact of heat treatment on enzyme efficacy

In commercial poultry feed production, dietary exogenous enzymes are included in feed to enhance nutrient digestibility by reducing anti-nutritional factors. For example, xylanases and β-glucanases have great efficacy in degrading β-glucans and arabinoxylans in rye, barley, wheat and oats based diets. Furthermore, the addition of phytase to poultry diets is known to effectively hydrolyse the bond between phosphorus and the phytate molecule, which increases phosphorus availability. However, heat treatment of feed can reduce the efficiency of phytase (Beaman et al., 2012; Slominski et al., 2007, Eeckhout et al., 1995). Exogenous enzyme thermostablity is a major concern in poultry feed processing as commercial diets are processed at >85°C while the limit for temperature stability for xylanase is 80–85°C (Silverside, 1999). Enzyme deactivation highly depends on the conditioning temperature and the conditioning time, with higher temperatures and prolonged conditioning times increasing inactivation (Beaman et al., 2012; Inborr and Bedford, 1994). On the other hand, increasing conditioning temperatures increases fibre solubility through excessive starch gelatinisation and enzyme β-glucanase supplementation linearly decreased digesta viscosity in temperatures between 75–95°C (Inborr and Bedford, 1994). This same study proved that increasing conditioning time from 30 seconds to 15 minutes linearly reduced and enzymes activity at any temperature from 75–95°C. Enzymes that are inherently thermostable can and should be protected by coating, thus preventing activity loss due to thermal treatment (Turner et al., 2007; Gilbert and Cooney, 2010; Rao et al., 1998).

Conclusion and implications

The commonly used treatments of broiler feed, pelleting, extrusion, and expansion combined with steam conditioning affect the performance in different ways. High feed density through compaction enables an increase of feed intake and reduced the time spent feeding, subsequently improving growth rate and feed to weight gain ratio. Pelleted and extruded feed have further advantages through reducing dust, avoidance of particle separation during transport, selective feed intake and reduced feed waste. The effect of feed treatment on the availability of nutrients, feed additives and hygienic status depends on a multitude of factors: level of pressure, temperature and moisture, duration of conditioning, type, particle size and thermolability of the raw components. Appropriate application of the procedure improves the digestibility of the main nutrients and reduces potentially harmful micro-organisms. Attention should be paid to possible tradeoffs between feed hygiene and improving nutrient digestibility. Conditions which reliably lead to a decontamination of feed can have negative effects on the digestibility of the main nutrients, vitamins and feed additives, such as enzymes. The use of high temperatures at short heat exposure such as the use of an expander allows to improve feed hygiene and control food borne diseases while limiting unwanted impact on nutrient digestibility. Coating heat sensitive feed ingredients such as vitamins and the use of heat stable enzymes can further reduce the adverse effects of thermal processing of feed.

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Feed Efficiency and Feeding Behaviour in Pekin Ducks

Abstract
Feed efficiency is more and more important for all kinds of animal production. Increased feed costs, the awareness of limited raw material resources and environmental issues are driving factors. Therefore individual feed intake of animals is measured and influenced in selection programs. In the past individual feed intake of meat type poultry has been recorded in single cage systems. Those systems are unfavourable for the heavier types of birds, especially the Pekin ducks and don't represent practical housing conditions. The utilisation of sophisticated RFID technologies enables the breeding companies nowadays to record even small meals of individuals under nearly practical conditions. In these testing units not only the amount of feed consumed can be recorded, it opens also the possibility to detect the feeding behaviour.

Keywords
Feed efficiency, Feeding Behaviour, Pekin duck, Genetic parameters

Introduction
Feed efficiency has become more and more important for all kinds of animal production, in response to rising feed cost and awareness of limited resources and environmental issues. Therefore, individual feed intake of the birds is measured and used in selection programs. In the past, individual feed intake of ducks has been recorded in single cage systems (Wolf, 1983; Klemm, 1985; Tieu H. van, 1986; Reiter, 1990; Klemm and Pingel, 1992; Klemm, Reiter and Pingel, 1994; Thiele, 1995), but this system is unfavourable for the ducks and may not reflect feeding behaviour under commercial floor conditions. The limited space in cages reduces locomotion of the birds and induces leg problems and mortalities, especially in heavy male lines. Even specially equipped single floor pens (Kain, 1989) with sufficient space miss the

social elements of large flocks and don't represent the ideal environment for testing the feed efficiency of individual birds. Using novel RFID technology, breeding companies are today able to record even small meals of individuals under nearly practical housing conditions. In these testing units not only the amount of feed consumed can be recorded, it opens the possibility to observe also the feeding behaviour of the ducks, in terms of frequency of meals and size of a single meal (Bley, 2003; Bley and Bessei 2008; Howie et al. 2009; Howie et al. 2010; Basso et al., 2014; Alletru and Thiele, 2016; Le Mignon, Blanchet and Chapuis, 2017). The availability and utilisation of these feeding stations accelerates the genetic progress in feed efficiency. Records of daily feed intake can be used to improve feed efficiency in combination with the weight gain during the testing period as the commonly known FCR or, independent from metabolic body weight and weight gain, as residual feed intake (RFI) (Aggrey et al., 2010; Herd and Arthur, 2009). Beside commonly known growth parameters, differences in the behaviour of single birds can be measured and analysed. This opens the possibility to select also on feeding behaviour to accelerate progress in feed efficiency or to maintain the natural feeding behaviour of the species. Maintaining the natural behaviour of domesticated animals is becoming more and more important in Western societies where ethical production of meat and wellbeing of animals is important to consumers. Recent examples are discussions about "exploding chicks" in the Dutch broiler industry and the "flip over syndrome" in the German duck industry.

The aim of this study was to evaluate the records of performance and behaviour traits of Pekin ducks measured in a feeding station, using a radio frequency identification system and to estimate genetic parameters of those traits.

Material and Methods

Feeding Station and Animals:

The feeding station is equipped with individual feeding places where only one duck can eat at the same time. Access to the

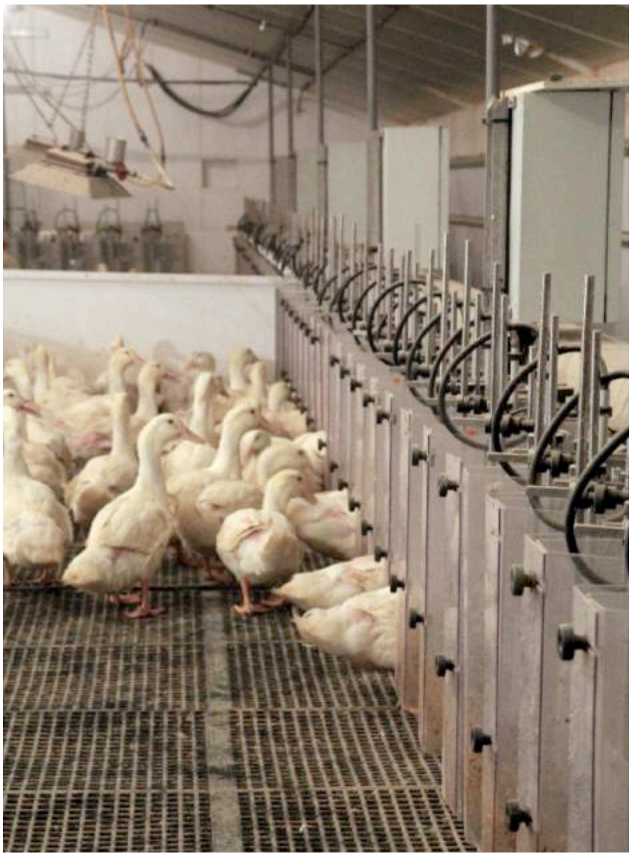

Fig. 1 & 2: Feeding Station to measure individual feed intake in free moving flocks.

Left: Entrance of the feeder station is designed so that only one duck has access to the feeder. Ducks in the feeding station are identified using RFID technique.

