Lohmann
Information

Cuxhaven, October 2011

Prof. Dietmar Flock,
Editor

Editorial

People in affluent countries may feel better if they reduce their own food intake and/or throw away less food with marginal “best before date”, but this will not help people in Third World countries, where poor education and limited job opportunities encourage people to migrate from villages to cities, hoping to find a better life. After reading the book “Poor Economics – A Radical Rethinking of the Way to Fight Global Poverty”*), you will probably agree with the authors that better education of boys and girls will be necessary to fight hunger due to poverty. It sounds simple, but is naïve to think that hunger could be completely eliminated across the world if all people who currently eat more than is good for their own health (and throw away edible food) could save the money and donate it so that the surplus could be shipped to the people who suffer from hunger (an estimated 1 billion people at both ends of the “normal distribution” of individual food consumption). Hungry people in the Third World may have other priorities than buying eggs or poultry meat if they had more money. Nevertheless, transmitting knowledge how to produce eggs and poultry meat sustainably, i.e. with minimal use of resources (feed and energy) and minimal burden on the environment, is a contribution to better human nutrition. In a future issue, we plan to include a paper on the benefits of egg consumption for brain development of infants and learning ability of school children. Similar beneficial effects may exist in slowing down mental aging in seniors.

As we are approaching the end of 2011, when egg production in conventional cages is supposed to stop in all EU countries, not only egg producers are wondering how the change to alternative systems will be handled in different countries, how this will affect import/export and how consumers, egg producers and – last but not least – laying hens will respond to various alternative management systems. Some farms who followed expert advice from the very beginning of pullet rearing are reporting excellent results in multi-tier floor systems, but risks of feather pecking and cannibalism remain in all systems unless beak treatment and/or control of light intensity are optimized according to farm-specific experience. If conventional cages were a “fool-proof” system to produce eggs at least cost, the alternative systems will require expert management, with due attention to technical details and the ability of chickens to get oriented in complex systems. Egg production will certainly be more expensive than from conventional cages, and producers have to pay more attention to marketing while minimizing feed and energy cost. While European consumers don’t need to worry about a possible shortage of eggs or exploding egg prices next year, egg producers need a realistic assessment of demand before investing in expensive free range and organic systems, hoping to benefit from these niche markets.

---

*) A. Banerjee and E. Duflo (2011). ISBN 978-1-58648-798-0,

Lohmann Information is jointly published by:
Lohmann Tierzucht GmbH, Cuxhaven, www.ltz.de
Managing Directors: Dr. Hans-Friedrich Finck, Prof. Dr. Rudolf Preisinger
and
Lohmann Animal Health GmbH & Co. KG, Cuxhaven, www.lohmann.de
Managing Director: Dr. Bruno Kaesler

This issue offers the following topics as food for thought:

1. We start with a look at developments in the global egg market. **Prof. Dr. Hans-Wilhelm Windhorst**, University of Vechta, Germany, reviews **“The Changing Global Egg Industry”** and shows that threshold countries account for the largest share of the increasing global production, whereas Europe is barely holding its own in total volume.
2. **Dr. Donald Bell**, University of California, Riverside, USA, analyzed a large sample of field data to demonstrate the variation in egg production and egg size between flocks of the same strain (LSL LITE). **“The Challenges of Management for Today’s High Performing Laying Hens”** calls attention to the large differences due to farm management and non-genetic effects in realizing the genetic potential.
3. At a time when Europe is terminating conventional cages, we should remember how the egg industry developed before speculating where it will go in Europe and other parts of the world. Mr. **Arnold Elson**, ADAS Gleadthorpe, UK, reviews **“Housing and Husbandry of Laying Hens: past, present and future”**, with reference to extensive scientific publications which have accompanied the developments.
4. **Thea van Niekerk** and **Berry Reuvekamp**, WUR Livestock Research, Lelystad, The Netherlands, describe **“The Rondeel™ - a new housing design for laying hens”**. The concept has been developed to meet higher standards of bird welfare and ecological efficiency than other floor systems and has found positive attention from visitors and the media. Time will tell whether the higher production cost can be recovered and whether beak treatment is not necessary in this system.
5. Most people in Europe are familiar with duck and goose meat as seasonal food in winter months, and this is an interesting niche market. **Prof. Dr. Heinz Pingel**, Landsberg, Germany, is recognized as an authority in waterfowl on the basis of his research and teaching at the University of Leipzig before reunification of Germany. In his paper **“Waterfowl Production for Food Security”**, he reviews trends in regional production and consumption between 1991 and 2009 and discusses opportunities for future developments.
6. The EU Court has recently ruled that bee keepers can sue growers of GM plants if their honey is contaminated, and many consumers in Europe are opposed to GM food or feed in animal nutrition. **Prof. Dr. Gerhard Flachowsky**, Institute of Animal Nutrition, FLI, Braunschweig, Germany, looks at **“Poultry Feed from Genetically Modified Plants”** on the basis of the results of long-term experiments.
7. Recommendations for optimal nutrition have been a recurrent subject in this publication since the 1950s, when Lohmann got involved in poultry nutrition and promoted feed additives. Over the years, recommendations have been refined, based on new research results. **Prof. Dr. Heinz Jeroch**, currently at Warmia and Mazury University Olsztyn, Poland, reviews **”Recommendations for energy and nutrients of layers”** and suggests specific needs for new research projects to provide a sound scientific basis for feed formulation under different management and climate conditions.

With kind regards,

Prof. Dietmar Flock,
Editor

The Changing Global Egg Industry

- The new role of less developed and threshold countries in global egg production and trade[1] -

Hans-Wilhelm Windhorst, Vechta, Germany

Introduction

Global shell egg production has shown remarkable dynamics over the past two decades. This growth was not homogeneous, however, and led to a considerable spatial shift of the centres of egg production. Whereas in 1990 developed countries still contributed over 52 % to global egg production, less developed and threshold countries shared 59 % in 2008. This shift is mainly a result of the fast growth of egg production in Asia, especially in China. In a detailed analysis, which was presented at the IEC spring conference in London, the author documented the dynamic changes of egg production and egg trade and presented a new spatial pattern of the global egg industry. The main results of that study will be presented in this paper.

The role of less developed and threshold countries in global egg production

Global shell egg production increased from 35.2 mill. t in 1990 to 61.2 mill. t in 2008 or by 73.6 %. It was, however, not a homogeneous growth as can be seen from the data in table 1. The highest absolute increase showed Asia with 22 mill. t, followed by North America with 2.7 mill. t, Central and South America with 1.6 mill. t and Africa with 1 mill. t. The remarkable increase of the production volume in Asia led to a considerable shift in the spatial pattern of egg production. Whereas in 1990 the contribution of Asian and European countries to the overall global production was still quite similar, the situation had completely changed in 2008. With a share of 58.6 % Asia was in an absolutely dominating position. In the same time period Europe lost almost half of its former share, all other continents were also not able to maintain their former contribution. Europe was the only continent with an absolute decrease of the production volume, it lost 1.5 mill. t. This was mainly due to the socio-economic transformation process in Eastern Europe. The described spatial shift reflects the dynamics of egg production in several less developed and threshold countries.

Table 1: The development of global egg production between 1990 and 2008 (Source: FAO database)

Continent	1990		2000		2008	
	Production (1,000 t)	Share (%)	Production (1,000 t)	Share (%)	Production (1,000 t)	Share (%)
Africa	1,542	4.4	1,923	3.8	2,532	4.1
Asia	13,803	39.2	29,102	56.9	35,864	58.6
N America*	5,361	15.2	7,159	14.0	8,095	13.2
SC America	2,633	7.5	3,249	6.4	4,296	7.0
Europe	11,663	33.1	9,480	18.5	10,193	16.7
Oceania	244	0.7	199	0.4	222	0.4
World	35,246	100.0	51,113	100.0	61,202	100.0

* Canada, Mexico, USA

---

[1] Abridged version of the author´s IEC Special Economic Report (April 2011): The changing role of less developed and threshold countries in the global egg industry.

The data in table 2 document the dramatic spatial shift which occurred in egg production in the analysed time period. In 1990, developed countries contributed 52.5 % to the global production volume, threshold countries 36 % and less developed countries 11.5 %. Only ten years later, the situation had changed thoroughly. Threshold countries were in a leading position with a share of 56.4 %. Developed countries had lost almost 20 % of their former share. In spite of an absolute growth in production volume, the contribution of less developed countries was lower than in 1990.

In 2008, threshold countries had further strengthened their position. In developed countries, production increased again, but growth rates were much lower than in less developed and threshold countries so that their contribution to the global production volume fell by another 4 %.

Table 2: The development of egg production in less developed, threshold and developed countries between 1990 and 2008 (Source: FAO database)

Development class	1990		2000		2008	
	Production (1,000 t)	Share (%)	Production (1,000 t)	Share (%)	Production (1,000 t)	Share (%)
Less developed	4,066	11.5	5,453	10.7	7,334	12.0
Threshold	12,680	36.0	28,792	56.4	36,204	59.2
Developed	18,518	52.5	16,776	32.9	17,566	28.7
World*	35,264	100.0	51,022	100.0	61,104	100.0

* global data differ slightly from table 1 because for some countries 1993 data were used as estimates of missing 1990 data and data for small islands were omitted

A closer look at the dynamics in the development classes in the analysed time period reveals that of the total increase of 26 mill. t, 23.6 mill. t or 90 % were contributed by threshold countries and almost 3.3 mill. t by less developed countries. Developed countries, on the other hand, lost about 1 mill. t of egg production.

In table 3, the ten leading egg producing countries, independent from their development status, are listed for 1990 and 2008. Of the ten leading countries in 2008, four were located in Asia, three in the Americas and three in Europe. Only one EU member country, France, was left among the top listed egg producing countries. Six of the ten leading countries were threshold countries and four developed countries. This documents the extraordinary role that threshold countries played in the dynamics of global egg production.

Table 3: The ten leading countries in shell egg production in 1990 and 2008 (Source: FAO database)

1990			2008		
Country	Production (1,000 t)	Share (%)	Country	Production (1,000 t)	Share (%)
China	6,561	18.6	China	22,749	37.2
USSR	4,582	13.0	USA	5,339	8.7
USA	4,034	11.4	India	3,060	5.0
Japan	2,419	6.9	Japan	2,554	4.2
Brazil	1,230	3.5	Mexico	2,337	3.8
India	1,161	3.3	Russia	2,118	3.5
Mexico	1.010	2.9	Brazil	1.845	3.0
Germany	985	2.8	Indonesia	1,123	1.8
France	887	2.5	France	948	1.5
Spain	666	1.9	Ukraine	855	1.4
10 countries	23,535	66.8	10 countries	42,928	70.1

The role of less developed and threshold countries in world egg trade

Only about 2.6 % of global egg production was traded in 2008; in contrast, 15.5 % of poultry meat was exported in the same year. The main reason for the comparatively low figure is the fact that shell eggs cannot be deep frozen in contrast to meat. On the other hand, eggs have the advantage of a relatively long shelf life and can be consumed as whole eggs without the necessity to refrigerate as in the case of meat.

Table 4: The development of global shell egg exports by less developed, threshold and developed countries between 1990 and 2008 (Source: FAO database)

Development class	1990		2008	
	Exports (1,000 t)	Share (%)	Exports (1,000 t)	Share (%)
Less developed	32.5	3.8	78.3	4.9
Threshold	108.1	12.6	458.0	28.4
Developed	714.0	83.6	1,075.6	66.7
Total	854.6	100.0	1,612.0	100.0

Table 4 shows that global egg exports were dominated by developed countries even though their share decreased by 16.9 % between 1990 and 2008. Threshold countries could expand their contribution by 15.8 % whereas that of less developed countries increased by only 1.1 %. A closer look at the absolute growth rates shows that the export volume of threshold countries increased by almost 350,000 t (+ 324 %), that of less developed countries by 45,750 t (+ 140.6 %) and that of developed countries by 361,600 t (+ 50.6 %). In spite of a smaller share, developed countries are still dominating shell egg exports.

Table 5: The development of global shell egg imports into less developed, threshold and developed countries between 1990 and 2008 (Source: FAO database)

Development class	1990		2008	
	Imports (1,000 t)	Share (%)	Imports (1,000 t)	Share (%)
Less developed	76.0	9.4	313	20.5
Threshold	122.5	15.2	163	10.7
Developed	607.9	75.4	1,050	68.8
Total	806.4	100.0	1,526	100.0

As can easily be seen in table 5, the import pattern differs considerably from the export pattern. In less developed countries the import volume increased by 237,200 t (+ 312 %), in threshold countries by only 40,400 t (+ 33 %) and in developed countries by 442,353 t (+ 72.8 %). Obviously, threshold countries were able to increase egg production much faster than less developed countries and were able to meet the increasing domestic demand much better. In contrast, in several less developed countries demand grew much faster than domestic production so that more eggs had to be imported.

Perspectives until 2015

In an earlier report to the IEC, the author presented a projection of the egg demand in 2015 compared to 2005 (Windhorst 2008). It was estimated that in 2015 another 12 mill. t of shell eggs would be produced to meet the additional demand (table 6). Asia would then contribute 62.1 % to global egg production, Europe 14.3 %.

Table 6: Projected hen egg production in 2015 by continents (Source: Windhorst 2008, p. 17, modified)

Continent	Production (1,000 t)	Share (%)
Africa	3,683	5.2
Asia	43,992	62.1
Europe	10,135	14.3
North America*	5,831	8.2
C S America	6,944	9.8
Oceania	292	0.4
World	70,877	100.0

* Canada, Mexico, USA

Table 7: Projected egg demand in 2015 by development status of countries; data in 1,000 t (Source: FAO database; Windhorst 2008, own calculations)

Development status	Demand (1,000 t)	Share (%)
Less developed	13,557	19.1
Threshold	42,207	59.5
Developed	15,113	21.3
Total	70,877	100.0

In table 7, such a projection is presented. It is estimated that a total production of 70.9 mill. t will be necessary to meet the global demand. Almost 60 % of global egg production in 2015 will be contributed by threshold countries, 21 % by developed countries and 19 % by less developed countries. If it will be possible in threshold countries as well as in several less developed countries to meet the growing demand by domestic production is a question which cannot be answered at this moment. It can, however, be expected that the present pattern of egg trade will not change thoroughly over the next years. There will still be three major clusters of egg trade, one in Northern America, on in Western Europe and one in South Eastern Asia. A fourth cluster between India and Western Asian countries is developing.

A new spatial pattern of the global egg industry

Because of our own limited experience and the lack of detailed studies dealing with the organisation and spatial pattern of the egg industry in less developed and threshold countries and because of the large number of research papers and the availability of statistical data on the egg industry in developed countries, we only too often forget that the extraordinary development of global egg production over the past twenty years has mainly been a result of the dynamics in a rather limited number of threshold and a few less developed countries. We need to deal more thoroughly with the egg industry in these countries and recognize that the centre of egg production is no longer located in the USA and Western Europe, but in Southern, Eastern und South-Eastern Asia and that a new regional cluster is being formed in some countries in Central and South America. This is the new spatial pattern of the global egg industry.