Right: Feed hoppers are fitted to electronic scales. Feed consumption is being recorded and stored on a PC.

Table 1: Growth parameters at the end of test (14 to 42 days of age)

	Mean	St. Deviation	Minimum	Maximum
Body weight (g)	3598	301	2380	4560
Breast Thickness (mm)	20.8	2.7	11	28
Conformation Score	3.2	2.7	1.0	6.0
FCR (kg/kg)	1.91	0.13	1.4	3.0
RFI *	5000	258	3365	6637

* The residual feed intake was transformed by RFI+5000 before running parameter estimation

entrance of the feeder is restricted on both sides by a transparent plastic wall, which can be adjusted to the needs of growing birds. A barrier has been added between the plastic walls to prevent other ducks from climbing over the companions while they are feeding. The single feeder places are designed to accommodate a weighing cell, located above the feed hopper. The accuracy of the weighing cell is about 0.2 g, which allows the measurement of even small meals of young ducklings. An antenna is mounted in front of one of the sidewalls of each feeder place. Eight antennas represent one module, which is controlled by a multiplexed RFID reader system. Each duck is marked with a wing band containing a HDX transponder with a unique ID. Above the entrance of each single feeder place a photoelectric sensor is mounted to control the presence of a duck.

When a duck is entering the feeding station and the sensor detects a movement, the weighing cell is set to TARA. After a duck leaves the feeder place, the sensor gives a signal to the system to record the amount of feed consumed as measured by the weighing cell, the feeder place, the date and time of entrance and exit into the unit and the transponder ID of the bird. All this information is transferred to a data base located on the PC running the recording software.

Our study is based on a sample of a much larger set of data, recorded in recent years. The sample represents 4630 Pekin duck males of two ORVIA pure lines, from four hatches in two years, which were tested for feed intake parameters and feeding behaviour traits during 28 days, from 14 to 42 days of age. The stocking density was 7.0 to 7.3 birds/m2 floor surface, 5.4 to 5.7 birds per nipple drinker, and 17.8 to 19.4 birds per single feeder place, with 16 hours light per day. The birds were fed ad libitum with pelleted commercial duck starter and grower feed, which was sieved to reduce the amount of mesh before supplied to the feeders. The drinkers were placed at a distance of 2-3 meters from the feeders and accessible ad libitum.

Traits and Analysis

Before estimating genetic parameters, the source data were screened for outliers, and questionable records were excluded, e.g. from birds resting in the station, records with undetected identities, extremely low total feed intake over the 28 day testing period and other identified outliers. Records for all traits were tested for normality before further analysis.

Feed intake and body weights were measured at 14 and 42 days, at the beginning and end of the test, in addition the breast thickness at 42 days. From these source records, feed efficiency was calculated in terms of feed conversion ratio (FCR = kg feed intake/ weight gain) and residual feed intake (RFI) was calculated as described below.

Residual Feed Intake

$RFI=FI-[a+b_1*BW^{0.75} + b_2*BW\ G]$

FI = Feed intake

BW = Body weight

BWG = Body weight gain

The residual feed intake was transformed to RFI+5000 before running the parameter estimation.

The feeding behaviour parameters recorded are the number of meals per day (TSUM), the average meal duration (TIME), the feeding rate as consumed feed per minute (RATE),

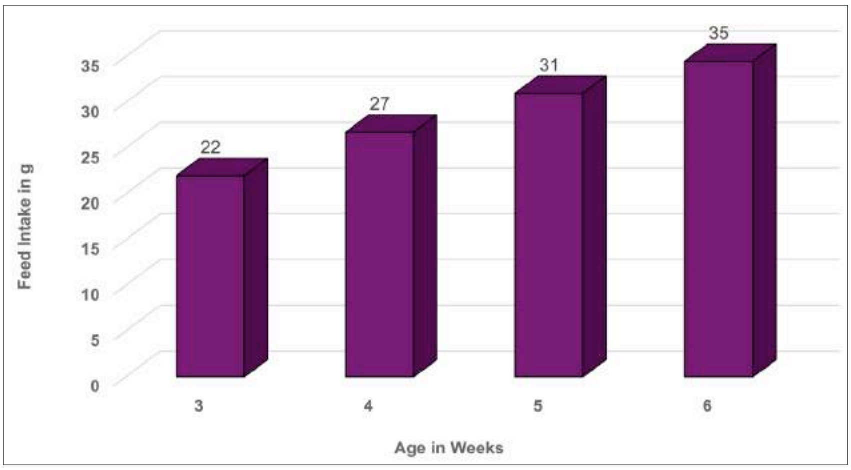

Fig. 3: Size of meals in g per week

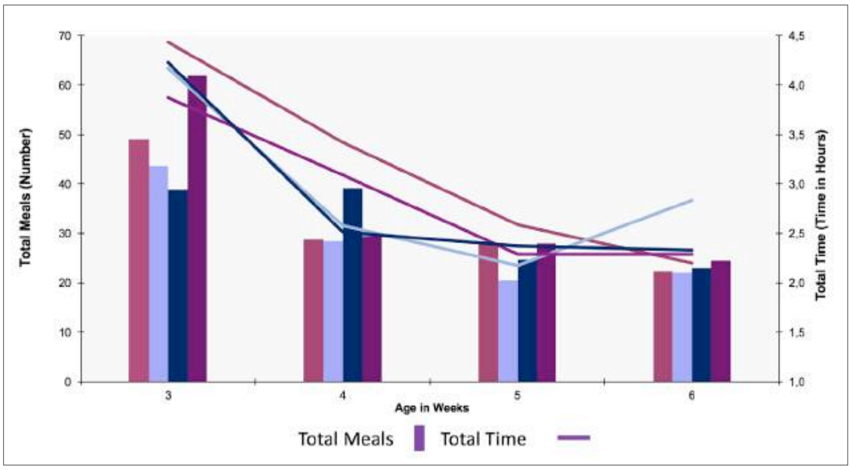

Fig. 4: Number of meals and time spent at the feeders per week

the average daily feed intake (ADF) and the duration of feed intake per day (FDUR).

Our analysis confirmed the findings of Howie et al. (2010) that the number of visits can be used to characterise a meal in Pekin ducks, provided accurate and continuous bird identification is guaranteed.

The parameter estimation was performed with the REML package VCE 6.0 (Groeneveld, 2010).

Multi trait animal model: Y = X β + Z u + e
Where: Y is a vector of observations (performance and behavior traits), β, u and e are the vectors of fixed, random and random residual effects respectively, and X and Z are known incidence matrices. The line, the generation and the time box (time period for tested animal) have been set as fixed effects.

Results and Discussion

As shown in Table 1, the level of growth performance and feed efficiency in both male lines and a sufficient phenotypic variation in those performance traits representing the genetic potential of the lines and have not been depressed by the testing environment.

Moderate to high heritability's and genetic correlations among the performance traits indicate sufficient scope for further improvement of those traits (Table 3). Selecting on RFI, i.e. eliminating the influence of body weight, is more promising than selection on FCR, especially when body weights should not be increased. A positive (unfavourable) genetic correlation between feed efficiency and breast thickness or conformation score was found. When ducks develop their flying abilities and gain breast meat yield, the development of abdominal fat reserves takes place parallel. When selecting on feed efficiency it is necessary to keep an eye on breast meat development to maintain good meatiness.

During the testing period, with increasing daily gain of the Pekin duck males, their feed intake increased. When growing and developing their feeding capacities, the number of meals and the duration per meal decreased. Due to their limited feeding capacities in early life, the feeding activities of the ducks are much higher in the first weeks compared to the end of the testing period.

The feeding behaviour parameters of the complete testing period confirm the results of Bley (2003), Bley and Bessei (2008) and Le Mignon, Blanchet and Chapuis (2017). The difference in the recorded feed intake per minute (RATE) might be linked to the higher stocking density in the ORVIA testing station. There is considerable variation in the behaviour of different birds. The findings of this study agree well with the results of the other authors, but the heritability's of the behaviour traits are higher than expected.

There is nearly no genetic correlation between the number of meals (TSUM), the feeding rate (RATE) and the residual feed intake (RFI). The average meal duration (TIME), the duration of the feed intake per day (FDUR) and the average daily feed intake (ADF) have moderate and relatively high positive genetic correlations with residual feed intake (RFI). Looking at the genetic correlations of these behaviour traits with FCR, a slightly negative effect of high feeding activities and feed efficiency is obvious. This has to be kept in mind to avoid a negative effect on the ducks' behaviour, when selecting on feed efficiency.

Table 2: Parameters feeding behaviour (total testing period)

	Mean	St. Deviation	Minimum	Maximum
TSUM (n)	31.4	10.7	9.4	106.4
FDUR (min/day)	9.3	3.2	3.4	41.1
ADF (g)	209	20.9	137	300
TIME (min/meal)	0.70	0.32	0.18	3. 95
RATE (g/min)	11	3	2	24

Table 3: Heritability (bold figures on the diagonal), genetic and phenotypic correlations of growth performance and feeding behaviour traits

h2	BW	AUS	CONF	FCR	RFI	TSUM	FDUR	ADF	TIME	RATE
BW	0.43	0.57	0.65	-0.06	0.04	-0.05	0.17	0.81	0.20	0.04
AUS	0.66	0.34	0.95	0.06	0.12	-0.15	0.01	0.51	0.15	0.12
CONF	0.62	0.84	0.32	0.11	0.16	-0.09	0.04	0.61	0.13	0.12
FCR	-0.17	-0.04	-0.01	0.34	0.91	-0.11	0.21	0.45	0.22	-0.10
RFI	0.00	0.07	0.08	0.89	0.38	-0.03	0.22	0.58	0.18	-0.09
TSUM	-0.12	-0.16	-0.15	0.02	0.08	0.48	0.26	-0.01	-0.65	-0.23
FDUR	0.08	0.03	0.03	0.16	0.20	0.23	0.46	0.28	0.55	-0.93
ADF	0.76	0.53	0.51	0.40	0.56	-0.02	0.18	0.40	0.23	-0.03
TIME	0.17	0.15	0.14	0.09	0.07	-0.56	0.55	0.13	0.40	-0.53
RATE	0.13	0.13	0.12	-0.07	-0.07	-0.22	-0.86	0.07	-0.49	0.49

BW=Body Weight; AUS=Breast Thickness; CONF=Conformation; FCR=Feed Conversion Ratio; RFI=Residual Feed Intake; TSUM= Number of Meals per Day; FDUR=Duration of Feed Intake per Day; ADF=Average Daily Feed Intake; TIME=Average Meal Duration; RATE=Feeding Rate

It has been shown that lines differ in their behaviour traits (Alletru and Thiele, 2016), and differences between lines in the correlations among feed efficiency and behaviour traits have been found in the ORVIA data pool.

Summary

The modern RFID technology enables the breeding companies nowadays to record even small meals of individuals under nearly practical housing conditions. In these testing units not only the amount of feed consumed can be recorded, it opens the possibility to observe also the feeding behaviour of the ducks, with the frequency of meals and the size of a single meal. The availability and utilisation of these feeding stations accelerates the genetic progress in feed efficiency. Records of daily feed intake can be used to improve feed efficiency in combination with weight gain during the testing period as the commonly known FCR or, independent from metabolic body weight and weight gain, as Residual Feed Intake (RFI). Feeding behaviour traits can give an input to fine-tune feed selection. They can be used either to support the selection on feed efficiency or to maintain the natural feeding behaviour of Pekin ducks, when selecting on feed efficiency.

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Genetic aspects of keel bone deformities and fractures determined by palpation in laying hens

Abstract
Bone deformities and fractures have been observed in laying hens since many years and are of concern in the context of modern egg production. One of the most frequently affected bones in laying hens is the sternum (keel bone). A simple method to identify changes of the sternum in live birds is by palpation. In the present study 5869 pure line hens of two different White Leghorn lines (LSL) were palpated twice, at the age of 46 and 70 weeks, to analyze the variation between and within lines. The intra-observer reliability for the palpation score was high (r= 0.82) in both lines. The heritability was moderate in line A, which had 75% deviations (h^2= 0.30), and low in line B, which had only 15% deviations (h^2= 0.15). The palpation score was not significantly correlated with body weight, egg weight and shell breaking strength, but early egg number appears to be negatively correlated with palpation score (r_g= -0.24 in line A and -0.54 in line B). The results of the present study indicate that selective breeding may help to reduce the susceptibility to keel bone changes, but at the expense of early egg production.

Keywords
genetics, bone deformity, bone fracture, laying hens, keel bone

Introduction
Like all birds, laying hens have the peculiarity of different bone types in their bone system. The cortical and trabecular bone systems give the birds the typical body shape and support their movement, whereas the medullary bone system allows the bird to store calcium for the formation of egg shells. The medullary bone system is subject to a constant assembly and dismantling process. In this process, the osteoblasts store calcium in the medullary bones while the osteoclasts extract calcium for the formation of the egg shell. An imbalance in this assembly and dis-

mantling process of the medullary bone causes the reduction of cortical bone system which may lead to osteoporosis, a complex disease expressed by a decrease in fully mineralized bone structure and an increased risk of fractures and deformities toward the end of the laying period (WHITEHEAD and FLEMING 2000).

Literature

COUCH (1955) described osteoporosis in laying hens, related a high incidence of fractures and mortality to cage management and introduced the term "cage layer fatigue". GREGORY and WILKINS (1989) described that 29% of caged layers in the United Kingdom suffered one or more bone fractures during their lifetime. The frequency of fractures was found to be higher by GREGORY *et al.* (1990) in cages (24%) than free range (14%) and aviary systems (10%). Depending on the technical environment and bird management, osteoporosis and broken bones are still observed in modern non-cage systems and call for continued attention. SANDILANDS (2011) reported 53% laying hens with a fracture and 41% with keel bone changes by the end of the laying period in non-cage systems. In general the percentage of hens with fractures at the end of the laying period was highest in free range and aviary systems with 54% and 68%, respectively. To evaluate the causes of fractures and the presence in different housing systems it is important to have a closer look on the age of the fracture. Old (healed) fractures arise during the laying period and are an indication for fractures which are related to the housing environment and are more frequently found in aviary (25%) and free range (12%) than cage systems (5%). The mainly affected bones in aviary systems are the keel bone and clavicle and can be attributed to crashes within the housing system (GREGORY *et al.* 1990). In contrast, fresh fractures are typically acquired during the depopulation and slaughtering process. According to GREGORY *et al.* (1994), 17% of the hens at the slaughterhouse had old fractures which have arisen during the time in the cage and 10% new fractures due to the loading and unloading process.

As pointed out by FLEMING *et al.* (1994), movement promotes the development and prevents the loss of structural bone tissue. Especially the possibility of flying in perchery systems, with perches on different levels, increases the breaking strength of the humerus compared to aviary and cage systems. The existence of genetic variation and the possibility to breed for increasing bone strength have been shown by BISHOP *et al.* (2010). From a commercial White Leghorn line, they developed two sublines by single trait selection in opposite direction on an index for bone quality and reduced the rate of fractures significantly within three generations. The estimated heritability for their bone quality index was $h^2 = 0.4$, the genetic correlation of the bone quality index with the presence of fractures was $r_g = -0.9$. Within 3 generations the incidence of fractures between the groups high and low bone quality index was reduced by the factor six. The genetic correlation between the bone quality index and the total number of fractures was $r_g = -0.64$.