Zusammenfassung

Eine neue räumliche Ordnung der globalen Eierwirtschaft
- Die wachsende Rolle von Entwicklungs- und Schwellenländern in der Welteierproduktion und im Eierhandel-

Die Dynamik der globalen Eierproduktion und des Handels mit Schaleneiern wies in den beiden zurückliegenden Jahrzehnten eine bemerkenswerte Dynamik auf. Das Produktionsvolumen erhöhte sich im betrachteten Zeitraum von 35,2 Mill. t auf 61,2 Mill. t oder um 73,6 %. Das Wachstum erfolgte jedoch nicht gleichmäßig. Während sich der relative Anteil Europas an der Welterzeugung zwischen 1990 und 2008 nahezu halbierte, konnte Asien seinen Anteil deutlich erhöhen und rangierte mit 58,6 % weit vor Europa und Nordamerika an der Spitze. Diese Dynamik wurde vor allem durch die starke Steigerung der Erzeugung in einer Reihe von Schwelleländern bewirkt. Sie stellten 2008 bereits 59,2 % der Weltproduktion. Der Anteil der Industrieländer sank im betrachteten Zeitraum demgegenüber von 52,5 % auf nur noch 28,7 %. Besonders hervorzuhaben ist die Sonderstellung Chinas, das 2008 37,2 % zur Welteierproduktion beisteuerte. Die genannten Verlagerungsprozesse wirkten sich auch auf den Handel mit Schaleneiern aus. Trotz deutlicher Einbußen stellten die Industrieländer jedoch noch jeweils zwei Drittel der weltweit getätigten Exporte und Importe. Während die Schwellenländer ihre Ausfuhren deutlich steigern konnten, waren die Entwicklungsländer wegen der schnell steigenden Nachfrage auf zunehmende Importe angewiesen. Im Jahr 2008 wurden gut 20 % aller weltweit gehandelten Eier von Entwicklungsländern eingeführt. Es ist davon auszugehen, dass die Schwellenländer und auch einige Entwicklungsländer ihre Produktion in den nächsten Jahren noch weiter steigern können, die Industrieländer demgegenüber weitere Marktanteile verlieren werden.

References

FAO database: faostat.fao.org

Windhorst, H.-W. (2008): A Projection of the Regional Development of Egg production until 2015. IEC Special Report April 2008. London.

Windhorst, H.-W. (2011): Frühjahrskonferenz der IEC – Herausforderungen an die globale Eierwirtschaft sind vielfältig. DGS Intern 17/2011, 3-5.

Author´s address

Prof. emeritus Dr. H.-W. Windhorst
Institute of Spatial Analysis and Planning
In Areas of Intensive Agriculture (ISPA)
University of Vechta
Driverstrasse 22, 49377 Vechta, Germany
hwindhorst@ispa.uni-vechta.de

The Challenges of Management for Today's High Performing Laying Hens

** Part 1: Egg Production and Egg Size **

Donald Bell, University of California, Riverside, USA

Introduction

"Genetic potential describes what you can hope to achieve in flock performance if everything goes right. Attainment of this potential, though, is dependent on all of your management decisions, which must be correct from one day of age until the flock completes its laying period" (Bell, 1982).

The objectives of our management programs have not changed during the last 30 years. We still see major ranges in all performance traits as the result of the application of producer skills.
In a series of three articles, the emphasis will be on the variation of performance from flock to flock, from producer to producer and from region to region. Data will be presented to illustrate these performance differences from a several year study of commercial table egg flocks in the United States. To remove the variability of results attributable to strain differences, only one strain will be used - the Lohmann LSL Lite. Similar flock variations are seen in all commercial strains which we assume are attributable to rearing and lay management differences.

The extensive volume of data available for this analysis will be presented in three parts:

- Part 1 will concentrate on egg production and egg weight.
- Part 2 will emphasize feed consumption and feed conversion.
- Part 3 will discuss mortality and focus on economic factors

The results to be presented are based on a subset of 74 flocks from 12 large integrated egg production firms located in various regions of the USA. The original study includes more than 200 flocks representing nine different white-egg strains (White Leghorns). Flock size averaged 79,662 pullets and ranged from 25,579 (5 smallest flocks) to 185,249 (5 largest flocks). The total study included 5.8 million hens (Bell, 2008-2011).

These flocks were housed at 18-20 weeks of age in 2001 to 2005. Records for each flock were kept for approximately two years. The majority of flocks were molted between 60 to 80 weeks of age. This report is based upon only one strain - the Lohmann LSL Lite - in order to focus on variation due to management, eliminating variance due to strain differences. Possible genetic changes due to selection within the 5-year period covered are ignored.

All flocks were kept in cages, and most flocks in controlled environment housing. Before statistical analysis, all records were checked for consistency, and obvious errors were removed. Table 1 lists the egg production and egg weight data for the period 19 to 60 weeks of age.

Data Quality and Analysis

The farms represented in this study had to be willing to share their data and maintain them on a daily basis. Each farm provided the author with weekly calculations for a series of measurements including: rate of lay, mortality, feed consumption per 100 hens per day and sampled egg weights. In addition, some cooperators also provided body weights and water consumption data. Other reports are available from the author on these and other related analyses.

Using the farm's calculated results, we re-calculated their original input figures (number of eggs, weight of feed, and a running count of hens based upon the loss rates reported). This technique worked backwards to exclude any additions to the flock which would have made our results less accurate. Some based their mortality rates on beginning counts which required recalculation of rates based upon "current" counts - a more meaningful method.

The accuracy of data varied from farm to farm. Egg counters are common sources of error. Feed inventories at the end of each week may be estimates or actual weights resulting in high consumption rates one week followed by a lower rate the next. Egg weights are usually sampled once per week. This sampling is particularly subject to error in the choice of a representative location for the sample - egg size varies within the house. As the source data are reviewed, adjustments may be required. This is usually done by interpolating from the data on prior and subsequent weeks.

The data being reported in this study are only a fraction of the overall data collected by the cooperating farms. Most producers have record systems to track individual nutrient intake (amino acids, minerals, energy, etc). All of the producers in this study also have egg cartoning facilities and record collection involves extensive descriptions of the size and quality of eggs being packed.

Table 1 lists the average egg production and egg weight-associated results by week. Complete records to sixty weeks of age were available for all flocks, before molting was induced anywhere between 60 and 80 weeks of age, interrupting weekly results and making averages meaningless. Second cycle performance, water consumption, seasonal performance, and performance of brown-egg vs. white-egg strains were also analyzed, but will not be reported here.

Table 1: Weekly Performance Data

Week	Hen-day EP (%)	HH eggs	Av. Egg Wt (g)	Daily Egg Mass (g)	Week	Hen-day EP (%)	HH eggs	Av. Egg Wt (g)	Daily Egg Mass (g)
19	7.7	0.6	43.9	4.7	41	92.2	131.5	60.8	56.1
20	24.5	1.8	44.6	13.0	42	92.2	137.8	60.8	56.1
21	50.1	5.3	47.6	24.4	43	92.0	144.0	61.0	56.2
22	71.8	10.4	49.9	36.1	44	91.6	150.3	60.9	55.9
23	83.9	16.2	51.9	43.7	45	91.3	156.4	61.1	55.8
24	90.3	22.5	53.7	48.5	46	91.1	162.6	61.2	55.7
25	92.1	28.9	55.0	50.7	47	90.9	168.7	61.3	55.7
26	93.2	35.3	56.0	52.2	48	90.6	174.8	61.3	55.5
27	93.2	41.8	56.7	52.8	49	90.2	180.9	61.3	55.3
28	93.6	48.3	57.4	53.8	50	90.2	187.0	61.5	55.5
29	93.8	54.7	57.9	54.3	51	89.6	193.0	61.4	55.1
30	93.7	61.2	58.4	54.8	52	89.2	199.0	61.5	54.9
31	93.8	67.7	58.7	55.1	53	89.0	204.9	61.7	54.9
32	93.8	74.2	59.1	55.5	54	88.6	210.8	61.7	54.6
33	93.8	80.6	59.3	55.6	55	87.9	216.7	61.9	54.4
34	93.7	87.1	59.5	55.7	56	87.6	222.5	62.1	54.4
35	93.5	93.5	59.8	55.9	57	87.3	228.3	62.1	54.2
36	93.2	99.9	60.2	56.1	58	86.9	234.0	62.2	54.1
37	93.1	106.2	60.3	56.2	59	86.2	239.7	62.4	53.8
38	92.8	112.6	60.4	56.0	60	86.1	245.4	62.5	53.8
39	92.8	118.9	60.4	56.1					
40	92.4	125.2	60.6	56.0	**Av**	**85.6**	**245.4**	**58.8**	**51.2**

BEST AND POOREST FLOCKS BY INDIVIDUAL PERFORMANCE TRAITS (74 U.S. FLOCKS)

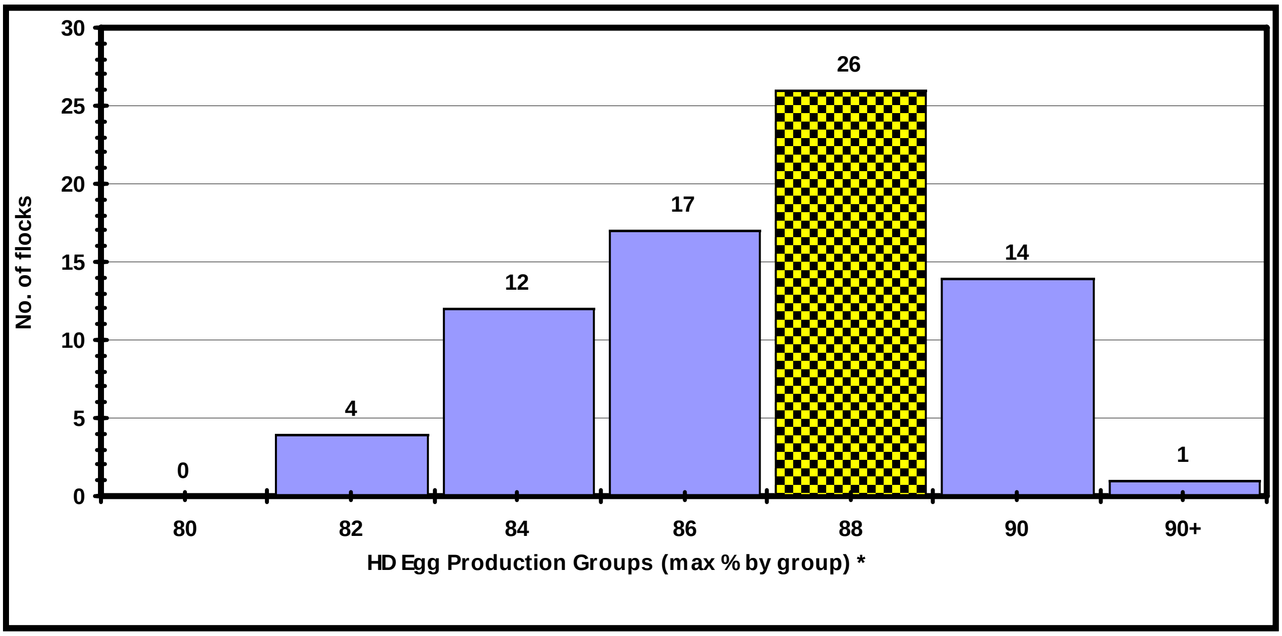
In Table 2, the differences between "best" and "poorest" results are shown for different egg production traits. Note that the flocks were sorted on each trait separately, i.e. flocks ranking among the top 5 in one trait may not be "best" in total profitability.

The data in table 2 demonstrate the wide variation in results between flocks and farms. The five best flocks exceed the breeder standard, and the comparison with the 5 poorest flocks illustrates the overall range of results that might be attained. The average results of the best 25% flocks may be considered as realistic goals for future flocks. The variability between the 74 flocks is expressed as a "standard deviation" and is shown in "frequency" distribution figures. Standard deviations represent approximately two-thirds of the flocks within plus or minus one standard deviation from the average - the smaller the number, the more uniform are the results.

Table 2: Best and poorest flocks per trait

Trait	Best/Poorest 5 flocks		Best/Poorest 25% of flocks		Overall Study Results and Uniformity 74 Flocks	
	Large	Small	Large	Small	Avg.	
Flock Size ('000)	185	26	138	38	80	N/a
	Best	Poorest	Best	Poorest	Avg.	Std. Dev.
Hen-day EP % wks 19-60	89.8	81.5	88.7	82.8	86.0	2.4
Wks of 90+ % EP	38	6	34	15	26	-
HH eggs to 60 wks	258.2	226.1	255.4	233.7	245.4	7.7
Av. Egg Wt. (g)	60.9	56.7	60.0	57.6	59.0	1.0
Daily Egg Mass (g)	53.5	47.3	52.9	48.8	51.2	1.7
Total egg mass (kg)	15.5	13.2	15.2	13.8	14.6	0.6

Figure 1. Frequency of Av Hen-day Egg Production Rates - 19 to 60 wks



* example: 88 weeks represents flocks between 86.1 and 88.0 inclusive.

Figure 2: Frequency of Hen-housed Eggs (to 60 wks)