The current most common method for the subjective assessment of bone changes in layers is the keel bone palpation. Changes of the keel bone have to differentiate in fractures and deformations. Fractures are characterized by sharp edges or by an offset in the carina. They can usually be identified by palpation as callus tissue. While fractures are an obvious defect in the carina, CASEY-TROTT *et al.* (2015) describes deformations as a deviation from the normal straight two-dimensional line of the carina, which is not due to a fracture. Other authors describe the deformation as a curved sternum or as an S-shaped sternum (FLEMING *et al.* 2004; HABIG and DISTL 2013). Two different palpation methods are being used. The "Simplified Keel Assessment Protocol" (SKAP) described by CASEY-TROTT *et al.* (2015) only records whether fractures and deformations are noticed, on a yes-no scale. This method is particularly easy to use and allows the comparison of different housing systems. In the study of CASEY-TROTT *et al.* (2015) 202 Lohmann LSL Lite hens from different housing systems were investigated at the age of 68 to 81 weeks by the SKAP procedure. The results show that 46% of the hens had a deformation and 52% had a fracture. A proportion of 37% of the hens showed neither a deformation nor a fracture. On the other hand, 35% of the hens had a fracture and a deformation. A more convenient method is the keel bone palpation as described by SCHOLZ *et al.* (2008) and KÄPPELI *et al.* (2011). In this method a distinction is made between a severe change involving a fracture, a slight change, and no change in the sternum. Table 1 shows an overview of various studies using the three-stage assessment on keel bones. According to DONALDSON *et al.* (2012), there is no link between the provision of higher perches, such as those found in perchery systems, and the occurrence of keel bone damages. KÄPPELI *et al.* (2011) show a higher incidence of keel bone damages in aviary systems. A general deterioration of the palpation score is expected toward the end of the laying period (FLEMING *et al.* 2004; DONALDSON *et al.* 2012; HABIG and DISTL 2013). According to BISHOP *et al.* (2010), there is a relation to the body weight and the occurrence of keel bone damages ($r_g = -0.25$). A disadvantage of the

Source	Housing system	Breed	No. of hens	Share of hens [%] with keel bone indications		
				none	slight	heavy
Fleming *et al.* (2004)	Single- cage	LSL	605	86.1	13.2	0.7
	Group- cage	ISA	100	94.0	5.0	1.0
	Single- cage	ISA	285	93.7	5.3	1.0
	Group- cage	ISA	75	92.0	8.0	0.0
	Group- cage	Hy-Line white	74	97.4	1.3	1.3
	Group- cage	Hy-Line white	50	83.3	14.6	2.1
	Aviary	Hy-Line white	100	84.0	14.0	2.0
Käppeli *et al.* (2011)	Aviary	mixed	/	43.4	29.9	26.6
	Floor pen	mixed	/	56.0	27.0	17.0
Donaldson *et al.* (2012)	Aviary	Hy-Line brown	30	41.7	28.7	29.6
	Perchery	Hy-Line brown	30	27.5	28.3	44.2

Table 1: Results of recent studies using the three-stage assessment on keel bones of layers kept in different housing systems

palpation method is the insufficient repeatability, especially in the case of untrained persons with little experience (CASEY-TROTT *et al.* 2015). In a study of KÄPPELI *et al.* (2011), the repeatability of the palpation decreased from the first day with r= 0.95 to 0.79 after 12 weeks. The simplest method to verify the true occurrence of fractures is a visual examination of post-slaughter fractures following the palpation. The accordance between the identified fractures by palpation and fractures shown at the slaughter house was 84%. The reliability for the identification of deformities was 91% (CASEY-TROTT *et al.* 2015). SCHOLZ *et al.* (2008) report that error rates of over 51% are possible between the fractures recorded by palpation and the true fractures identified after slaughter.

Animals and Statistical Methods

In this study a total of 5869 white pure line hens of the LSL breeding program were scored twice by keel bone palpation. Two Lines, line A (n= 2979) and line B (n= 2890), were investigated under comparable conditions on the same farm, in a single bird cage with a round metal perch. The pedigree structure was 90 sires of each line, with 35 daughters per sire in line A and 33 daughters per sire in line B and 4 daughters per dam in both lines. The birds were reared together in a floor barn until 18 weeks of age. After rearing with a day length of 9 hours, the light was gradually increased to 15 hours per day. The hens were fed ad libitum in a two phases: phase 1 from 19 to 45 weeks of age, with 3.9% calcium; phase 2 from 46 weeks until depopulation at the age of 72 weeks, with 4.2% calcium content.

The first palpation was conducted at 46 weeks, the second one at 70 weeks of age. For the palpation the hen is fixed with the left hand by the wings, while the right hand is palpating the keel bone. The direction for the palpation is from cranial to caudal along the carina sterni. The evaluation included the difference of the carina from ventral against dorsal and the lateral shift out of the strait line. The keel bone evaluation was done in a modified scheme according to SCHOLZ *et al.* (2008). A four stage assessment was used. If there was no change in the keel the score 4 was given. If there was a small drift in the keel, score 3. By heavier drifts in the keel the score 2 and if there was a fracture in the keel, the score 1 was given. Only the score of the worst incidence was given each time. The palpation was done by one person. The intra-observer reliability was estimated by a two time palpation of 125 birds in both Lines.

The statistical analysis was made with the software SAS 9.3. Correlation between the palpations was estimated by Spearman-Rho. Differences were tested for statistical significance by the Mann-Whitney U-Test. The genetic variances and covariances were estimated in a mean value mode by the restricted maximum likelihood method (REML) with the computer software VCE 4 (GROENEVELD 1998). This model was used to assess the heritability of the palpation score and genetic correlations with other traits of economic interest: feed intake, body weight, early laying performance, laying performance at peak, egg weight and shell breaking strength.

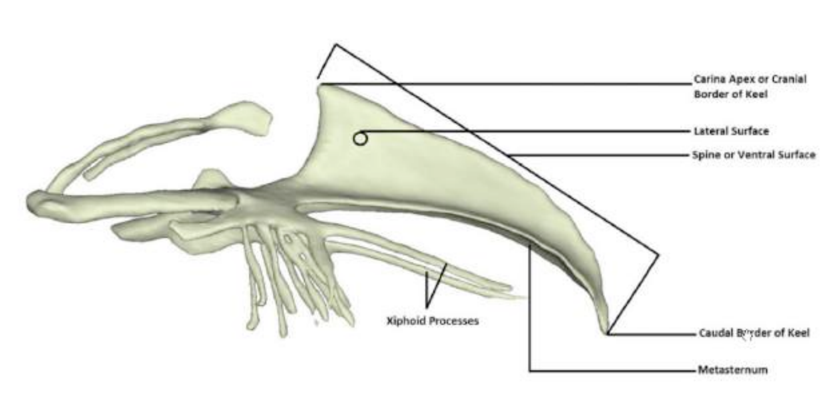
$$Y_{ijkl} = \mu + H_i + S_j + a_k + e_{ijkl}$$

Y_{ijkl} = dependent variable
μ = total average value
H_i = fixed effect house
S_j = fixed effect of hatch week
a_k = random animal effect
e_{ijkl} = effect of error

Results and Discussion

The estimated intra-observer reliability of the keel bone palpation was r= 0.82 in this study. In the study of STRATMANN *et al.* (2015) an intra-observer reliability of r= 0.7 and an inter-observer reliability of r= 0.54 were estimated. The inter-observer reliability is important when the palpation is done by more than one person, which is necessary in large groups of hens. In subjective traits like the palpation, the validation and repeatability of the measurement

Figure 1: Anatomical description of the keel bone (CASEY-TROTT et al. 2015)



is a serious challenge. The slight difference between a small and a heavier deformity in the keel bone is sometimes not easy to distinguish. The identification of fractures over sharp edges or callus tissue is often even more difficult. The reliability and inter-observer reliability should be improved by teaching the people in palpation and compare their palpation experiences. The evaluation of the validity has to be carried out from time to time by post mortem examinations (CASEY-TROTT *et al.* 2015).

The results of the conducted palpation of this study at 46 and 70 weeks of age are shown in table 2. At both palpation dates there is a much higher incidence of total indication in line A compared to line B. The incidence of fractures in line A increased from 6.5% at 46 weeks to 9.5% at 70 weeks of age. In line B fractures were negligible with 0.1%. Therefore it is important which genotype is used in other approaches. Layers of line A could be used as sentinel birds to take a closer look at different housing equipment for pullets and laying hens which are likely to affect the development of such deviations.

In line A the proportion of hens with and without an indication in the keel bone is nearly the same at the first and second date of palpation. At 46 weeks of age 76.3% of the hens of line A and 14.3% of line B have a keel bone indication. In the second palpation at 70 weeks of age 73.4% and 15.8% respectively show indications. The correlation between the two palpation dates is $r_p = +0.8$. In a detailed comparison of the two palpation dates it becomes obvious, that the number of fractures and strong deformities increase by time which is in accordance to FLEMING *et al.* (2004), DONALDSON *et al.* (2012) and HABIG and DISTL (2013). At 70 weeks of age FLEMING *et al.* (2004) recorded for 13.2 % of the tested LSL layers a slight change in the keel bone whereas only 0.7 % of the tested layers showed a heavy change in the keel bone. Therefore, the main percentage of LSL layers (86.1%) show no keel bone indication. This coincides with the data of line B from the present study that shows intact keel bones for 84.2% of the tested white layers. The other investigated breeds ISA and Hy Line of FLEMING *et al.* (2004) obtained equal proportions of keel bones with and without indications like the line B in the current study. Similar results on keel bone indications as shown for line A in this study with 73.4 % are published by KÄPPELI *et al.* (2011) and DONALDSON *et al.* (2012) for brown layers in floor and aviary systems at the late stage of production. But KÄPPELI *et al.* (2011) considers that a comparison on keel bone indications of layers tested in different housing systems is only comparable to a limited extent. Furthermore, KÄPPELI *et al.* (2011) and DONALDSON *et al.* (2012) investigated keel bone deformations on brown layers that show due to RICZU *et al.* (2004) and HABIG and DISTL (2013) a higher bone strength than white layers.

The difference in keel bone indications between line A and line B is at both palpation dates significant ($p<0.05$). Considering the same environment and the same palpating person of both lines, this difference is also due to genetic aspects. The possibility to select on better bones and the chance to reduce the incidence of fractures has been shown by BISHOP *et al.*

	Share of hens [%]			
	Palpation I		Palpation II	
Palpation score	Line A [n= 2979]	Line B [n= 2890]	Line A [n= 2979]	Line B [n= 2890]
1	6.5	0.1	9.5	0.1
2	43.2	3.1	50.0	6.3
3	26.6	11.1	13.9	9.4
4	23.7	85.7	26.6	84.2
Sum modified (score 1-3)	**76.3**	**14.3**	**73.4**	**15.8**
Sum unmodified (score 4)	**23.7**	**85.7**	**26.6**	**84.2**

Table 2: Distribution of the palpation score in the first and second palpation at 46 and 70 weeks of age in line A and line B

	h^2	genetic correlations					
	Palp	FC	BW	EN1	EN2	EW	BS
Line A	0.30	+0.04	-0.01	-0.24	+0.12	+0.10	+0.04
Line B	0.15	-0.15	-0.06	-0.54	-0.02	-0.01	-0.13

SE for Line A= 0.01- 0.02 SE for Line B= 0.02- 0.08

Table 3: Heritability estimates (h^2) of the palpation score (Palp) and genetic correlations to feed consumption (FC), body weight (BW), early egg number (EN1), egg number at peak production (EN2), egg weight (EW) and shell breaking strength (BS) in the line A and line B at 46 weeks of age

(2000). The authors estimated a heritability of h^2= 0.4 for their bone quality index. In the present study, the estimated heritability for the keel bone palpation score is h^2= 0.30 for line A. The lower variance within the palpation score in line B leads to the lower heritability of h^2= 0.15 for line B. However, it is planned to continue palpation in the tested lines. Therefore, repeated measurements and additional family information will increase the reliability of the estimated breeding values in the future. The emphasized relationship of BISHOP *et al.* (2010) between body weight and keel bone changes could not be verified with this study. The genetic correlation between the individual body weight and palpation score of both lines are r_g= -0.01 and -0.06. Even the shell breaking strength and egg weight is due to low genetic correlations not affected by the keel bone status. As shown in table 3 only the early egg number would be affected by selection on better keel bones. The negative genetic correlations of r_g= -0.24 in line A and r_g= -0.54 in line B would especially in line B decrease the early egg number.

The negative correlation between early egg production and palpation score indicates that late maturing hens are less likely to develop bone defects, which could actually be an advantage in terms of lifetime performance. To assess the usefulness of the palpation score as a novel trait in commercial breeding programs for laying hens, it would be desirable to determine the breeding values for bone quality of all selected male line males and collect data on bone quality of their pedigreed cross-line daughters under a range of commercial conditions. This data could be used in the progeny generation to simulate a selection to answer the question, how much progress could be achieved in one generation depending on the relative emphasis of bone quality.

Conclusion

The presence of bone fractures and deformities in different husbandry systems has been documented and discussed in the literature by several authors who agree that this is a multifactorial problem. A decrease of bone changes can only be achieved by an improvement of the housing system, feed composition and the laying hen itself. The shown influence of genotype in this study has to be considered in other approaches. The tested keel bone palpation is an easy and readily implemented method to determine bone changes in layers. Further investigation is needed to figure out the inter-observer reliability of the keel bone palpation. The option to breed for better bone strength has been shown by BISHOP *et al.* (2010). Considering the moderate heritability of h^2= 0.30 and h^2= 0.15 for both tested lines in the shown study, an improvement of the layer keel bone status by selection seems to be possible. The estimated genetic correlations indicate no effect on the egg weight, shell breaking strength and body weight. Regarding the tested traits, only the early egg number would be negatively influenced by selection for better keel bones.

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Dynamics and patterns of the EU egg industry

Abstract

Five years after the banning of conventional cages in 2012, the number of laying hens and of egg production has stabilized. Enriched cages are the dominating housing system with a share of 55.6%, followed by barn systems (25.7%), free range (14.1%) and organic systems (4.6%).The share of the four housing systems differs, however, considerably between the single member countries. Egg production increased by 6.1% between 2012 and 2017 and reached a volume of 7.5 Mio t. The regional concentration is very high. The five leading member countries contributed 57.7% to the overall production volume of the EU. The EU is dominating global egg trade. More than half of all eggs which reach the international markets are either exported or imported by EU member countries. The Netherlands are the dominating egg exporting country, followed by Poland. Germany holds an unchallenged first place among the leading egg importing countries.It is expected that between 2017 and 2025 egg production in the EU will grow faster than consumption resulting in an increasing egg surplus. If this cannot be exported either as shell eggs or as egg products, a lasting phase of low egg prices may be the result.

Keywords

EU, laying hen husbandry, egg production, egg trade

Introduction: The role of the EU in the global poultry industry

In 2015, the 507 Mio inhabitants of the 28 EU member countries contributed 6.8 % to the global population. The six leading countries alone shared 70.4 % in the population of the EU. With a share of only 6.8 % in the world population, the EU contributed 21.8 % to the global gross national product (GNP). This documents the high development status of most of the member countries. But in 2015 the per capita GNP differed considerably between the member countries. With only 6,300 € in Bulgaria respectively 8,100 € in Romania the lowest values were reached, in contrast, the per capita GNP was highest in Luxembourg with 89,900 €, followed by Ireland with 55,100 € and Denmark with 46,800 €. In 17 of the 28 member countries the per capita GNP was lower than the EU average of 28,800 €.