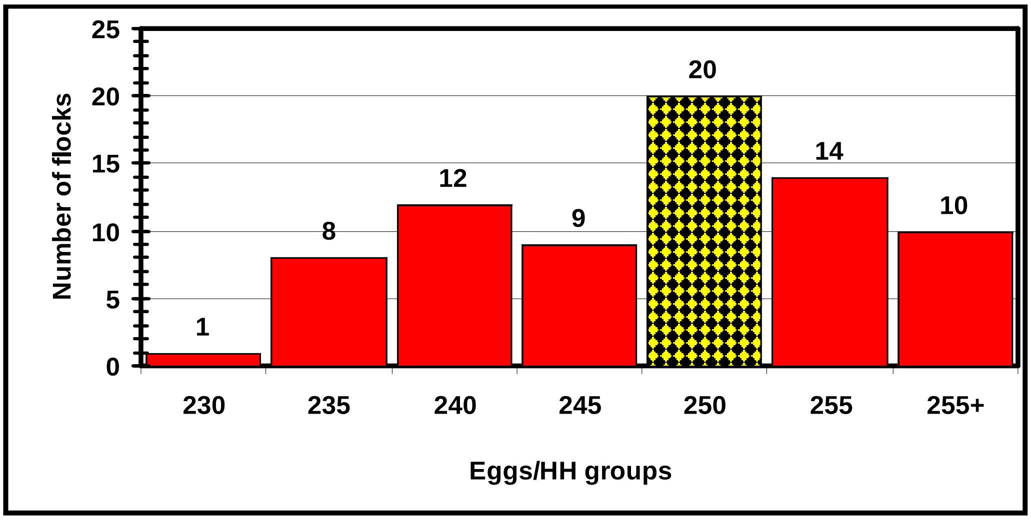


Figure 3: Frequency of Total Egg Mass (kg) - 19 to 60 wks

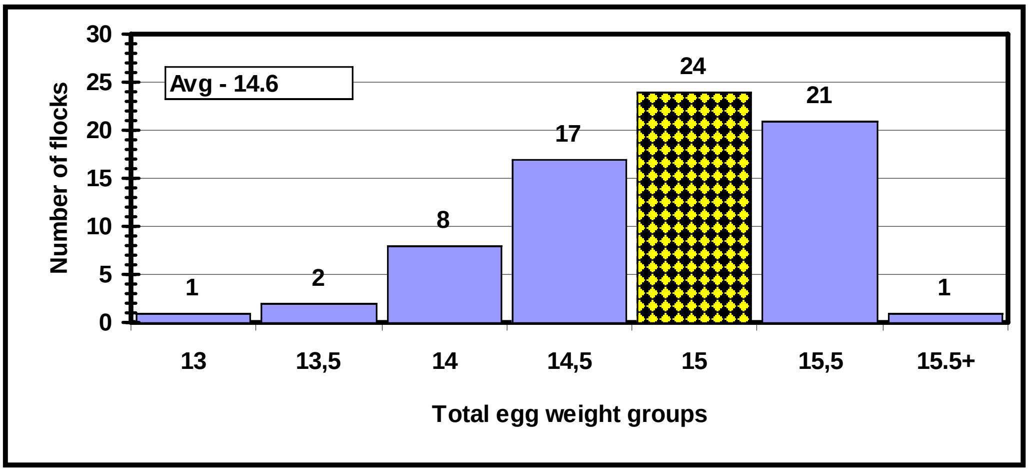


Figure 4: Hen-day Egg Production (%) - 19 to 60 wks

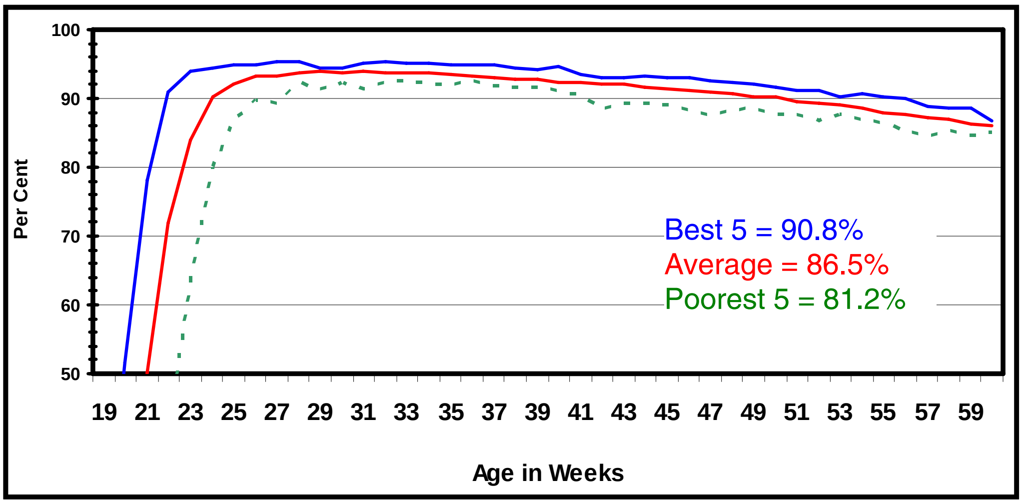


Figure 5: Cumulative Hen-housed Egg Production to 60 wks

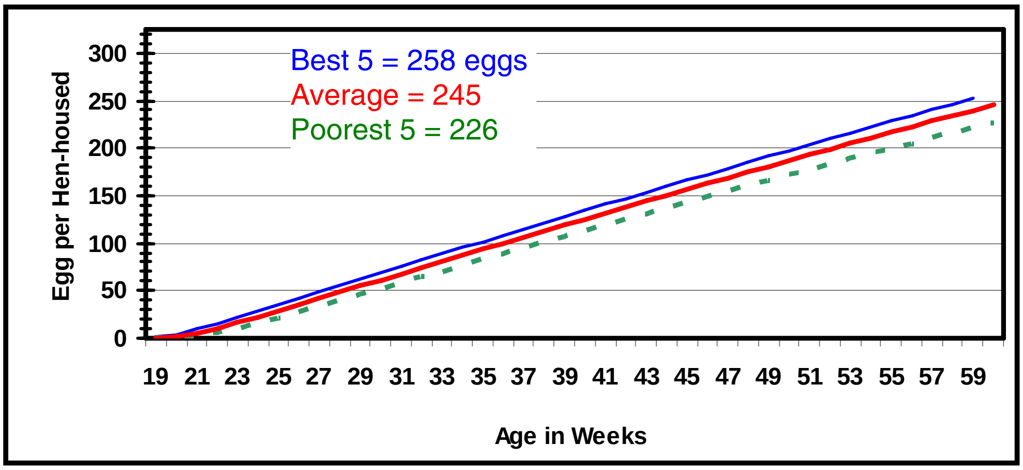


Figure 6: Average Egg Weight (g/egg) - 19 to 60 wks

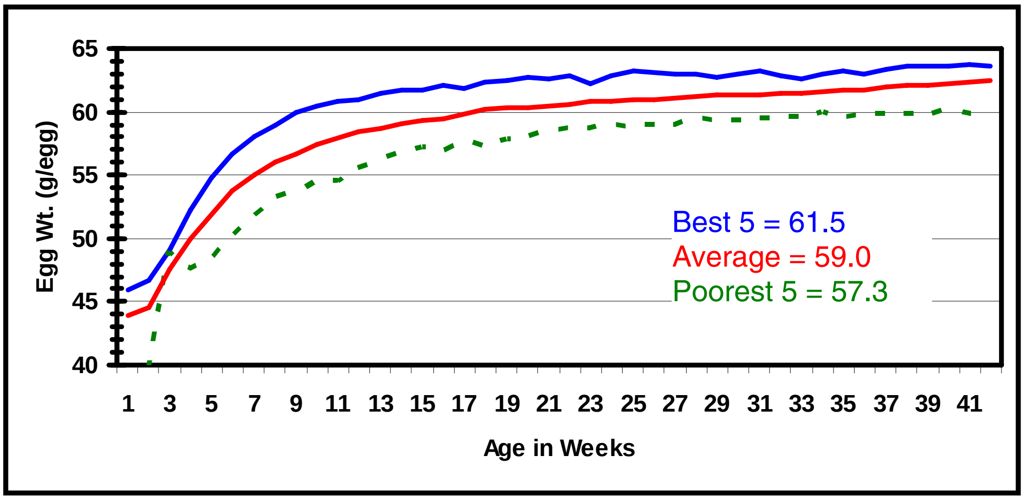
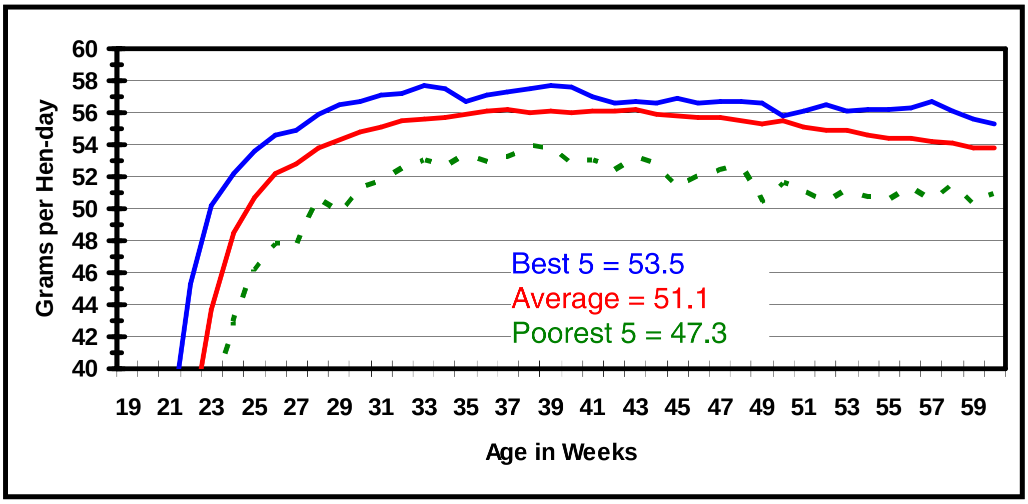


Figure 7: Daily Egg Mass (g) - 19 to 60 wks



Discussion

Significant differences in egg production and egg weight traits between flocks were demonstrated in the data reported above. Comparing just the top 5 and the low 5 flock results, we see differences of 32 eggs in hen-housed egg production and 2.3 kg total egg mass to 60 weeks of age. Since these differences refer to single flocks, the differences between farms will be less extreme. Nevertheless, they suggest major differences in farm management skills on the part of egg producers.

Egg mass is calculated by multiplying the rate of lay times the average egg weight in grams. As shown in Figure 7, the maximum egg mass per day in this study is about 58 grams, which is substantially less than the 60 to 64 grams seen in other countries and different strains bred for higher egg weight, e.g. LSL classic. The pricing of eggs in different countries obviously has a major effect on the optimal average egg weight for the producer in a given area. In the U.S., there is little incentive to produce eggs above 60 to 65 grams (47.5 pounds per case) because the pricing system does not reward the producer extra for eggs of that size. Egg producers actually restrict their egg weight because the extra size requires additonal feed without compensation.

Flock results are primarily a management tool, i.e. a “warning” that performance may not be up to the standards of the breeder or other egg producers. To identify specific “causes” for such discrepancies requires on-farm consultations.

What are common causes of farm-to-farm differences?

Suboptimal results are associated with things we've done incorrectly in the past or in the present time. In other words, the rearing program has a major impact on future results as well as current management. Errors in management during the rearing stage are quite often evident in differences in point-of-lay body weights. These results are commonly seen all the way into production. Get your weights right and you'll be on your way to optimum performance in your laying flocks.

Many management systems can lead to body weight problems and future laying house deficiencies. Major issues include: space allowances, beak trimming, immunization programs, lighting, selection of temperature environments, and general nutrient intake. Dozens of experiments at the formal research and farm-applied levels have shown small (1-5 egg) differences attributable to these factors. On the other hand, major effects amounting to more than 20 eggs per hen have been observed when the range of normalcy is exceeded. The differences in management can oftentimes result in only small or no differences in performance at normal levels; but when these practices are extended too far, we may see dramatic drops in performance.

In 1973-74 research at the Gleadthorpe Research Facility in the U.K. conducted an important study of the effects of rearing programs (Hearn 1975, 1976). Chicks from a common source (breeder flock) were placed on 12 farms with various management programs. At 18 weeks they were transferred to the main laying facility and maintained with exactly the same hen-house management. Results ranged as listed in Table 3 below.

These results clearly demonstrate the contribution that immature pullet management has on layer performance far into the laying period. It's important to note that these are not measurements from the same flock; flock profitability has not been evaluated.

Layer management, on the other hand, has a major effect on current results. This has been well documented with many management systems. Space (floor, feeder and watering) is commonly observed to have a 12-20 egg or more effect within the lay house when different allowances are compared.

Recent well-designed University experiments at North Carolina State (Anderson, 2001) have shown small but significant performance differences by varying space and hens per cage allowances. Table 4 lists several significant effects of only slight space/density differences from this research.

It is important to note that the differences between these results are attributable to very small differences of floor and feeder space per hen and colony size.

Table 3. Gleadthorpe Flock Results (18 to 72 wks) - ranked by indiv. trait

Trait:	Low Results	High Results	Average Results
Rearing Period			
Mortality (%)	4.5	29.5	13.5
20 wk body wts (g)	1406	1860	1680
Age at 50% hen-day EP	158	184	170
Peak HD EP (%)	75.4	83.4	79.3
Laying Period			
HD EP (%)	62.6	67.2	65.4
HH eggs to 72 wks	189	234	222
Daily Feed Intake (g)	106	114	112
Av. Egg Wt (g)	59.0	63.3	61.8

Table 4. The Effects of Small Differences in Cage/Density Types (July, 2011) (11 White Leghorn strains - to 69 wks of age)

System			
Hens per age		5	7
Floor space		497 cm^2 (77 in^2)	471(73 in^2)
Feeder space	Signif. Differ.	12.2 cm (4.8 in.)	11.6 cm (4.6 in.)
Hen-day EP (%)	yes	86.0	85.0
HH eggs to 69 wks	yes	305.8	300.7
Av Egg wt (g/egg)	no	60.6	60.5
Mortality (%)	no	4.6	6.2
Egg mass (g/hd)	yes	53.0	52.4
Daily feed intake (g)	no	107.0	106.0

Other factors including health and nutrition can also result in major economic losses. Environment factors (including light, temperature and air quality) have also been shown to affect both rearing and laying results. Some factors may affect results by only a few eggs, but in most cases, these factors have additive effects to the overall results obtained. Most important is that small differences in results can represent a large percentage of overall farm profits.

The next article in this series will discuss feed consumption and conversion results based upon the data from this study. After that, we'll report on the mortality effects and conclude with the overall effects as they affect farm profitability.

Zusammenfassung

Managementbedingte Varianz in der Leistung moderner Legehybriden als Herausforderung

Teil 1: Legeleistung und Eigewicht

Aus einem größeren Volumen detaillierter Praxisdaten wurden die Leistungen von 74 Herden eines einheitlichen Zuchtproduktes (Lohmann LSL Lite) bis zur 60. Lebenswoche analysiert. Dies ist der erste von drei Beiträgen, in denen die Variation der wöchentliche Legeleistung und des Eigewichtes analysiert wird; in den folgenden Beiträgen sollen die Merkmalskomplexe Futterverzehr und Futterverwertung sowie Tierverluste und Gesamtwirtschaftlichkeit untersucht werden. In den Tabellen 1-3 und den Abbildungen 1-7 werden die wöchentlichen Durchschnitte dokumentiert und die besten und schlechtesten Herden gegenübergestellt, um das Ausmaß der Varianz in einzelnen Merkmalen deutlich zu machen. Anschließend werden unter Hinweis auf veröffentlichte Versuchsergebnisse mögliche Ursachen von Abweichungen vom genetischen Potenzial diskutiert.

References

Bell, D.D. (1982) Pullet Quality. Poultry Digest, August 1982, pp 376, 378, 380.

Bell, D.D. (2008 to 2011) Egg Economics Update. University of California Extension publications 285 to 335.

Anderson, K.E. (2001) First cycle report of the 38th North Carolina layer performance and management test.

Hearn, P.J. (1975) Effect of rearing on subsequent egg production.
ADAS Gleadthorpe Experimental Husbandry Farm Poultry Booklet 3: 57-67.

Hearn, P.J. (1976) The effect of rearing on subsequent egg production.
ADAS Gleadthorpe Experimental Husbandry Farm Poultry Booklet 4: 49-55.

Author's Address:

Donald Bell (emeritus)
Poultry Extension Dept.
University of California, Riverside
e-mail: donlucybell@charter.net

Housing and Husbandry of Laying Hens: past, present and future

H. A. Elson, ADAS Gleadthorpe, Meden Vale, Mansfield. UK

This review briefly traces the origins of the domestic fowl and its spread throughout the world. It goes on to consider important historic, traditional, conventional and modern developments in the housing and husbandry of laying hens. These periodic terms are used according to the definition of Gordon and Charles (2002) i.e. historic: pre 1914, traditional: 1918 to 1953, conventional: from 1953 to late 1990s. The modern era has been added to cover the most recent period i.e. during the turn from the second to the third millennium up to the present time, with a glimpse of the future. As commented 9 years ago, when reviewing half a century of the egg industry, “egg production has a long history but it is easier to look back forty years than to look forward ten!” (Elson, 2002).

Origins and spread

The progenitor of the domestic fowl was the Red Jungle Fowl (*Gallus gallus*), modern forms of which are found in Cambodia, India, Myanmar, Malaysia and Thailand. Crawford (1990) pointed out that one of the wild jungle fowl (Gallus domesticus) may have also contributed to the domestic fowl. These progenitors must have shared biological features, including aspects of behaviour, which predisposed them for domestication (Appleby *et al.*, 1992). It is believed that the fowl was first domesticated in Southeast Asia over 8000 years ago (Yamada, 1988) and established in China by about 6000 BC (West and Zhou, 1989). Its spread westward from Asia was documented by Crawford (1990): it eventually reached Europe, strongly influenced by the Roman Empire. During the earlier stages of domestication, the fowl was probably valued mainly as a sacrificial bird, or for cockfighting. It was the Romans who developed its potential for agriculture, creating specialised breeds (Thomson, 1964), including productive laying hens that formed a complex poultry industry (Wood-Gush, 1959). Pliny wrote that in Roman times there were birds laying an egg every day (Wood-Gush, 1971). With the decline of the Roman Empire the industry collapsed and did not resume on a large scale until the nineteenth century AD.

Development of an egg industry

Eggs now make a considerable contribution to animal protein in the human diet. Towards the end of the second millennium it was estimated that there were over 10 billion chickens in the world (FAO, 1990). There are few cultures that do not consume eggs in large quantities. Egg production in a variety of systems has grown to meet the increased demand.

Over the years, exchanges of scientific and technical information, increasingly on an international level, have greatly influenced the development of poultry systems. The World’s Poultry Science Association (WPSA) has been influential in encouraging research and development and in promoting its results worldwide. In particular Working Group 9 of the European Federation of WPSA (Poultry Welfare and Management), established in 1973, has had a positive effect on the study and development of greatly improved systems of egg production (Elson *et al.*, 2011).

In reviewing such developments reported in British Poultry Science over the past fifty years, Elson (2010) concluded that a variety of the findings of its papers have enlightened our understanding of many aspects of poultry housing and husbandry and thus led to improved performance. New techniques are often quickly implemented. In recent times bird welfare and environmental considerations have greatly affected legislation and egg production systems (Elson, 2002). The facilities and expertise required for egg production are now so specialised that the industry has become separated into distinct sectors. In developed countries there has been a progressive reduction in the number of producers and increase in unit size. Some egg companies have become vertically integrated to incorporate cereal production and feed preparation, stock multiplication, rearing, growing, egg production, processing and marketing (Appleby *et al.*, 1992). Several of these operate in more than one country. Poultry breeding is now largely in the hands of multi-national companies. Marketing of eggs and their products takes place globally.