The efficiency of the EU poultry industry finds its expression in the contribution to the global production volumes of eggs

[1] The paper is part of a special report which the author prepared for the spring conference of the International Egg Commission (IEC) in Monte Carlo in April 2017.

and poultry meat. In 2015, the EU member countries shared 10.3 % in global egg production and even 11.7 % in world poultry meat production. The EU is the only region in which laying hen husbandry in conventional cages is prohibited. In 1999, the EU Commission passed Directive 1999/74/EU which demanded from the member countries to ban conventional cages from 2012 on and to prohibit from 2002 on the installation of this housing system. The Directive allowed that member countries could prohibit conventional cages earlier than 2012. Austria and Germany made use of this regulation and banned this housing system already in 2010. This decision had, as will be documented in the following parts of the analysis, far reaching impacts on the development of the laying hen inventories, egg production and egg trade. This was especially the case in Germany because of the earlier banning and also in several other countries. For two to three years, the decision of the German government to ban conventional cages already in 2010 changed the intra-EU trade with eggs considerably. The self-sufficiency in Germany dropped to less than 55 %, resulting in a sharp increase of egg imports from the Netherlands, Spain and Poland. As most of the changes in production and trade occurred between 2010 and 2015, the analysis is focused on this time period.

The main goals of this paper are:

➔ to analyze the dynamics of the laying hen inventories and of egg production between 2010 and 2015 in the member countries,

➔ to document the spatial shifts in egg production and egg trade between 2010 and 2015,

➔ to discuss present challenges for the egg industry in the EU member countries and to present perspectives considering these challenges.

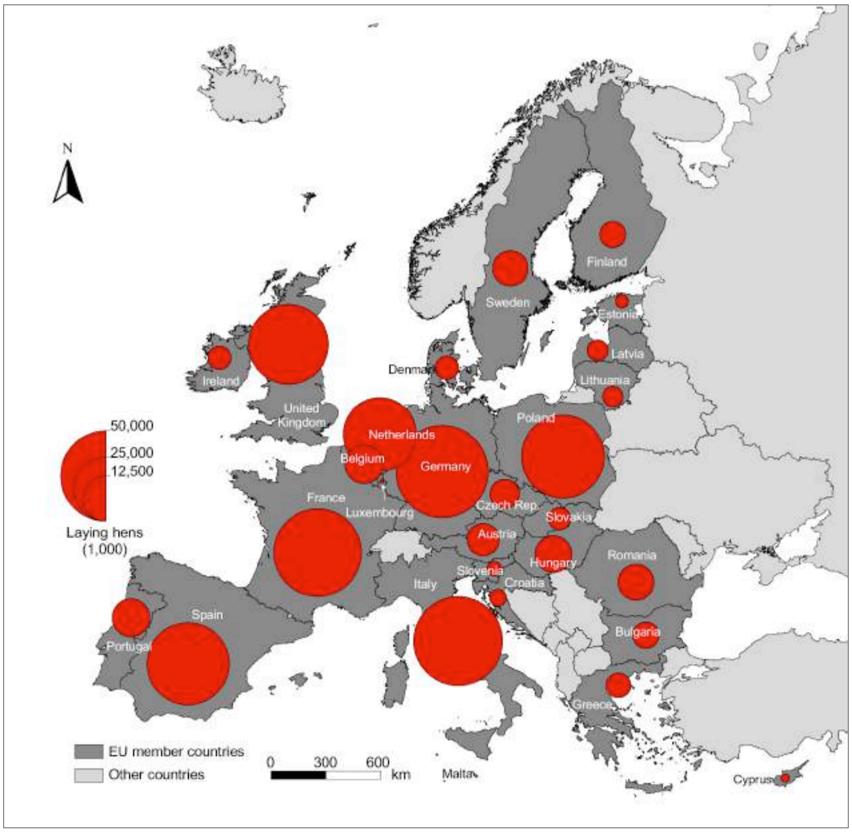

Figure 1: Laying hen inventories in EU member countries 2015 (Source: MEG 2016)

Table 1: The ten EU member countries with the highest laying hen inventory in 2010, 2013 and 2015 (Source: MEG 2010, MEG 2016)

2010			2013			2015		
Country	Hens (1,000)	Share (%)	Country	Hens (1,000)	Share (%)	Country	Hens (1,000)	Share (%)
Italy	49,575	13.7	Italy	60,312	15.9	Germany	51,791	13.5
Spain	46,592	12.8	Germany	49,903	13.1	Italy	48,199	12.6
France	45,531	12.6	France	47,041	12.4	France	46,770	12.2
Germany	41,729	11.5	Spain	38,409	10.1	Poland	41,916	11.0
UK	38,911	10.7	Poland	37,649	9.9	Spain	41,266	10.8
Netherlands	33,448	9.2	UK	36,626	9.6	UK	38,991	10.2
Poland	32,781	9.0	Netherlands	32,924	8.7	Netherlands	32,838	8.6
Belgium	9,264	2.6	Belgium	8,442	2.2	Belgium	8,893	2.3
Sweden	6,519	1.8	Portugal	7,235	1.9	Portugal	8,770	2.3
Romania	6,215	1.7	Sweden	7,053	1.9	Hungary	8,211	2.1
10 countries	310,565	85.6	10 countries	325,594	85.6	10 countries	327,645	85.6
EU	362,628	100.0	EU	380,490	100.0	EU	382,774	100.0

Table 2: Top ten EU member countries with highest increase of laying hen inventory from 2010 to 2015 (Source: Own calculations)

Country	Increase (1,000)	Increase (%)
Germany	10,062	24.1
Poland	9,135	27.9
Portugal	2,641	41.0
Hungary	2,571	45.6
Romania	1,618	26.0
France	1,239	2.7
Sweden	1,214	18.7
Bulgaria	1,148	36.3
Ireland	874	36.5
Latvia	300	12.7
10 countries	30,802	-

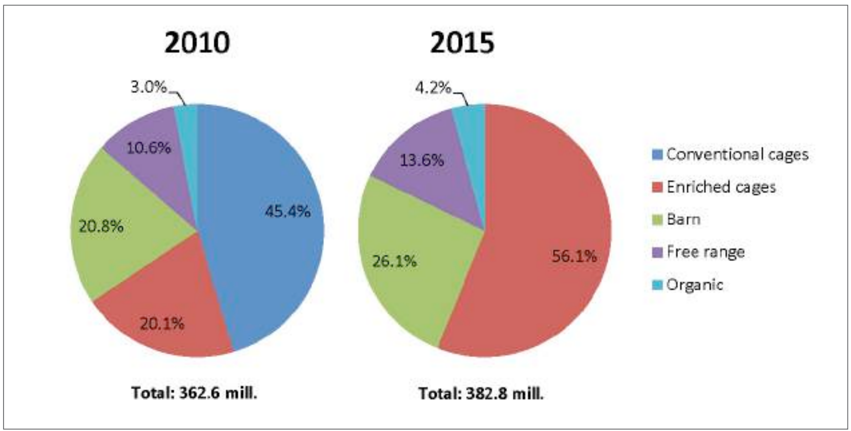

Figure 2: Housing systems for EU laying hens (Source: MEG 2012 and 2016)

1. Dynamics in the EU laying hen inventories and in housing systems

The first part of this paper will deal with changes in the laying hen inventory in the EU and in the housing systems resulting from the implementation of Directive 1999/74/EU.

Between 2010 and 2015 the number of laying hens in the EU increased from 362.6 Mio birds to 382.8 Mio birds or by 5.6 %. But the inventory decreased between 2014 and 2015, a result of the declining numbers in particular in Spain and Italy. The spatial distribution of the laying hen population in the EU member countries in 2015 is documented in **Figure 1**.