Historic period (before 1914)

Although its roots go back to Roman times, the egg industry really started during the nineteenth century. There is limited recorded information of developments during the centuries leading to the establishment of the egg industry, but some publications give glimpses of significant milestones in the UK.

Between the thirteenth and eighteenth centuries chickens seem to have been farmyard scavengers. In one thirteenth century manor the poultry were under the care of the dairywoman; each hen was "to answer for 115 eggs and 7 chickens" (Prothero, 1936). Rogers (1866) indicated that the number of fowl on eleven estates varied from 7 to 49 on each estate over the years 1333 – 1336, and their role in the economy was a very minor one. They were more important to the peasants and, in areas where coinage was short, were used to pay land rent. However, with the advent of the nineteenth century, poultry farming was advocated as a specialised enterprise on an increased scale.

During this period breed societies appeared and poultry clubs were formed all over Britain (Charles, 2002). This stimulated the establishment of breed standards and poultry stock improvement. Some of these clubs, e.g. the Sussex Club, concentrated on maintaining breed characteristics. Others, e.g. the Utility Poultry Club (UPC), carried out trials to improve performance aimed at achieving high fecundity and stamina.

The Complete Farmer made a plea for the development of poultry farming along scientific lines (Anonymous, 1807). Subsequently, a few large poultry establishments came into existence (Wood-Gush, 1959). By the late 1800s there was a thriving egg industry in France, described at that time as the egg factory of the world, and many eggs were imported into England until larger units were established in the UK.

Traditional period (1918 – 1953)

Until this time egg production took place mainly on general farms as small or farmyard flocks or at a few specialised establishments with larger flocks.

This new period was characterised by considerable progress in the mainly land based egg industry, interrupted by World War II. In the early stages egg production was based on small flocks of hens kept outdoors on mixed farms alongside other livestock and crop enterprises.

Various aspects of the history of the rapid growth of egg production and the development of housing systems in the UK during this period have been the subject of many accounts published over the past 25 years e.g. by Hewson (1986); Telford *et al.* (1986); Appleby, Hughes and Elson (1992); Crawford (1995); Whittle (1998) and Charles (2002).

After World War I egg production became a popular occupation for returning troops looking for an outdoor country life. Eggs were scarce and prices high, especially in winter due to seasonal production, so despite high feed costs due to shortages following the war and moderate efficiency, margins were considerable from well managed flocks (Robinson, 1961). Thus small specialist laying flocks grew rapidly, mainly kept on permanent pasture. The egg industry grew considerably in importance during the inter-war years; when the WPSA (founded in London in 1912 as the International Association of Poultry Instructors and renamed WPSA in 1928 – Hann, 1996) met at Crystal Palace in 1930 it was opened by the Duke of York and attended by almost 100,000 visitors!

By 1933 there were almost 70 million poultry in the UK (MAF, 1934). Similar expansion also took place in other parts of Europe e.g. the Netherlands; the French egg industry was already well established, having started earlier. However, during the 1930's there were numerous challenges e.g. egg prices slumped and mortality greatly increased to over 20%. The problems encountered included 'fowl sick' land, salmonella pullorum, red and scaly leg mite, coccidiosis, worms, comb frostbite, crop binding and losses to predators (Elson, 1988); these were associated with the extensive systems used and caused the high mortality (Robinson, 1961). Egg output suffered and many egg producers left the industry.

The **free range** (FR) system was quite different then from what is called FR today. Laying hens were kept on well drained hard wearing nutritious pasture at low stocking densities (about 250 birds/ha) either in small mobile houses with slatted floors, usually arranged in rows that were moved frequently (often weekly) across the field (image 1), or in small enclosures called fold units. The latter consisted of a small house with an attached covered run; they were also usually in rows and were moved daily (image 2). In both variations the hens normally used the house only for roosting at night and nesting during the morning; they did, of course, also take limited shelter there in inclement weather. Fold units also afforded some protection from predators. Feed, grit and water were always provided outside in these extensive systems. The hens were often mixed with sheep to achieve better grazing and land management. Robinson (1961) quoted estimates of feed savings of up to 10% by hens grazing on good quality fresh young grass.

Image 1. Traditional free-range houses

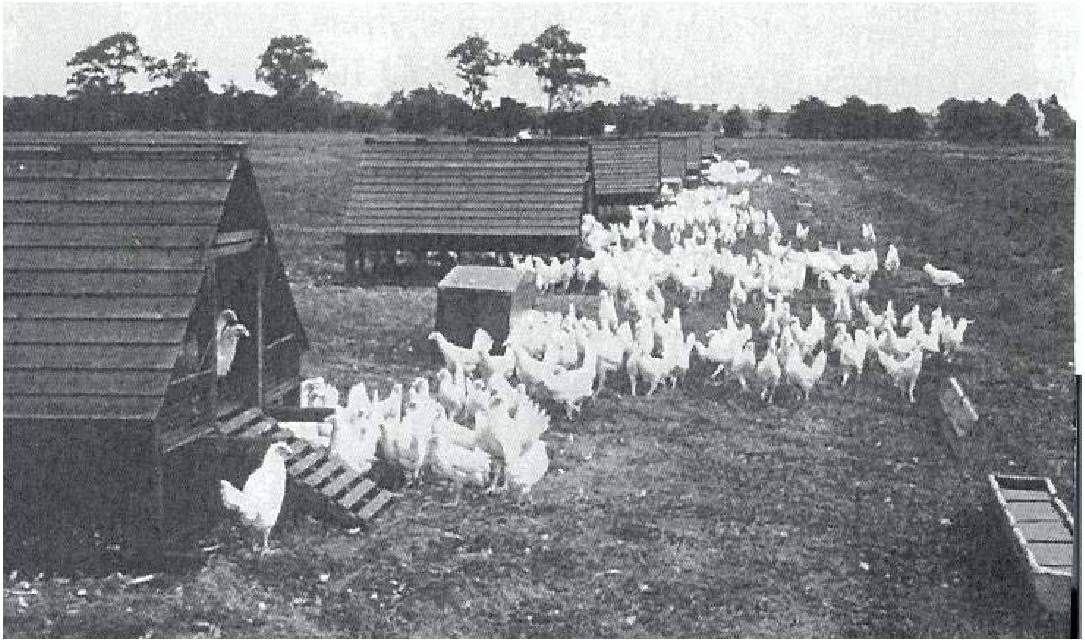
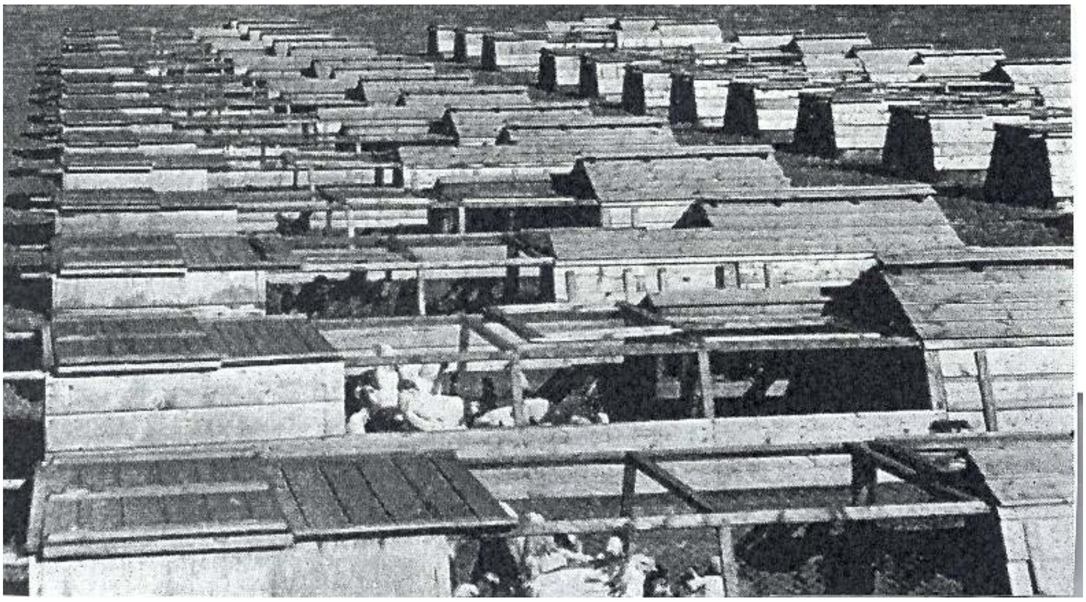


Image 2. Rows of fold units on range



The **semi-intensive system** (SI) became popular with egg producers and pullet rearers from about 1925 onwards. It was more akin to what is currently called FR, had a higher stocking density of up to about 750 hens/ha and consisted of fixed houses with alternate grassed pens used in rotation. The houses allowed hens more space than FR ones so that birds could spend more time inside especially in winter. Feed was sometimes provided inside but there was always at least a daily ‘scratch feed’ of grain outside.

An important discovery was the **value of lighting** for egg production. Although not practiced much because it was difficult to apply in small FR houses, it became known in the mid-1920s that extending day length by artificial light to stop it diminishing after mid-summer increased egg output in the autumn and winter months; this was thought then to be due to extended days allowing birds more time to eat (Fairbanks and Rice, 1924). This was effective for the few that tried it, using oil lamps, but would not come into its own till later when the subject was better understood (Morris and Fox, 1958) and intensive housing took over and made it easier to apply.

The **war years brought great changes**. Egg production was severely affected by feed rationing, which reduced both the quality and quantity of feed available. General farmers survived best because they had home-grown cereals available (Robinson, 1961). Many producers left the industry, the number of laying hens kept fell drastically, egg production declined and production systems remained much as they were before the war. This situation continued for a few years after the war, although the move into intensive housing systems started in the late 1940s.

Conventional period (1953 to late 1900s)

1953 was a key turning point in the development of the poultry industry. Poultry feed rationing came to an end in the UK (Whittle, 1998), which allowed expansion of the industry in size and technical efficiency in response to consumer demand for cheaper and more abundant supplies of eggs. Writing in 1954, Coles noted that in the USA 90% of laying hens were kept intensively, mainly on deep litter; the figure for Britain at that time was 35% (about half of them in cages and the other half on deep litter) and rose rapidly to 90% in cages by 1966 and a peak of 95% in cages in1980 about 4% still being on deep litter - see figure 1 - (Elson, 2002).

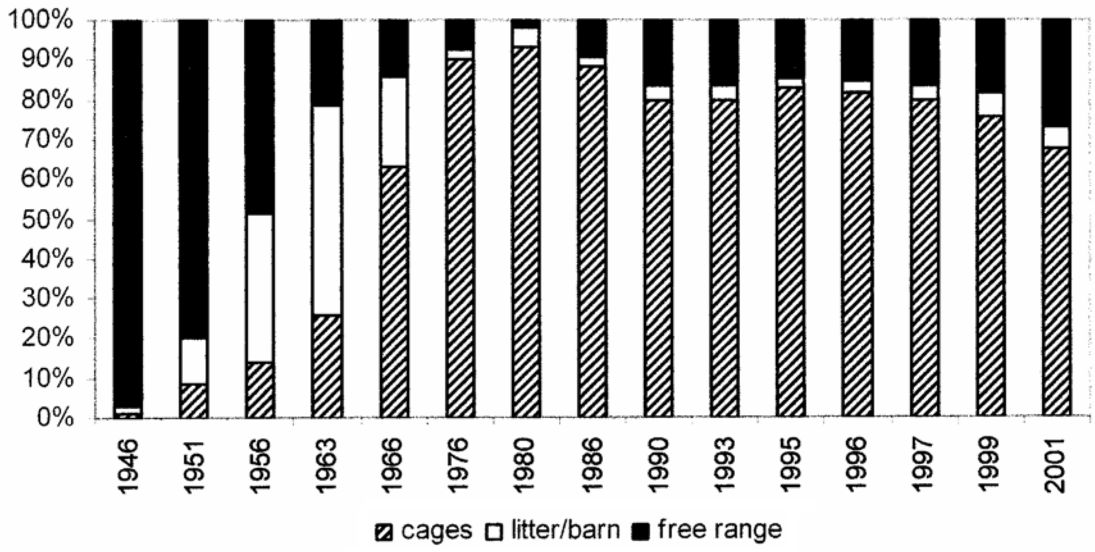


Figure 1: Changes in UK egg production systems, 1946-2001

Adapted from data of MAFF and DEFRA and the Museum of the British Poultry Industry

2007: cages 62%, barn 4%, free range 34%.

The above references to deep litter would appear to indicate a system that came and went within about 30 years. If well managed, the system had several benefits (Goode, 1957) but was quickly overtaken by cages, which are better suited to large-scale economic egg production. Certain elements of the deep litter system were incorporated into barn housing, often used in conjunction with the modern FR system that came into use during the 1980s (Elson, 2004).

Animal Machines (Harrison, 1964) and the Brambell Report (1965) drew attention to the need to protect the welfare of livestock kept under intensive systems. The 'battery' laying cage was the focus of debate, which led to much research and development to improve its design and management and that of various alternative husbandry systems for laying hens (Elson, 1989). European legislation to protect laying hen welfare followed (CEC, 1988) and further influenced the conditions under which eggs were produced (Appleby *et al.*, 1992).

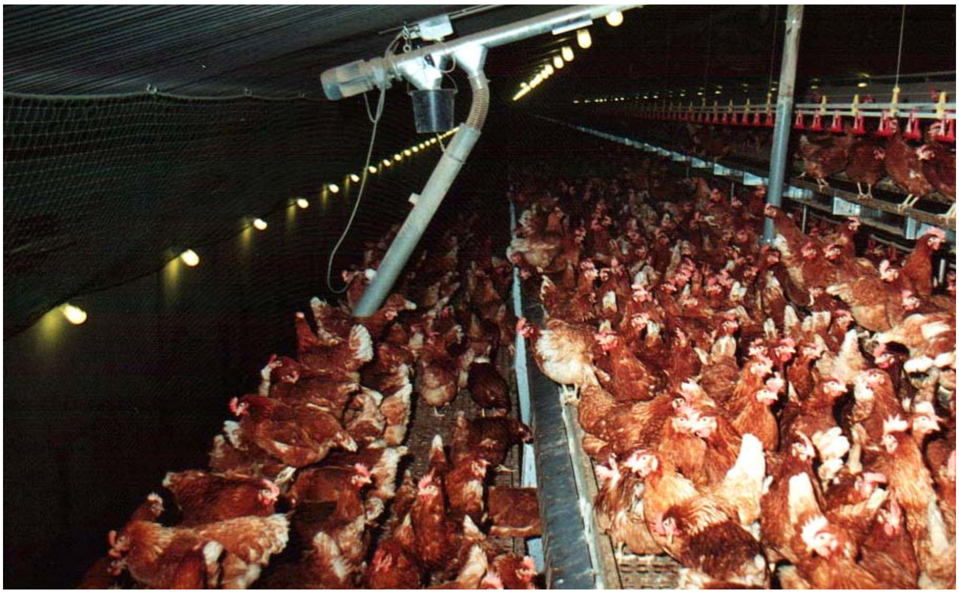
The world energy crisis of 1974 focussed attention on feed conversion efficiency and led to the conservation of bird heat to maintain house temperature during winter, more efficient mechanised feeding and minimisation of waste. Meanwhile, intensive methods of poultry husbandry dominated the scene in most developed countries until the 1980s when, as a result of the welfare debate and the development of a niche market, FR laying hens were re-introduced in Britain and some other northern European countries, initially on a small scale. These developments could be seen as moves back from intensive production towards land based ecological approaches, more integrated with sustainable agriculture.

Modern period (1990 to the present)

This period has been characterised by increasing concerns over animal welfare, pollution of the environment, global warming and the serious threat of infectious diseases e.g. Avian Influenza (AI). Each of these concerns has influenced developments in both the intensive and extensive sectors of the egg industry.

An important effect of poultry welfare legislation was to reduce stocking density (SD). Thus more space was required in conventional cages and they are to be phased out by 2012. Furnished (enriched) cages (FCs) were conceived when the welfare deficiencies of barren conventional ones were realised. Their forerunner was the 'get-away' cage, designed by Elson (1976) to provide hens with perches and nest boxes in an enlarged space. Its development led on to two new concepts: multi-tier aviaries (see image 3) and FCs (Elson, 1988). The use of FCs was intended to enhance hens' behavioural repertoire and welfare without the disadvantages of non-cage and extensive housing. They have an even lower SD than modern conventional cages plus nest boxes, perches and litter (CEC, 1999).

Image 3. Multi-tier aviary



The design of FCs has been gradually refined, resulting in much improved performance and welfare. Group size has been an important consideration, especially in relation to variation in damaging pecking in differing genotypes with or without beak treatment. The trend has been to move from small groups of 8 to 10 hens, used mainly in Scandinavia (image 4), to much larger 'colony' cages (FCLs) for groups of up to 90 hens – see image 5 (Elson and Tauson, 2011).

Large scale studies, in which performance and welfare have been compared across all currently available systems, enable us to conclude that with good management they are at least as good in FCs as in any other system, and probably superior (Elson and Croxall, 2006; Sherwin *et.al.*, 2010). A special design of FCL providing greater height and space, Kleingruppenhaltung, has been introduced in Germany and the Netherlands.

The trend towards non-cage (NC) and extensive production continues at the expense of intensive methods, but organic egg production remains a niche product. Most modern FR houses are fixed and even mobile ones are usually fairly large, and only moved about once a year. Feed and water are provided inside the house, the outside feeding of the traditional period now being unacceptable because it attracts wild birds, rodents and predators. Modern FR houses are also much larger than traditional ones, and have more space (maximum SD 9 hens/m² - CEC, 1999). Efficient multi-tier aviary housing is increasingly being used in NCs and as the housing part of FR systems.

Image 4. Small furnished cage (FCS) for 8 hens

Image 5. Large furnished cage (FCL) for 60 hens

The effect of the above factors is to discourage hens from leaving the house; those birds that do range are often only outside for short periods and may stay near the building. Large pop-holes are now used, and trees planted or other structures added to provide shelter and shade to encourage birds out and across the range (image 6). The downside of this is that increased mortality due to smothering and/or predation is more likely.

Image 6. Modern free-range farm

The future

CEC (1999) requires the demise of all conventional cages in the EU by 2012, and has accelerated the move into FCs and NCs; this is likely to continue over the next few years. The use of FCs has also begun to spread beyond Europe; a few recent installations have been made in the USA, where agreement has recently been reached between industry and welfare institutions that they should be accepted as meeting legislative requirements to replace conventional laying cages by 2025 (United Egg Producers, 2011). Further worldwide spread is likely.

FCs have potential for further improvement especially in terms of cage and group size, litter and lighting provision, the development of a technique to blunt beaks and redirect pecking away from feathers and catching and handling during depopulation (Elson and Tauson, 2011). Adequate litter provision to satisfy hens' ethological needs, including dust-bathing, needs further research and development. This may require greater area and depth of litter as well as frequent litter replenishment.

NCs, especially FR systems, are vulnerable to increased welfare challenges because hens going outside are exposed to greater risks of infectious disease, endoparasitic infestation, smothering and predation, which can result in much higher mortality (Elson, 2008). Energy use and the carbon footprint are also higher in extensive systems. Housing system design and management will therefore require close attention.

Meerpohl (2009), asked to consider likely developments in poultry keeping over the next 25 years, suggested that “We are not going to experience any spectacular new methods of poultry husbandry but will undoubtedly see continuous further developments and improvements of existing systems that, in the end, are certainly going to surprise us”. One such innovative development may be the Dutch **Rondeel NC system**, which incorporates new ideas and technology; it has yet to be perfected but opens up new possibilities including a combination of indoor and limited covered outdoor FR (Niekerk, 2011). If accepted as FR in the same way that the semi-intensive system was in the 1980s, the Rondeel could prove to be a big advance on current FR and as efficient as modern FCLs.

Zusammenfassung

Managementsysteme für die Haltung von Legehennen: Vergangenheit, Gegenwart und Zukunft

Der Autor beschreibt die Entwicklung von Haltungssystemen für Legehennen von der Antike bis in die Gegenwart und stellt dabei folgende Zeitabschnitte heraus: Anfänge vor dem Ersten Weltkrieg, die "traditionelle" Haltung bis in die 1950er Jahre, die "konventionelle" (Effizienz-betonte) Haltung bis etwa 1990 und die "moderne" (zunehmend Tierschutz-betonte) Haltung in den letzten 20 Jahren. Bei der Weiterentwicklung von Haltungssystemen dürften Ressourcen (Futterverwertung, Energie)- schonende Produktion und minimale Umweltbelastung ebenso an Bedeutung gewinnen wie die Akzeptanz seitens der jeweiligen Gesellschaft - wobei Überraschungen nicht auszuschließen sind.

References

Anonymous (1807). The Complete Farmer or General Dictionary of Agriculture and Husbandry. Rider and Wead. London.

Appleby, M.C., Hughes, B.O. and Elson, H.A. (1992). Poultry Production Systems: Behaviour, Management and Welfare. CAB International.

Brambell, F.W.R. (1965). Report of the Technical Committee to Enquire into the Welfare of Animals kept under Intensive Livestock Husbandry Systems. Command Paper 2836. HMSO. London.

CEC. (1988). Council Directive 88/166/EEC laying down minimum standards for the protection of laying hens kept in battery cages. Official Journal of the European Communities. L74.

CEC. (1999). Council Directive 99/74/EC laying down minimum standards for the protection of laying hens. Official Journal of the European Communities. L 203.

Charles, D.R. (2002). Food, farming and the countryside: past, present and future. Nottingham University Press.

Coles, R. (1954). Changes in the pattern of poultry keeping. Journal of the Royal Agricultural Society of England 115: 69-82.

Crawford, R.D. (1990). Origin and history of poultry species - chapter 1 in Poultry Breeding and Genetics. Elsevier Science Publishers. Amsterdam.

Crawford, R.D. (1995). Origin, History and Distribution of Commercial Poultry – chapter 1 in World Animal Science Series: Poultry Production. Elsevier Science BV. Amsterdam.

Elson, A. (2002). Half a century of egg production - 1962 to 2012. Poultry International 41(5): 8-16.

Elson, A. (2004). The laying hen: systems of egg production. Proc. WPSA 27th Poultry Science Symposium on the Welfare of the Laying hen. Bristol pp. 67-80. CAB International Publishing, Wallingford.

Elson, A. (2008). Do extensive poultry systems really offer superior welfare? Poultry International 47(3):10-14.

Elson, H.A. (1976). New ideas on laying cage design-the “Get-away” cage. Proc. 5th European Poultry Conference. Malta. 1030-1041.

Elson, H.A. (1988). Poultry management systems - looking to the future. World’s Poultry Science Journal 44: 103-111.

Elson, H.A. (1989). Improvements in alternative systems of egg production. Proc. 3rd European Symposium on Poultry Welfare. Tours. 183-199.

Elson, H.A. (2010). Poultry housing and husbandry. British Poultry Science. 51: 23-34.

Elson, H.A. and Croxall, R.A. (2006). European study on the comparative welfare of laying hens in cage and non-cage systems. European Poultry Science 70: 194-198.

Elson, H.A. and Tauson, R. (2011). Furnished cages for laying hens. In: Alternative Systems for Poultry – Health, Welfare and Productivity. CABI Oxford.

Fairbanks, F.L. and Rice, J.E. (1924). Artificial illumination of poultry houses for winter egg production. Cornell Extension Bulletin 90.

FAO (1990). FAO Production Yearbook. Vol. 44. Food and Agriculture Organisation of the United Nations. Rome.

FAWC. (1997). Report on the Welfare of Laying Hens. Tolworth.

Gordon, S.H. and Charles, D.R. (2002). Niche and Organic Chicken Products: their technology and scientific principles. Nottingham University Press.

Hann, C.M. (1996). A brief history of the World's Poultry Science Association. In: UK Branch 50th Anniversary. WPSA UK Branch.

Harrison, R. (1964). Animal Machines. Stuart. London.

Hewson, P.F.S. (1986). Origin and development of the British poultry industry: the first hundred years. British Poultry Science 27: 525-540.

MAF. (1934). Returns from Agricultural Holdings in England, Wales and Scotland.

Meerpohl, B. (2009). Keeping poultry in the future. World Poultry. 25(6). 14-15.

Ministry of Agriculture and Fisheries data in Robinson, L. (1961) p.2.

Morris, T.R. and Fox, S. (1958). Artificial light and sexual maturity in the fowl. Nature 181:1522-1523.

Niekerk, Th.G.C.M. (2011). [Insert Title & page nos.] Lohmann Information. 46 (2):

Prothero, R.E. (1936). English farming past and present. 1961 edition. Heinemann and Frank Cass and Co. London, first published 1912.

Robinson, L. (1961). Modern Poultry Husbandry. Crosby Lockwood. London.

Sherwin, C.M, Richards, G.J. and Nicol, C.J. (2010). Comparison of the welfare of layer hens in four housing systems in the UK British Poultry Science. 51: 488-499.

Telford, M.E., Holroyd, P. and Wells, R.W. (1986). History of the National Institute of Poultry Husbandry, Nuffield Press.

Thomson, A.L. (1964). A New Dictionary of Birds. Nelson. London.

United Egg Producers. (2011). Historic agreement hatched to set National Standard for nation's egg industry. www.unitedegg.org/homeNews/UEP_Press_Release_7-7-11.pdf

West, B. and Zhou, B. (1989). Did chickens go north? New evidence for domestication. World's Poultry Science Journal 45: 205-218.

Whittle, T.E. (1998). A Triumph of Science: a 70 year History of the UK Poultry Industry. Poultry World Supplement.

Wood-Gush, D.G.M. (1959). A History of the Domestic Chicken from Antiquity to the 19th Century. Poultry Science 38: 321-326.

Wood-Gush, D.G.M. (1971). The Behaviour of the Domestic Fowl. Heinemann. London.

Yamada, Y. (1988). The contribution of poultry science to society. World's Poultry Science Journal 44: 172-178.

Author's address:

arnold.elson@adas.co.uk

Rondeel™, a new housing design for laying hens

Thea van Niekerk and Berry Reuvekamp
WUR Livestock Research, Lelystad, The Netherlands

Introduction

In 2003/4 a project was initiated and financed by the Dutch agricultural ministry to develop new housing systems for laying hens that would be sustainable and acceptable by the public. The leading issue in the process of developing new housing designs was animal welfare and not directly cost reduction. The project resulted in two completely new designs (Bos *et al*. 2004, Bos & Groot Koerkamp, 2008). One of these, the Rondeel™, has been realized on commercial scale in 2010. Although theoretically the system was sound, it had not been tested and thus no experience with keeping hens in this system was available. Therefore research was conducted on the first flock to investigate the functioning of the system, the adaptation of hens to it, the use of the various areas and the fitness of the birds (Niekerk & Reuvekamp, 2011).

The Rondeel™ is more expensive to build than traditional aviary or free range houses and therefore egg production costs are higher. This should be recouped by selling the eggs as a special product. This has been achieved in two ways. Firstly the eggs were sold in special boxes that uniquely identified the eggs as being produced in the Rondeel™. Secondly the eggs were sold with 3 stars of the special “Beter Leven” (better life) hallmark of the Dutch animal welfare organization “Dierenbescherming”. This Hallmark for animal welfare grants one, two or three stars to products in various supermarkets indicating the level of welfare the animals had during their life. Three stars is usually granted to organic farming, as in that type of husbandry no mutilations of animals are carried out (Dierenbescherming, 2011). The Rondeel™ was also granted three stars under the condition that hens would not be beak trimmed. An exemption was made for the first flock, because otherwise the risk for the farmer would have been too high (both a new, not tested husbandry system and not-trimmed hens). Therefore only a minority of the hens were not trimmed.

Layout

The Rondeel™ is a circular building that can house 30,000 hens in 6 sections, located around the central management quarters (Figure 1). Egg collection is located in these management quarters; also a manure drying tunnel is situated below ground level there. Visitors facilities are sited on the second floor and in the top of the building climate control with heat exchangers is located. To give access to the management quarters, the circle of the building is not completely closed. The 6 sections for the laying hens are not equal in size. The sections on either side of the entrance to the building are smaller and contain 3,000 hens each. The other 4 sections each contain 6,000 hens.

Figure 1: Layout of the Rondeel™

The large sections have night quarters (dark sections in drawing) on each side, a day quarter (bright sections in drawing) in the middle and a wooded fringe at the outer side. The two small sections only have one night quarter each. Night quarters are equipped with an aviary system (Bolegg Terrace from Vencomatic). Each night quarter is split in two halves by netting, making one part available for one section and the other part for the adjacent section. Day quarters have no separation and hens from both night quarters can use it freely.

The day quarters are located between the night quarters. Floors are covered with artificial grass. On the outer side a semi-circular box, filled with peat, provides dust bathing facilities. In the middle of the day quarters some circular drinkers are located. The roof of the day quarters is made of wind- and waterproof transparent material that makes the day quarters very bright. According to the manufacturer the transparent roof material lets through about 80% of the UV-light spectrum.

The wooded fringe comprises a circular area around the building, divided with wire fencing into 6 sections corresponding to the 6 inside sections. The earth floor is covered with woodchips. Originally it was furnished with trees and bushes, but these were destroyed by the hens in a few weeks. Later some tree stumps were placed in the wooded fringe. The outer circle of the wooded fringe forms a wire mesh fence. The top of the wooded fringe is covered with netting to prevent predators getting in and hens getting out.

Between the night quarters and the day quarters an insulated curtain over the full length can be rolled down to close off the night quarters. A netted curtain over almost the full width of the day quarters can be rolled down between the day quarters and the wooded fringe.

Economics

Eggs produced in the Rondeel™ are sold as barn eggs, as the wooded fringe does not meet the required dimensions for free range. To compensate for the more expensive Rondeel™ house a premium on the eggs is needed. This was realized by selling the eggs as a special product in specially designed round boxes made of coconut vessels. To argue why these eggs are special, some extra hallmarks are obtained. First the already mentioned animal welfare hallmark was obtained under the condition that no beak trimming would be performed. Indeed the second flock in the Rondeel™ is not trimmed at all. Another hallmark for environmental care (Milieukeur) was granted because the low energy cost of the system. Two heat exchangers from Agro Supply take care of climate control in the system and pre-and re-drying of the manure.

An important characteristic of the Rondeel™ is the communication to the public. The house has a visitors aisle from where visitors can see the birds and the egg packing section. Visitors are also allowed to walk outside the wooded fringe and look at the birds from there. An active promotion is carried out to attract visitors and to make them understand how eggs are produced in a sustainable way.

Results rearing for first flock

The first flock in the Rondeel™ was of the Lohmann Brown Lite genotype, hatched on December 14, 2009. The pullets were reared in a house with in height adjustable platforms and ample daylight. The latter was deliberately chosen as the Rondeel™ house has a high level of daylight. In this way the difference between rearing and laying houses would be minimized. In the rearing house pullets had no access to free range. Grain was scattered to prevent feather pecking. At the end of the rearing period the feather cover of the hens showed signs of pecking damage (although this was not much considering the fairly high light intensity the birds received). Measures to prevent feather pecking were taken in the layer house as soon as the birds were housed, to reduce the risk of feather pecking continuing there. As for growth, feed intake and uniformity the rearing flock was average: not too heavy and not too light in bodyweight.

Variation in the laying house

In the laying house the hens were housed in the 6 sections at 19 weeks of age. As mentioned, two sections housed 3000 hens and the other 4 sections housed 6000 hens. These 4 larger sections differed from each other in some details. One section had, as a test, a different artificial grass mat on one half of the day quarters. The other half of the day quarters had the same artificial grass as all other sections. One section had a visitor's aisle running through the day quarters. This will be built in all Rondeel houses as it is part of the concept to open the house to visitors without compromising the hygiene. One section was populated with non-beak trimmed birds. The fourth large section had no specific features. In total 30,000 hens were placed.