The regional concentration of the laying hens in the EU is rather high. As can be seen from the data in **Table 1**, the four countries with the highest inventories shared over 50 % of the total number of laying hens in 2010 and 2013 and over 49 % in 2015. The share of the ten leading countries was very stable with 85.6 % over the whole time period. A closer look at the dynamics at country level reveals (**Table 2**) that the highest absolute increase occurred in Germany with 10.1 Mio and in Poland with 9.1 Mio hens. On the other hand, the inventories in Spain fell by 5.2 Mio hens and in Italy by 1.4 Mio. The high absolute growth in Germany is a result of the banning of conventional cages as early as 2010. The composition of the ten leading countries also changed in the analysed time period. Between 2010 and 2013 Germany won two positions and ranked at second place behind Italy. Romania was replaced by Portugal. In 2015, Germany ranked as number one, followed by Italy, France and Poland. Spain lost one position and Hungary replaced Sweden.

Because of the implementation of Directive 1999/74/EU, conventional cages had to be abandoned by 2012. This changed the composition of the housing systems for laying hens in the EU. In 2010, 45.5 % of the laying hens were still kept in conventional cages and only 20.1 % in enriched cages. Five years later, 56.1 % of the hens were housed in enriched cages, 26.1 % in barn systems, 13.6 % in free-range systems and only 4.2 % in organic systems. **Figure 2** documents that within a comparatively short time the shift from conventional cages which had dominated laying hen husbandry for several decades to alternative housing systems could be realized. When the EU Commission passed Directive 1999/74/EU in 1999, egg producers in many countries argued that the transformation to alternative housing system would be too cost intensive, lead to a turmoil on the European egg market and cause severe problems regarding the health of the laying hens. Even several years before the deadline of conventional cages some countries in Eastern and Southern Europe asked for a prolongation of the transformation period. This was not accepted by the EU Commission, arguing that the industry had had sufficient time to change their housing systems. In retrospective, most of the articulated fears did not come true even though the transformation caused problems in some countries.

Table 3: The development of egg production in the EU between 2010 and 2015; data in 1,000 t (Source: MEG 2010; MEG 2016)

Year	Egg production	Index (2010 = 100)
2010	7,189	100.0
2011	7,171	99.7
2012	7,043	98.0
2013	7,371	102.5
2014	7,404	103.0
2015	7,537	104.8

2. Dynamics and spatial shifts in EU egg production

The following part of the paper will analyze the impacts of the transformation of the housing systems in laying hen husbandry on egg production at EU and member country level.

From the data in **Table 3** one can see that the last phase of the transformation of the housing systems led to a decrease of egg production between 2010 and 2012 by about 150,000 t or 2 %. Once the transformation was concluded, the production

Table 4: The top ten EU member countries with the highest egg production in 2010, 2013 and 2015 (Source: MEG 2010, MEG 2016)

2010			2013			2015		
Country	1,000 t	Share (%)	Country	1,000 t	Share (%)	Country	1,000 t	Share (%)
France	954	13.3	France	986	13.4	France	991	13.1
Spain	918	12.8	Spain	925	12.5	Spain	929	12.3
Italy	852	11.9	Germany	848	11.5	Germany	870	11.5
UK	718	10.0	Italy	798	10.8	Italy	830	11.0
Netherlands	711	9.9	UK	726	9.8	UK	751	10.0
Germany	656	9.1	Netherlands	723	9.8	Netherlands	722	9.6
Poland	637	8.9	Poland	564	7.7	Poland	593	7.9
Romania	310	4.3	Romania	355	4.8	Romania	350	4.6
Belgium	168	2.3	Belgium	173	2.3	Belgium	177	2.3
Hungary	168	2.3	Hungary	162	2.2	Czech Rep.	158	2.1
Top 10	6,092	84.7	Top 10	6,260	84.9	Top 10	6,371	84.5
EU (28)	7,189	100.0	EU (28)	7,371	100.0	EU (28)	7,537	100.0

volume increased again and was 350,000 t or 4.8 % higher than in 2010. The comparatively low decrease of the production volume during the transformation process is due to the fact that in some countries, especially in Southern Europe, conventional cages were permitted to be used parallel to the newly installed alternative housing systems. The remarkable growth of the production volume since 2012 resulted in an oversupply and a phase of low prices for the egg farmers. To stabilize the situation, placing of pullets was reduced in several countries, at least for a short time, without a lasting success, however.

A closer look at the dynamics at country level shows (**Table 4**) that the regional concentration in egg production was also high even though a bit lower than in the laying hen inventories. The four leading countries shared between 47 % and 48 % in the total production volume of the EU. The contribution of the ten leading countries to the overall egg production in the EU was also very stable; it fluctuated only between 84.5 % and 84.9 % in the analysed time period. The composition of the ten leading countries was also very stable, only Hungary was replaced by the Czech Republic in 2015. In the first four ranks the composition changed, however. In 2010, the United Kingdom had replaced Germany. This was a result of the banning of conventional cages in Germany as early as 2010 and a decrease of the production volume because of the necessary transformation to alternative systems with many empty layer places. In 2013, Germany ranked in third place again and the United Kingdom lost one position. In 2015, the four leading countries had stabilized their production again and the former order was re-established.

Between 2010 and 2015 Germany had the highest absolute growth with 240,000 t, followed by Romania, France, the United Kingdom and the Czech Republic. The highest relative growth values showed Germany and the Czech Republic. It has to be mentioned that the extraordinary increase in Germany is due to the earlier banning of conventional cages and the fast recovery of the laying hen inventories and of egg production while the transformation in most of the other EU member countries began two years later. The absolute decline of egg production was highest in Poland with 44,000 t, followed by Italy and Hungary. The highest relative decrease was to be found in Hungary and Croatia. With the exception of Italy all countries with a considerable loss in their production volume were located in Eastern Europe.

The main results of the first two parts of the analysis can be summarized as follows:

➔ The transformation of the housing systems in laying hen husbandry did not cause a drastic decline of the laying hen

Table 5: The development of EU egg exports to non-EU countries respectively imports from non-EU countries between 2010 and 2015 (Source: EU Commission, Committee for the Common Organisation of the Markets)

Year	Exports* (t)	Index (2010 = 100)
2010	181,719	100.0
2011	217,105	119.5
2012	185,716	102.2
2013	219,683	120.3
2014	232,859	128.1
2015	283,130	155.8
Year	Imports* (t)	Index (2010 = 100)
2010	34,244	100.0
2011	20,806	60.8
2012	37,446	109.4
2013	20,378	59.5
2014	13,626	39.8
2015	18,869	55.1

* includes shell egg equivalents for egg products but not hatching eggs

Table 6: The ten leading non-EU countries of destination of the EU egg exports* in 2010, 2013 and 2015 (Source: EU Commission, Committee for the Common Organisation of the Markets)

2010			2013			2015		
Country	Exports (t)	Share (%)	Country	Exports (t)	Share (%)	Country	Exports (t)	Share (%)
Japan	52,923	29.1	Japan	66,935	36.0	Japan	73,487	25.9
Switzerland	45,072	24.8	Switzerland	41,888	22.5	USA	49,451	17.5
Angola	10,414	5.7	Thailand	6,406	3.4	Switzerland	41,593	14.7
Taiwan	7,145	3.9	Russian F.	5,982	3.2	U. Arab. Em.	15,113	5.3
Thailand	6,186	3.4	S. Korea	3,420	1.8	Israel	11,592	4,1
U. Arab. Em.	5,888	3.2	U. Arab. Em.	1,767	1.0	Thailand	5,147	1.8
Russian F.	5,293	2.9	Israel	1,060	0.6	Hong Kong	4,308	1.5
Philippines	3,176	1.7	Hong Kong	409	0.2	Taiwan	4,082	1.4
Israel	1,308	0.7	USA	180	0.1	Russian F.	3,854	1.4
Iraq	20	0.0	Mauritania	79	0.0	S. Korea	3,455	1.2
10 countries	137,425	75.6	10 countries	128,126	69.0	10 countries	212,082	74.9
Total	181,719	100.0	Total	185,771	100.0	Total	283,130	100.0

* includes shell egg equivalents for egg products but not hatching eggs

inventory. This is partly a consequence of the parallel use of the old and alternative housing systems in several member countries between 2010 and 2012.