Light intensity

The sections were reasonably comparable in light intensity and variation was mainly caused by changing weather conditions. Night quarters were always darker than day quarters. The general light intensity in the Rondeel™ was much higher than that usually seen in layer houses: for the night quarters about 190 lux was measured and for the day quarters more than 3000 lux. The light intensity in the wooded fringe was almost equal to outside at about 6000 lux.

The light distribution in the day quarters was very even. This was achieved by the roof design of the day quarters. The transparent material used filtered out sharp contrasts between shady and sunny spots.

Litter quality

The artificial grass mat slowly became soiled with manure. This was foreseen and the idea is to clean the mat during the laying period mechanically. However, no substantial cleaning of the artificial grass was carried out. There were two reasons for this. First of all the machine to clean the mat had to be newly developed and this was not yet ready at the time the first flock was in the Rondeel™. The second reason was, that by not cleaning a good impression could be obtained what would happen with the artificial grass over the time of the laying period. Thus, only some minor incidental cleaning was carried out, e.g. after a water leakage.

Soiling of the artificial grass started at the sides along the night quarters and in the corners near the central unit. Although soiling at 42 weeks of age (the last measurement) was substantial, hardly any capped areas were seen. At the end of the laying period the artificial grass was completely covered with litter.

The litter in the night quarters stayed dry and loose. The litter in the dust baths (peat) initially was hardly used. It was not clear why this theoretically ideal dust bath material was not used, but a possible explanation could be that hens had ample possibilities to dust bath in the wooded fringe and in the night quarters. In the second part of the laying period litter material from the day quarters was moved to the dust baths and thereafter they were used more. The non-beak trimmed hens were also provided with bales of straw in the dust baths, making this area even more attractive.

Management

As the Rondeel™ had never been tested before, many management issues were unknown. When the first flock was housed, they were kept in the night quarters for a few days to facilitate them finding food, water and nest boxes. After a few days over the full length of the night quarters the curtains were rolled up, giving hens access to the day quarters. At first this was done in two steps. The curtains first were rolled up about 1 metre and a few hours later they were completely rolled up. This was done to make sure not too much light would fall on the nest boxes. Later experiences indicated that the curtains could be rolled up completely from the start without causing problems with floor eggs.

When returning from the day quarters, birds can choose to enter the night quarter on the left or on the right. One of the first concerns was how the birds would distribute over these two night quarters. As the Rondeel™ is round, some night quarters are catching the last sun of the day, others are not catching any sun etc. If all birds would choose the same night quarter, problems with space and ventilation could be expected. However, there did not seem to be any tendency to use one night quarter more than the other. Up to the end of the first laying period birds distributed fairly evenly over both night quarters.

Another concern related to the ventilation in the day quarters. These were naturally ventilated by means of the open side to the wooded fringe. No ventilation openings were made in the transparent roof. Theoretically this would be sufficient in hot circumstances, but some experts questioned if there wouldn’t be too much heat building up underneath the transparent roof. Fortunately during a hot period it appeared that the temperature at bird level was not too high and thus extra ventilation in the roof was not necessary.

At the end of the first flock the farmer indicated that the production was nodifferent from flocks in other non-cage systems. Mortality at 50 weeks of age was about 4.5%, which is normal for Dutch non-cage flocks.

Behavioural studies

To determine the use of the facilities in the Rondeel™ behavioural observations were carried out. After some pilot observations it became clear that live observations were not possible, because the birds were extremely calm and curious and reacted too much to the observers. Therefore video cameras were used to record behaviour in the night quarters, day quarters and wooded fringe. The number of observed areas differed for these 3 parts of the henhouse, as the size of these areas differed. For the behaviours given in table 1 the numbers of hens performing them were counted (scan sampling). After 10 minutes the counts were repeated. Before and after these counts the number of hens in the observed area were counted. For pecking behaviour (table 2) the same areas were used. During 5-8 minutes (depending on the number of areas to observe) all observed pecks were recorded (continuous recording).

Data were analysed using analysis of variance (continuous data) or a logistic regression analysis (percentages; GenStat Release 13.1). In case of significant differences (P<0.05) or a tendency to a difference (P<0.10) the procedures PAIRTEST (Performs t-tests for pairwise differences) and PPAIR (Displays results of t-tests for pairwise differences) were used.

The results of the behavioural studies are given in tables 1 and 2. At 25 weeks of age more movements were seen in the day quarters compared to the night quarters and the wooded fringe. The spacious and light environment does in fact stimulate this. At 42 weeks of age however no significant difference was found for movements. In the night quarters less scratching and floor pecking were recorded, both at 25 and 42 weeks of age. In the wooded fringe less preening was seen at 25 weeks of age. At 42 weeks of age still less preening was seen in the wooded fringe, but also in the night quarters. Preening was mainly done in the day quarters. These findings are in accordance with expectations and do fit in the functions of the different areas.

Table 1: Behaviour at 25 and 42 weeks of age in the various areas of the Rondeel™ (% of number of observed birds)

	Resting	Moving	Scrat-ching	Preening	Drinking	Eating	Dust bathing
25 weeks	P=0.018*	P<0.001	P=0.008	P=0.013	N.A	N.A.	N.A.
Wooded fringe	0.0	23.3 a	13.5 a	3.1 a	0.0	0.0	9.4
Day quarters	2.9	46.6 b	6.0 a	9.0 b	0.0	0.0	1.7
Night quarters	2.7	26.7 a	2.6 b	8.4 b	16.8	23.7	2.3
42 weeks	P<0.001	P=0.062*	P=0.001	P<0.001	N.A	N.A.	P=0.649
Wooded fringe	0.4 a	23.8	9.3 a	1.0 a	0.0	0.0	8.3
Day quarters	3.7 b	35.1	4.6 b	11.7 b	0.0	0.0	5.4
Night quarters	1.5 c	27.6	2.0 c	6.5 a	15.1	20.7	5.3

* PAIRTEST doesn't give significant differences
a, b, c: different small letters in vertical direction represent a significant difference within age (P<0.05)

Table 2: Pecking behaviour at 25 and 42 weeks of age in the various areas of the Rondeel™ (% of number of observed birds)

	Head	Severe	Gentle	Object	Floor	Vent
25 weeks	N.A.	P=0.015*	P=0.321	N.A.	P<0.001	—
Wooded fringe	0.0	0.4	4.1	10.8	269.4 a	0.0
Day quarters	0.3	2.8	4.7	0.0	224.1 a	0.0
Night quarters	0.3	1.7	6.2	0.0	74.8 b	0.0
42 weeks	N.A.	P=0.010	P=0.125	N.A.	P<0.001	N.A.
Wooded fringe	1.0	2.4 ab	1.3	0.3	228.1 a	0.0
Day quarters	0.4	4.7 b	4.3	0.8	138.7 a	0.2
Night quarters	1.8	1.1 a	2.4	0.0	49.8 b	0.0

* PAIRTEST doesn't give significant differences
a, b: different small letters in vertical direction represent a significant difference within age ($P<0.05$) no wound pecking has been observed

For a number of behaviours differences were found between sections. Less movements were seen in the small sections and the section with a visitor's aisle. This accords with the expectation, because in both situations there is less space for the hens to move over large distances.

With regard to feather pecking no problems have occurred. At 25 weeks there seemed to be a tendency to more severe feather pecking in the day quarters, but this difference was not statistically significant. At 42 weeks of age more severe feather pecking was recorded in the day quarters than in the night quarters. This could be expected based on the high light intensity in that area.

In the night quarters hardly any floor pecking was seen, despite the presence of litter. Probably the hens could satisfy their pecking behaviour enough on the artificial grass and in the wooded fringe.

Measurements exterior

In table 3 the results of the measurements on exterior are given per section of the Rondeel™ and on average for the Rondeel™. The method according to Welfare Quality® was used (WQ 2009). From each section 100 birds were individually scored on six parts: comb (pecking wounds at comb), keel bone (strait or deformation), feet (condition foot pad), beak (beak shape), plumage (condition of the feathers on the back of the head and neck, on the back or around the vent area). These six items reflect possible welfare or pecking issues. For each body part the score runs from 0 (=good) to 2 (=bad). The average scores are given for all 6 sections of the Rondeel™ as well as the average over all six sections. The section with non-beak trimmed birds had better beak scores, which was according to expectation. Non trimmed beaks usually have no abnormalities and a normal shape of the beak, resulting in the best score (being 0). The average for this section was slightly higher than zero, because in the random sample of 100 birds for this section a few beak trimmed hens appeared present. As sections are only separated by a net curtain these trimmed hens will have originated from adjacent sections. The non-trimmed birds had slightly more skin damage, although the overall level was very low. Very few birds with wounds were seen and if skin damage was present it was mostly no more than some pecks or scratches. As non-trimmed beaks can cause more skin damage it was in accordance with expectation that these birds had more skin damage. The level of comb pecks also seems higher, but this was not statistically different. The overall high score for comb pecks is due to the scoring system: the highest score is given as soon as 3 (minor) pecks are present. Feather condition was not statistically different for non-beak trimmed hens compared to the trimmed birds.

The high scores for keel bone deformation are also caused by the scoring system: only two categories were scored, being 0= straight keel bones or 2= deformed keel bones. The majority of hens had only minor deformations.

Table 3: Results of exterior measurements

Section	Comb	Keelbone	Feet	Beak	Feathers	Skin
Small	1.28	1.66	0.28	1.24 b	0.65	0.02 a
Not beak trimmed	1.75	1.78	0.40	0.18 a	0.95	0.10 b
Visitor's aisle	1.29	1.67	0.40	1.27 b	0.65	0.02 a
Alternative art. grass	1.08	1.80	0.46	1.21 b	0.45	0.00 a
Beak trimmed hens	1.07	1.72	0.53	1.17 b	0.46	0.01 a
Small	0.91	1.72	0.58	1.21 b	0.55	0.00 a
Average Rondeel™	**1.23**	**1.73**	**0.44**	**1.05**	**0.62**	**0.03**
Average WQ-project	0.81	1.68	0.59	0.80	1.68	0.27
WQ-organic farm 1	1.46	1.80	0.64	0.02	1.65	0.29
WQ-organic farm 2	1.97	1.91	0.46	0.00	0.27	0.03

For each body part a 3-point scale was used from 0 (=good) to 2 (= bad)
a,b: different letters indicate a significant difference ($p<0.05$) in vertical direction between different sections of the Rondeel™. The analysis is only done on the Rondeel™- results, not on those of the WQ-project.

Welfare Quality® measures

To get an idea of how good or bad the Rondeel™ scored compared to the Dutch average , the data were compared with measurements carried out with the same Welfare Quality® (WQ) protocol (Welfare Quality®, 2009) on 22 commercial farms with non-cage systems in the Netherlands (no statistical analysis was done for this comparison). Two of those farms were organic and thus had non-beak trimmed birds. In the other 20 farms the birds were beak trimmed. Apart from the average of all 22 farms (called Average WQ-project), the scores of the 2 organic farms are given.

On average the Rondeel™ scored slightly higher on comb pecking, but the scores were in line with the 2 organic flocks. Keel bone scores were in the same range as well as foot scores. Beak scores were higher, except for the non-trimmed birds that had scores in line with the two organic flocks. There is no good explanation for the higher beak scores for the trimmed hens, but it could be due to a slight change in the beak scores used in the earlier protocol compared to the final published WQ-protocol. Feather damage was lower compared to the average of the WQ-project and was in between the scores of the two organic flocks. Scores for skin lesions were much lower than in the WQ-project, meaning that hardly any skin damage was found.

In general one can conclude that the results of the Rondeel™ were better than the average of the 22 WQ-flocks. The scores of the non-trimmed hens were in line with the two organic flocks.

Discussion and Conclusions

One should realize that the results are only from one flock in one house with a lot of attention from all involved parties. No general conclusions can therefore be drawn concerning the results in general in Rondeel™ houses. Also this first Rondeel™ flock had only partly non beak trimmed hens, whereas the next flocks will all be non-beak trimmed. This will increase the risk of feather pecking and cannibalism. However, these first results are very promising. The non-trimmed birds did not perform a lot of pecking behaviour despite the high levels of light. Special attention needs to be paid to the cleaning of the artificial grass mat. In the second Rondeel™ house a machine is being used to frequently clean the turf. At the moment it seems this will work successfully.

The Rondeel™ concept aims to combine issues like animal welfare, environmental care and consumer demand. Although the wooded fringe does not meet the requirements for free range, it does provide the birds with range possibilities, without any risk of predators. Also it is easier to control and disinfect than large areas free range. In cases of infectious diseases and the necessity to lock birds in the henhouse, the day quarters provide more possibilities to keep the birds occupied and to prevent feather pecking than other non-cage systems. Although firm conclusions cannot be drawn based on one flock, the first results in the Rondeel™ are promising and thus so far a success. No major problems have occurred and the hens adapted to the system well and made good use of all facilities. Despite the fact that rearing was not free of feather pecking, no problems in this area were encountered. In fact this flock had better feather cover than the average seen in flocks of similar age.

Zusammenfassung

Rondeel™ , ein neues Haltungssystem für Legehennen

In diesem Beitrag wird das Ergebnis einer ursprünglich vom Niederländischen Landwirtschaftsministerium angeregten und von der Firma Rondeel BV zur Praxisreife entwickelten neuen Haltungssystems für Legehennen vorgestellt, das Kriterien der Nachhaltigkeit gerecht wird und Aussicht hat, von anspruchsvollen Verbrauchern akzeptiert zu werden. Der Hennenplatz im Rondeel System ist zwar teurer als im Volierensystem, aber die höheren Produktionskosten je Ei sollen durch gezielte Werbung neutralisiert werden: eine attraktive Verpackung mit dem drei-Sterne-Gütesiegel des Niederländischen Tierschutzbundes (vergleichbar mit Bio-Eiern) und einem Gütesiegel für niedrigen Energieverbrauch des Systems (aufgrund natürlicher Ventilation und anderer energiesparender Maßnahmen). Wie der Name besagt, handelt es sich um einen Rundbau, der 6 Abteile mit insgesamt 30.000 Hennen vorsieht. Das Rondeel System unterscheidet sich von anderen Bodenhaltungssystemen vor allem durch den Rundbau, der große überdachte Flächen mit Tageslicht ermöglicht. Interessenten können sich aus einem Besucherraum in der zweiten Etage und aus einem Besuchergang in einem Abteil davon überzeugen, dass sich die Hennen nach menschlichem Ermessen wohl fühlen. Der erste Durchgang war ermutigend, eine abschließende Bewertung soll erst nach weiteren abgeschlossenen Durchgängen erfolgen.

References

Bos, A.P., K.H.d. Greef, P.W.G. Groot Koerkamp, Y.M.v. Hierden, M.A.W. Kommers, S.M.A.v.d. Kroon, J.A.v. Ruth and E.E.C.v. Wijk, 2004. Houden van hennen : op naar gelukkige kippen, trotse boeren en tevreden burgers. Wageningen – Lelystad, Wageningen UR, ISBN 90-6754-791-3. (Dutch publication; translated title: Keeping of laying hens - towards happy chickens, proud farmers and satisfied citizens).

Bos, A.P. and P.W.G. Groot Koerkamp, 2008. Keeping of laying hens : Development and co-design of new husbandry concepts for laying hens for sustainable egg production. Presentation at 8th European IFSA Symposium (2008-07-09), Clermond-Ferrand, France.

Dierenbescherming, 2011. Beter Leven kenmerk. http://beterleven.dierenbescherming.nl

Niekerk, T.G.C.M. van, & B.F.J. Reuvekamp, 2011. Het Rondeel™ , resultaten gedrag en welzijn eerste legronde. Wageningen UR Livestock Research, rapport 473. 32 pag. (Dutch publication; translated title: The Rondeel™, results behaviour and welfare first laying cycle)

Welfare Quality®, 2009. Welfare Quality® assessment protocol for poultry (broilers, laying hens). Welfare Quality® Consortium, Lelystad, Netherlands. 114 pp.

Thea.vanNiekerk@wur.nl

Waterfowl Production for Food Security

Heinz Pingel, Landsberg, Germany

Introduction

Domestic ducks and geese trace back to two species of waterfowl each: the mallard duck (Anas platyrhynchos) and the muscovy duck (Cairina moschata), the greylag goose (Anser anser) and the swan goose (Anser cygnoides). Ducks and geese were known in ancient China and Egypt, where they had already achieved considerable status at that time. The use of duck and goose meat, eggs as well as feathers and downs has been traced back to very early times in history.

Meat and eggs of waterfowl have high nutritional value as human food. People eat meat of ducks and geese not only because they like the taste, but also for its high nutritional value in terms of optimal composition of essential amino acids as well as favourable composition of fatty acids, with a high percentage of polyunsaturated fatty acids and a favourable ratio of omega 6- to omega 3-fatty acids. Duck and goose meat has a unique flavour and a delicious taste. It is economical, and quick and easy to prepare and serve. Processing of waterfowl eggs as salted eggs, “thousand year eggs” (pidan) and balut has a long tradition in some Asian countries. Waterfowl is also widely used as a source of down feathers.

Feed for ducks and geese is not commonly used for human consumption and there is no strong competition between waterfowl and human nutrition. Waterfowl can utilize cheap feed resources on rural farms. Waterfowl kept on fish ponds increases the amount of plankton as feed for fish. In view of these advantages, we can expect that ducks and geese will become increasingly important for reducing hunger and improve food security for many rural families.

Generally, poultry convert feed to human food efficiently and need only short periods to adjust to market demands. Laying ducks provide a steady source of food. Meat ducks and geese need only a relatively short time to produce edible food.

Development of waterfowl meat production

Millions of people in the world are currently suffering from starvation or malnutrition. Can waterfowl production contribute to the improvement of nutritional standards and food security of a growing world population? Especially in countries of Eastern and Southern Asia, significant amounts of meat and eggs are produced from ducks and geese and are important for the economy of these countries. The development of waterfowl production since 1991 is shown in the following table 1.

Table 1: Development of global waterfowl meat production (million tons) (FAOSTAT 2011)

	1991	2001	2009
Total Poultry meat	43.1	71.5	92.0
Duck meat	1.33	2.98	3.81
Pct. of total poultry	3.09	4.16	4.14
Goose meat	0.77	1.91	2.47
Pct. of total poultry	1.78	2.67	2.68

The share of duck and goose meat of total poultry meat production increased from 4.87 % in 1991 to 6.83 % in 2001 and 6.82 % in 2009.

Although ducks and geese are well known all over the world, their economic importance and contribution to food security varies considerably between continents and countries. To show the role of waterfowl meat and eggs for food security, we consider the changes of total and per capita production from 1991 to 2007. Especially the change in per capita production characterizes the role in the actual contribution for food security, because it takes the growing human population into account. Tables 2 and 3 will demonstrate the contribution of each continent to global duck and goose meat production. Asia is the leading continent in duck meat production with a share of 82.2 %, followed by Europe with 12.4 %. Asia has also the highest increase of total and of per capita duck meat. Almost 10 per cent of poultry meat in Asia is produced by ducks compared with 4.1 % in the world. Duck meat production in Africa and Latin America is neglible.

Table 2: Duck meat production per continent between 1991 and 2007 (Calculations based on FAOSTAT data, 2009).

	Total 2007 1000 t	Relative to 1991 %	Duck per cap. g	Relative to 1991 %	Share of poultry %	Relative to 1991 %
World Total	3,580	269	540	215	4.09	133
Asia	2,942	308	733	244	9.68	112
Europe	445	194	606	192	3.21	165
North America	91	191	270	169	0.43	110
Africa	58	127	60	83	1.60	70
Latin America	38	84	66	64	0.21	28
Oceania	11	238	320	180	1.09	114

Also for goose meat the regional pattern varies considerably (Table 3).

Table 3: Goose meat production per continent between 1991 and 2007 (Calculations based on FAOSTAT data, 2009).

	Total Goose 1000 t	Relative to 1991 %	Goose per cap. g	Relative to 1991 %	Share of poultry %	Relative to 1991 %
World	2,230	290	336	233	2.54	143
Asia	2,104	323	525	256	6.92	117
Europe	72	90	97	88	0.52	75
Africa	56	147	59	97	1.57	82
Latin America	1.03	112	1.8	86	0.006	40
North America	0.90	106	2.7	90	0.004	57
Oceania	0.12	150	3.4	113	0.012	75

With 94 % of total goose meat production, Asia accounts for a dominant share of global goose production. Goose production dropped by 10% in Europe between 1991 and 2007, but increased in Asia by 223 % and contributed 6.9 % to total poultry meat. Goose consumption in America and Oceania is very low and has no commercial significance.

Table 4 shows the growth in different Asian countries. China alone has 65 % of the global duck meat, followed by Malaysia, Thailand and Vietnam. With the exception of Thailand and Bangladesh, duck meat production increased in all these countries, especially in Laos, Myanmar and Korea. Malaysia has the highest per capita production with 4.4 kg, followed by Taiwan with 3.4 kg and China with 1.8 kg. Myanmar, Thailand and Republic of Korea have more than 1 kg per capita. The drop in duck meat production in Thailand is apparently the result of Avian Influenza control programs, whereas Bangladesh has a preference for duck eggs. Duck meat accounts for the highest share of total poultry meat in Cambodia (32.5 %), North Korea (25 %), Vietnam and Laos (19 %) and China (15.5 %).

Table 4: Duck meat production in Asian countries between 1991 and 2007 (Calculations based on FAOSTAT data, 2009).

Country	Duck meat 1000 t	Relative to 1991 %	Duck per cap. g	Relative to 1991 %	Share of poultry %	Relative to 1991 %
China	2329	348	1800	310	15.5	104
Malaysia	111	285	4400	200	10.7	118
Thailand	85	88	1300	75	7.9	71
Vietnam	84	210	970	162	19.0	79
Myanmar	74	617	1400	483	9.2	64
India	73	252	70	206	3.2	43
Taiwan[1,2]	62	85	2690	80	9.9	98
Korea Rep.	57	570	1160	504	10.0	322
Indonesia	44	400	190	317	3.6	189
Philippines	31	238	380	181	4.5	180
Bangladesh	14	101	100	77	8.7	51
N. Korea	11	190	440	157	25.0	128
Cambodia	8.3	198	670	140	32.5	135
Laos	4.0	800	610	508	18.7	275

1) TAI (1999), ²) JENG FENG HUANG (2011)

The major non-Asian countries with high duck meat production are listed in Table 5.

Table 5: Duck meat production between 1991 and 2007 in some non-Asian countries (Calculated from FAOSTAT data, 2009).

Country	Duck meat 1000 t	Relative to 1991 %	Duck per cap. g	Relative to 1991 %	Share of poultry %	Relative to 1991 %
France	234	198	3700	179	15.7	222
Germany	56	267	680	262	5.0	125
Hungary	51	165	5200	174	13.5	153
UK	35	152	600	150	2.4	109
Netherland	15	167	915	153	2.2	138
Ukraine[3]	60		1200		24.0	
USA	83	198	290	171	0.4	114
Canada	7.4	145	225	123	0.6	87
Argentina	7.5	129	190	107	0.6	42
Mexico	21	117	200	95	0.8	39
Egypt	39	170	520	88	5.9	55
Madagascar	11	150	550	90	15.3	89
Reunion	3.3	122	4325	96	16.4	73
Australia	10	267	490	188	1.2	120

³) ZAKHATSKY, 1999

The leading country in Europe is France, where Muscovy and Mule ducks are also used for fatty liver production by forced feeding. Hungary has the highest per capita production in the world (5.2 kg) and has a strong tradition as exporter of fatty liver products. In both countries, ducks account for 14-15 % share of poultry meat production. The USA and Australia have also doubled their duck meat production to satisfy the demand of Asian immigrants, but the share of total poultry meat is relatively low due to very high broiler and turkey meat consumption. Remarkable is the high duck meat production in Reunion with 16.4 % share of poultry meat. Egypt and Madagascar are the only two other African countries with appreciable duck meat production.

With regard to geese production China has a share of 93.9% of the world, followed by Ukraine and Egypt. The goose meat production in the world was increased by 293 %. This was caused by the high share of China with a growth to 328 % (Table 6).

Table 6: Development of goose meat production in the top countries between 1991 and 2007 (Calculated based on data of FAOSTAT, 2009).

	Goose meat 1000 t	Relative to 1991 %	Goose per cap. g	Relative to 1991 %	Share of poultry %	Relative to 1991 %
World	2230	290	336	233	2.54	143
China	2092	328	1580	287	13.9	98
Ukraine[3]	97	-	1900			
Egypt	43	148	570	110	6.8	71
Hungary	27	61	2800	67	7.16	57
Poland	19	231	500	238	2.09	88
Taiwan[1,2]	17	57	740	57	2,7	67
Italy	12.8	-	220	-	1.24	-
Madagascar	12.6	137	630	86	17.5	81
Israel	3.4	79	520	57	0.64	29
Iran	2.5	96	30	75	0.17	30
Myanmar	2.5	156	50	125	0.31	16
UK	2.4	77	40	80	0.16	53
Czech Rep.	2.3	-	230	-	3.1	-
France	2.3	33	40	33	0.15	11
Germany	2.1	37	30	50	0.18	17
Turkey	2.0	57	30	50	0.18	21
Ireland	1.2	188	270	147	0.86	134
Canada	0.9	106	270	87	0.07	58
Thailand	0.8	67	12	55	0.07	50
Argentina	0.5	104	40	88	0.045	40

1) TAI, 1999; 2) JENG FENG HUANG, 2011; 3) ZAKHATZKY, 1999

With regard to per capita goose meat production, Hungary leads with 2.8 kg, followed by the Ukraine with 1.9 kg and China with 1.58 kg. Increased production was observed in China, Egypt, Poland, Myanmar and Ireland only. The share of goose meat to poultry meat decreased in all countries, except China and Ireland. Ukraine and Taiwan are missing in FAO-Statistics. Therefore, changes could not be calculated.

The FAO-Statistics rank the top 20 countries in duck and goose meat production as shown in Table 7.

Table 7: Top 20 duck and goose meat producing countries in 2007 (FAOSTAT, 2009)

Duck meat			Goose meat		
Country	Share, %	Prod. Mill. $	Country	Share, %	Prod. Mill. $
World	100	4,485	World	100	4,254
China	65.0	3,028	China	93.9	3,997
France	6.5	303	Egypt	1.88	80.1
Malaysia	3.5	162	Hungary	1.63	69.5
USA	2.4	111	Poland	0.83	35.1
Viet Nam	2.3	109	Madagascar	0.54	24.0
Thailand	2.3	108	France	0,27	11.4
India	2.1	97	Israel	0.15	6.5
Myanmar	1.85	87	Iran	0.11	4.8
South Korea	1.58	74	Myanmar	0.10	4.3
Hungary	1.48	69	UK	0.09	4.0
Germany	1.18	55	Turkey	0.09	3.8
Egypt	1.09	51	Germany	0.08	3.3
UK	1.0	47	Ireland	0.05	2.0
Philippines	0.86	40	Canada	0.04	1.7
Indonesia	0.71	33	Thailand	0.04	1.5
Bangladesh	0.61	29	Bulgaria	0.03	1.3
Mexico	0.57	27	Croatia	0.03	1.1
Poland	0.51	24	Argentina	0.02	1.0
Netherlands	0.35	17	South Africa	0.02	0.9
North Korea	0.31	14	Philippines	0.02	0.7
Top 20, %	96.1			99.9	

The top 20 countries produced 96.1 % duck meat and 99.9 % goose meat of total world production, and represent an estimated value of 4.485 and 4.254 billion US$, respectively. China alone contributes 65 % of global duck production, followed by France, Malaysia, USA, Vietnam and Thailand, and 93.9% of goose production, followed by Egypt, Hungary, Poland and Madagascar.

Development of waterfowl egg production

Processing of duck eggs to produce “salted eggs” and “thousand year eggs” or alkalized eggs has a long tradition in China and other Asian countries. In some countries like Philippines pre-incubated eggs (Balut) are used for consumption. In the other continents waterfowl eggs are used more or less for incubation only.

Between 1991 and 2009 total production of eggs for consumption increased by 74 %, hen eggs by 72 % and “other” eggs (mainly duck eggs) by 102 %.

Table 8: Development of world egg production between 1991 and 2009 (million tons) (FAOSTAT 2011)

World egg production	1991	2001	2009
Total eggs	39.10	56.40	68.0
Chicken eggs	36.53	52.26	62.83
Other eggs	2.57	4.14	5.19
Share of total , %	6.57	7.34	7.63

About 95 % of non-hen eggs were produced in Asia, of which China alone contributed 83.2 %. As shown in Table 8, per capita production increased by 47 %, from 0.47 kg to 0.69 kg.

Table 9: Production of “other” (mainly duck) eggs in Asian countries 1991 and 2009 (Calculations based on FAOSTAT data, 2009).

Country	Total other eggs 1000 t	Relative to 1991 %	Per cap. eggs g	Relative to 1991 %	Share of total eggs %	Relative to 1991 %
World	4,590	178	692	147	7.2	109
Asia	4,354	182	1085	144	11.3	83
China	3,821	204	2899	155	14.9	75
Thailand	310	105	4720	89	36.5	96
Indonesia	208	175	900	138	15.0	63
Bangladesh	76	317	510	232	29.7	108
Philippines	73	133	820	92	12.1	79
Vietnam	70	-	820	-	27.5	-
Taiwan[2]	31	-	1347	-	7.4	
Rep. Korea	28	712	570	633	5.2	577
Myanmar	18	300	330	94	7.0	49
Malaysia	11	110	410	75	2.3	77

[2] JENG FENG HUANG, 2011

The per capita production shows considerable variation. Thailand, Philippines, Myanmar and Malaysia reduced per capita production. China ranked second with 2.9 kg behind Thailand with 4.7 kg per head. The biggest jump made the Republic of Korea with an increase to 712 % for total duck eggs and to 633 % of duck eggs per head. China, Thailand, Indonesia, the Philippines, Bangladesh and

Vietnam account for more than 99 % of the world total production of “other” or duck eggs. In countries like Thailand (36.5 %), Bangladesh (29.7 %) and Vietnam (27.5 %), duck eggs contribute significantly to total egg consumption.

Trade of waterfowl products

The comparison of export and import of duck and goose meat between 2001 and 2007 shows some changes (Table 10). China could increase duck and goose meat export to 141 and 108 %, respectively. The Netherlands doubled duck meat export, but France, Hungary and Thailand reduced duck meat export to 81 %, 66 % and 23 %, respectively. Japan and Hong Kong have been the main importer for duck meat in Asia. In Europe Germany und UK are the main duck meat importer.

Table 10: The leading duck meat exporting and importing countries in 2007 (FAOSTAT, 2009)

Country	Export 1000 t	Country	Import 1000 t
World	123.4	World	127.8
China	30.8	Hong Kong	41.6
Thailand	4.6	Japan	6.6
Netherlands	16.8	Germany	14.9
Hungary	16.1	UK	8.8
France	12.5	Spain	5.4

Table 11 shows the most important countries for export and import of goose meat. The main exporting countries are Poland, China and Hungary, while Germany is the main importing country. Germany imports duck meat mainly from France and The Netherlands, geese from Hungary and Poland. Self-sufficiency of duck and goose meat in Germany is only 60 % and 13 %, respectively.

Table 11: The leading goose meat exporting and importing countries in 2007 (FAOSTAT, 2009)

Country	Export 1000 t	Country	Import 1000 t
World	44.1	World	31.3
Poland	18.0	Germany	20.5
China	14.0		
Hungary	10.6		

In some countries, especially France, Hungary and China, geese and ducks are force-fed to produce fatty livers. Forced feeding utilizes the ability of waterfowl to take in large amounts of feed and to deposit a lot of fat in the liver. This is essential for wild migrating ducks and geese. In France more than 30 million Muscovy and Mule drakes are used for fatty liver production per year. In 2007 France exported 2510 tons fatty liver (Foie Grass), followed by China and Thailand with 712 tons each (FAOSTAT, 2009). In Europe, the practice of forced feeding is opposed by poultry welfare and illegal in several countries.