➔ Egg production decreased by only 2 % between 2010 and 2012 because of the permitted parallel use. It recovered faster than expected and because of the expansion of hen places led to an oversupply with eggs and low egg prices at farm gate for some time, especially in late 2013 and in 2014.

➔ A reduction of placed hatching eggs and pullets was able to stabilize the situation for some time, but it was not before the second quarter of 2016 that prices reached a level again which allowed profits.

3. Dynamics and spatial shifts in EU egg trade

In contrast to poultry meat, shell eggs for consumption are not traded in large amounts and over long distances. Only about 2.9 % of the global egg production is exported respectively imported. Most of the eggs are traded within relatively confined areas. One problem in dealing with the dynamics and patterns of egg trade of the EU is that in some of the available data sets it is not distinguished between the trade between EU member countries and trade with non-EU countries. In the database of the FAO it is not possible to separate the egg trade between the member countries and non-EU countries. Of the 2 Mio t of eggs which are traded according to the FAO database, about 1.2 Mio t are exported by EU member countries. But less than 300,000 t are exported to non-EU countries. In the data set published by the Committee for the Common Organization of Markets of the EU Commission only trade with non-EU countries is documented. In this paper, only the dynamics and trade patterns of the EU with non-EU countries will be presented in a short overview, based on the data which the above-mentioned Committee of the EU Commission publishes regularly. Another data problem is that this data set includes the eggs equivalents for the exports of egg products. It cannot be decided, to what amount shell eggs for consumption or egg products were exported.

Table 5 shows the development of EU egg exports to non-EU countries respectively EU egg imports from non-EU countries. A closer look at the data reveals the close interdependency between the trade volumes and the implementation of Directive 1999/74/EU. Between 2010 and 2015, egg exports to non-EU countries increased by about 101,000 t or 55.5 %. It was, however, not a continuous increase. The earlier banning of conventional cages in Germany and Austria in 2010 and for the whole EU in 2012 resulted in a decrease of the production volumes. When the transformation to other housing systems was completed, exports increased again. The sharp increase between 2014 and 2015 is a consequence of the oversupply with shell eggs and the rising imports of the USA because of the AI outbreaks in 2015. A similar dynamics show the egg imports. The decreasing self-sufficiency in Germany, as the leading egg importing country, made additional imports from non-EU countries necessary. The same steering factor explains the increase in 2012 when all countries had to ban conventional cages. When the transformation was completed and production increased again, imports fell to the average level.

Table 6 shows a remarkable fluctuation in the composition and ranking of the countries. In 2010, 98,000 t or 53.9 % of the total export volume went to Japan and Switzerland. These two countries ranked also as number one and two in 2013, sharing 58.5 % of the overall exports. In 2015, the USA

Table 7: The five leading non-EU countries of origin of the EU egg imports in 2010, 2013 and 2015 (Source: EU Commission, Committee for the Common Organisation of the Markets)

2010			2013			2015		
Country	Imports (t)	Share (%)	Country	Imports (t)	Share (%)	Country	Imports (t)	Share (%)
USA	14,009	40.9	USA	15,179	40.2	India	5,743	30.4
Argentina	7,937	23.2	Argentina	10,159	26.9	Ukraine	3,665	19.4
India	3,211	9.4	India	3,657	9.7	Argentina	3,232	17.1
Norway	1,722	5.0	Albania	2,321	6.2	USA	2,745	14.5
Israel	941	2.7	Norway	1,474	3.9	Albania	1,544	8.2
5 countries	27,820	81.2	5 countries	32,790	86.9	5 countries	16,939	89.8
Total	34,244	100.0	Total	37,722	1000	Total	18,869	100.0

* includes shell egg equivalents for egg products but not hatching eggs

replaced Switzerland as the second most important country of destination. Because of the much higher total exports, the three leading countries shared 58.1 % of the total export volume. It can be expected that the exports to the USA was a singular event caused by the shortage of eggs for further processing and of egg products resulting from the massive outbreaks of Avian Influenza in the northern Midwest in 2015 (Windhorst, 2016). The AI outbreaks in the USA also led to a considerable increase of the EU exports to the United Arab Emirates and Israel which had in preceding years imported egg products mainly from the USA. Because of the import ban on poultry products from the USA, they had to look for other countries which could step in. Export data for the first six months of 2016 show that exports to Japan fell considerably, a result of the AI outbreaks in some EU member countries in early 2016 (EU Commission 2016).

In Table 7, the changes in the composition and ranking of the five leading countries from which the EU imported eggs and egg products are documented. In 2010 and 2013, the USA and Argentina ranked as number one and two. Together they shared between 74% respectively 77 % of the total import volume. In third place ranked India. All three countries exported mainly egg powder and some eggs for further processing but no shell eggs for consumption. Because of the AI outbreaks and the import ban on poultry products from the USA and the oversupply in the EU, imports decreased considerably. Imports from India increased and Ukraine became one of the leading countries of origin and could also stabilize its position in the first half of 2016 as more recent data shows. Imports from the USA further decreased because of the imposed import ban by some member countries.

The preceding analysis revealed that because of the lack of detailed data on the exports and imports of eggs and egg products it is very difficult to present a complete picture of the dynamics, trade patterns and trade flows. Nevertheless, the presented data give a good overview on the present pattern of the foreign trade of the EU with eggs and egg products.

4. New challenges for the EU egg industry

The EU has been one of the innovation centres for intensive, market-oriented egg production. This is not only true for breeding, but also for the development of new technologies in housing systems. The international fairs impressively document the EU´s leading role, i.e. at the EUROTIER in Hanover, the VIV Asia in Bangkok or the IPPE in Atlanta. But criticism regarding the keeping of laying hens in conventional cages also originated in the EU, and the EU is still the only region in which this housing system is prohibited. From the EU, the requirement for alternative housing systems spread to several other countries, i.e. the USA, Canada, Australia and New Zealand. Recently, also in some developing countries, for example in Mexico, food retailers and fast food restaurants announced that they will only list or use eggs produced in alternative housing systems from 2022 or 2025 on. Cage free has become the new magic word.

When the implementation of Directive 1999/74/EU was fulfilled in 2012, one could have expected that a phase of less criticism would begin. But this was not the case. Very soon, new points of criticism inflamed the discussion regarding modern egg production in large flocks. Three new challenges can be identified: banning of beak treatment, banning of killing one-day old male chicks and prohibiting animal production at all. It is not surprising that NGOs from Germany, the Netherlands and the United Kingdom are the opinion leaders.

At the moment, Germany seems to be the forerunner regarding the banning of beak treatment in countries with large layer inventories. Beak treatment of laying hens is banned since the second half of 2017 in Austria, but the majority of the hens had already untreated beaks. Some of the leading countries of origin for Germany´s egg imports will have to adjust to the new regulation if they want to remain in the market. Field studies with untreated flocks have shown that herds with white hens are causing lesser problems regarding feather pecking and cannibalism than brown layers. But problems can also show up in white layer herds.

The challenge of identifying the sex of a chick before starting the hatching process or in the early days of hatching cannot be solved satisfyingly at the moment. Several research projects are going on in Canada, the USA, Israel, Germany and some other countries. New technologies have been developed but it is still an open question if these technologies will be able to handle 100,000 hatching eggs per day and with which results. As it seems, some technologies are working on small scale, but they are still too time-consuming and too cots-intensive. Field studies to use the male chicks for meat production have shown that because of the unfavourable feed conversion, the colour and taste of the meat and the limited acceptance of these birds by consumers, this alternative use is obviously not a promising way to solve the problem (Schmidt et al. 2016).

Considering the challenges which the egg industry has to cope with, it can be assumed that egg production in the EU will not grow much in the coming years. Because of this perspective every endeavour should be made to spread the knowledge about the unchallenged role of eggs as the best protein source in human nutrition.

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