Waterfowl is also widely used as a source of feathers and downs. They are obtained at the time of slaughter as a valuable by-product. The harvesting of feathers and downs from live ducks and geese during the partial moulting at intervals of about seven weeks can be an additional source of income from fattening geese kept on pastures beyond 22 weeks of age and from breeding or laying ducks and geese in small-scale farms. In 2000 the value of world trade of 55,000 tons downs and feathers was 600 million US$ (WEZYK and CYWA-BENKO, 2002).

Contribution of waterfowl production for food security

Our analysis of available statistics on waterfowl production indicates extreme differences in their importance for food security. Duck and goose meat producers in industrialized countries can focus on seasonal demand for special products to recover the higher production cost, e.g. the Christmas goose or smoked goose breast in Germany and in central Europe and the Peking duck in East Asia. The increasingly popular Asian restaurants in Europe and North America offer a wide range of special dishes and contribute to a growing demand for duck meat. In China and other Asian countries with a high percentage of Chinese people, intensive production of duck meat and duck eggs is expected to increase.

Intensive production systems have been developed during the past 50 years through activities of breeders, nutritionists and specialists for management and health. Fully integrated duck operations have been established, with own parent-stock. Further genetic progress can be expected in feed efficiency, meatiness, egg number, fertility, hatchability and reduced incidence of disorders by selection for “robustness” (HALL, 2006). While producers of waterfowl meat and eggs focus on full utilization of the current genetic potential, primary breeders, nutritionists and management specialists will focus on further improvement of efficiency, with due attention to animal welfare and environmental considerations.

Consumers in developed countries are not only interested in the price and quality of the final product, but also in the manner in which meat is produced. That means that intensive production systems for ducks and geese have to be organized in such a way that the welfare of the birds is not compromised and negative influences on the environment are minimized (RODENBERG *et al.*, 2005). Some people with high income may prefer meat from organic or ecological production systems. Traditional producers of ducks and geese in free range with access to water for bathing can focus on this niche market.

In developing countries, extensive production in small-scale or family farms is common. In some countries of south-east Asia more than 80 % of poultry is kept in small-scale family farms. DINESH *et al.* (2008) described an FAO supported project in five provinces of Cambodia, involving almost 100 duck farms. About 80 % of the ducks were common laying type ducks and about 20 % Muscovy ducks. The ducks are reared on free range and survive mainly by scavenging, but most farmers give extra feed, mainly grain from their own farm. The average flock size in the provinces ranged between 10 and 204. Very few farmers used improved breeds for upgrading the flock. More than 40 % of the farmers hatched the ducklings in their own farm, using a Muscovy duck or a brooding hen. Others bought ducklings from the neighbor or local market. The houses were usually constructed with on-farm material, but 7 % did not provide any shelter. More than 70 % of the farmers did not use veterinary service and vaccination programs. The average egg number per duck was less than 50; the average female body weight between 1.3 and 1.4 kg. After meeting the family requirements, 57 farmers sold surplus eggs and 53 sold growers, drakes and spent ducks either at the local village market or to a local trader.

Extensive waterfowl production in small-scale farms plays a vital role in rural areas in Asian countries for utilization of cheap natural feed resources by scavenging, like insects, worms, snails and snakes. But the productivity under these conditions is low. The availability of low-cost or no-cost feed might compensate the disadvantage of low performance. A supplement of concentrate with minerals and vitamins will be adequate to provide a balanced ration. This is an easy and effective way to increase production and improve food security under scavenging conditions.

As GUE’YE (2009) stated, “Family poultry represent an appropriate system for supplying the fast growing human population with high quality protein and providing additional income to resource-poor small farmers, especially women. Although requiring low levels of inputs (housings, feeds, breeds, vaccines, drugs, equipment and time/attention), family poultry farmers contribute significantly to food security, poverty alleviation and the ecologically sound management of natural resources”

However, small-scale producers are often constrained by limited information, access to appropriate technologies, support services and markets, which could otherwise substantially improve productivity and income generation. Along with these basic problems, diseases like Highly Pathogenic Avian Influenza (HPAI) hurt especially rural duck farmers (DINESH *et.al*, 2008). In view of the significant increase in waterfowl meat and egg demand in recent decades, small-scale farms in south-east Asia could benefit from the application of current knowledge to generate family income from waterfowl production:

- Use of ducklings and goslings of improved genotypes from parent-stock farms.
- Use of concentrate with vitamins and minerals as feed additive for better utilization of scavenger feed to ensure a balanced nutrition. Mold growth in paddy rice, maize and peanuts should be controlled by suitable storage.
- Management should be improved, especially for ducklings and goslings during the first weeks, by providing additional heat, drinking water and protein rich feed.
- Use of veterinary services and vaccination programs to control diseases.
- Extension service supported by radio programs and demonstration farms for basic training and continuing education.

HUQUE (1996) advocated the improvement of small-farmers skill with participation of women. SHELDON (2000) emphasized education and training at all levels, including agricultural extension, full involvement of women at all stages of the development, provision of low-cost credit facilities, and the development of suitable marketing systems, including cooperatives.

Duck farming in most south and south-east Asian countries consists of large numbers of small farms and only few intensive commercial farms. Where integrated waterfowl production has been established, family farms should be included and supported. By introducing a contract purchase and sales system, family farms can be assisted in increasing their production capacity with access to the market. Non-Governmental Organizations (NGOs) can also play a significant role in supporting backyard duck production (PEETHAMBARAN and JALALUDEEN, 2005).

In Africa and Latin America we find extensive areas with similar climatic conditions as in south-east Asia, and it is surprising that we find so little waterfowl in these parts of the world. In most African countries more than 70-80 % of poultry is kept on family farms (SONAIYA, 2007), but the share of waterfowl is low. There is apparently little demand for waterfowl products, duck meat and eggs are seldom found. Perhaps there is a lack of information on the nutritional value of these products. Geese are mostly kept as pets or guards. In Latin America chicken meat production has been increased in recent decades and is much cheaper than duck meat. BONINO and VELEZ (1992) reported that in Argentina farmers have changed from Peking ducks to broiler production because consumers prefer leaner meat and vertically integrated broiler operations can produce poultry meat more efficiently.

Due to their good foraging and reliable brooding behavior, Muscovy ducks are especially suitable for scavenging systems; they also adapt better to hot climate than chickens. The Muscovy duck would be suitable for small–scale rural farmers in Africa and Latin America and could contribute to food security. In rural tropical areas where meat cannot be conserved, ducks provide an excellent protein source for a family for one or two days. The eggs are naturally incubated and the ducklings are reared and protected by the duck mother.

Waterfowl is generally easier to rear than chickens, especially on small family farms in regions with hot and humid climate. Wherever such climatic conditions exist, support for waterfowl production on family farms seems justified to ensure increased productivity and food security.

Summary

The production of waterfowl can contribute to the improvement of the nutritional standards of the human population. Feed for waterfowl is not commonly used for human consumption and there is no strong competition between waterfowl and human nutrition.

In comparison with chickens, ducks and geese play a minor role in production of meat and eggs. But in certain countries of East and South-East Asia ducks and geese produce significant amounts of meat and eggs, with a sharp rise in production during recent decades. Duck meat production increased from 1.3 million tons in 1991 to 3.8 million tons in 2009; geese meat production was 0.76 million tons in 1991 and 2.47 million tons in 2009, and total waterfowl production accounts for 6.8 % of total poultry meat. The largest duck and goose producer is China with 65 % and 94 % of the world production, respectively.

Duck egg consumption has a long tradition in China and South-East Asia with 10-30 % of total egg consumption. Waterfowl is also widely used as source for feathers and downs.

Large-scale production of ducks and geese need more efforts for higher efficiency and for improving product quality by breeding, nutrition and management according to the requirements of animal welfare and environment protection. Family poultry farmers (small-scale production) with low levels of inputs (housings, feed, breeds, vaccines, drugs, equipment and time/attention) contribute significantly to food security, poverty alleviation and ecologically sound management of natural resources. They should have more access to improved breeds, appropriate technologies and support services, which could substantially improve productivity, income and food security. Efficient waterfowl farming requires appropriate disease control, use of strains with high genetic potential and management conditions compatible with natural behaviour and welfare of the birds.

Waterfowl is easier to manage than chickens in regions with hot and humid climate. Under such conditions waterfowl can be preferred as contributor to food security.

Zusammenfassung

Die Wassergeflügelproduktion kann zur Verbesserung der Ernährung der Weltbevölkerung beitragen. Da das Futter für Wassergeflügel kaum für die menschliche Ernährung verwendet wird, ist die Nahrungskonkurrenz zwischen Wassergeflügel und Menschheit von geringer Bedeutung.

Im Vergleich zum Huhn spielen Enten und Gänse nur eine untergeordnete Rolle in der Fleisch- und Eierproduktion. In verschiedenen Ländern Ost- und Südost-Asiens werden jedoch große Mengen an Fleisch und Eiern von Enten und Gänsen erzeugt mit deutlicher Produktionssteigerung in den letzten Jahrzehnten.

Von 1991 bis 2009 wurde die Entenfleischproduktion von 1,3 Mill. t auf 3,8 Mill. t und die Gänsefleischproduktion von 0,76 Mill. t auf 2,47 Mill. t gesteigert. Insgesamt beträgt der Anteil des Wassergeflügels 6,8 % der gesamten Geflügelfleisch-produktion. Der größte Produzent von Enten- und Gänsefleisch ist China, mit 65 % bzw. 94 % Anteil der Weltproduktion.

China und Süd-Ost-Asien haben auch eine lange Tradition im Verzehr von Enteneiern mit 10-30 % Anteil am gesamten Eierverbrauch. Weiterhin wird Wassergeflügel genutzt als Quelle für Federn und Daunen.

Die Produktion von Enten und Gänsen in großen Unternehmen erfordert eine höhere Effizienz und Verbesserung der Produktqualität durch Züchtung, Fütterung und Management unter Berücksichtigung des Wohlbefindens der Tiere und des Umweltschutzes. Kleinproduzenten mit geringem Aufwand hinsichtlich Unterbringung, Futter, Leistungsfähigkeit der Tiere, Krankheitsprophylaxe und Betreuung tragen dennoch zur Sicherung der Ernährung, zur Minderung der Armut und zur ökologischen Nutzung natürlicher Ressourcen bei. Sie sollten aber mehr Zugang zu züchterisch verbesserten Tieren, zu geeigneten Materialien und zu Dienstleistungen haben, um über die Leistungssteigerung das Einkommen und das Niveau der Ernährung verbessern zu können. Eine effiziente Produktion erfordert auch für den Kleinbetrieb eine tierärztliche Betreuung und sachgerechte Beratung, sowie leistungsfähige Tiere und Bedingungen, die mit dem natürlichen Verhalten und dem Wohlbefinden der Tiere vereinbar sind.

Wassergeflügel ist in feucht-heißen Regionen einfacher zu halten als Landgeflügel und sollte in solchen Gebieten stärker zur Sicherung der Ernährung herangezogen werden.

References

BESSEI, W. and NYVOLD, S (1990) Waterfowl production – some general aspects. Proc. of FAO expert consultation on waterfowl production in Africa. 5-19.

BONINO, M.F. and VELEZ, A.M. (1992) Influence of natural and artificial incubation on the hatchability in the Argentine Muscovy duck eggs. Proc. 9th Int. Symp. on Waterfowl, Pisa-Italy,115-117.

DINESH, M.T., GEERLINGS, Ellen, SCHWABENBAUER, Karin, SÖLKNER, J., THIEME, O., WURZINGER, Maria (2008) Characterization of the domestic duck production systems in Cambodia. FAO-Report, pp 96.

FAO-Statistics 2009 und 2011,

GUE'YE, E.F. (2009) The role of networks in information to family poultry farmers. World's Poultry Science Journal 65, 115-124.

HALL, T. (2006) Breeding for the future. World Poultry 22, 11, 20-21.

HUQUE, Q.M.E. (1996) Improving skills of the small farmers in poultry management. 20th World's Poultry Congress, New Delhi, India, Vol. 1, 47-60.

JENG FENG HUANG, (2011): personal communication

PEETHAMBARAN, P.A. and JALALUDEEN, A. (2005) Performance of Kuttanad ducks under backyard. Proc. of the 3rd World Waterfowl Conf., Guangzhou, 292-294.

RODENBERG, T.B., BRACKE, M.B.M., BERK, J., COOPER, J., FAURE, J.M., GUÉMENÉ, D., GUY, G., HARLANDER, A., JONES, T., KNIERIM, U., KUHNT, K., PINGEL, H., REITER, K., SERVIÈRE, J. AND RUIS, M.A.W. (2005) Welfare of ducks in European duck husbandry systems. World Poultry Science Journal, 61, 633-646.

SHELDON, B.L. (2000) Research and development in 2000: Directions and priorities for the World's Poultry Science Community. Poultry Science 79:147-158.

SONAIYA, E.B. (2007) Family poultry, food security and the impact of HPAI. World's Poultry Science Journal 63, 132-138.

TAI, C., WANG, T. and HUANG, C.C. (1999) Production systems and economic characters in waterfowl. Proceeding of 1st World Waterfowl Conference, Taiwan, 19-31.

WEZYK, S. and CYWA-BENKO, K. (2001) Global trends in waterfowl production and science. Archiv für Geflügelkunde, 66, 48-49.

ZAKHATSKY, N.I. and BONDARENKO, Y.V. (1999) Waterfowl production in Ukraine. Proceedings of 1st World Waterfowl Conference, Taiwan, 450-453.

Author's Address:

Prof. Dr. Heinz Pingel
Institute of Agricultural and Nutritional Science, University of Halle (Saale),
Theodor Lieser Street 11, 06120 Halle (Saale), Germany
Heinz.pingel@landw.uni-halle.de

Prof. Dr. Heinz Pingel
Tornaer Weg 37 a, 06188 Landsberg

Poultry Feed from Genetically Modified Plants

Gerhard Flachowsky
Institute of Animal Nutrition, FLI, Braunschweig, Germany

Summary

The growing World population and limited natural resources require a more efficient utilization and conversion of resources in available phytogenic biomass. In the future there will be a very strong competition for arable land or phytogenic biomass resp. between food/feed, fuel, fibre and further industrial materials as well as areas for settlements and natural conservation. Therefore plant breeding should focus on high yielding plants with low external inputs (Low Input Varieties). Apart from traditional plant breeding, plant biotechnology may contribute to this objective.

Presently, we are in an initial phase of this breeding technology. The cultivation of genetically modified plants (GMP) increased from 1.7 (1996) to about 148 million ha (2010), i.e. about 10% of total arable land. Most modified cultures are soybean, maize, cotton and rapeseed, mainly with increased tolerance against herbicides and insecticides or higher resistance against insects.

Safety and nutritional assessment of food/feed from GMP is urgently necessary. Strict regulations for these assessments exist in many countries. The results of the nutritional studies are summarized in this review. Up to now more than 1 billion ha of GMP have been cultivated all over the world. Nutritional assessment starts with compositional analysis followed by digestion and feeding studies, fates of transgenic DNA and newly expressed proteins. Up to now most studies were done with GM-crops of the 1^{st} generation (plants with input traits; without substantial changes in composition). No unintended effects in composition or contamination (except lower concentration of mycotoxins) and nutritional assessment of feeds from GM-crops of the 1^{st} generation were registered in about 150 scientific studies with food producing animals. Most of the studies were done with broilers. Transgenic DNA and newly expressed proteins did not show other properties as plant DNA or native plant proteins during feed treatments or in the animals.

Other experimental designs for nutritional and safety assessment are recommended for GM-plants with output traits or with substantial changes in composition (plants of the 2^{nd} generation).

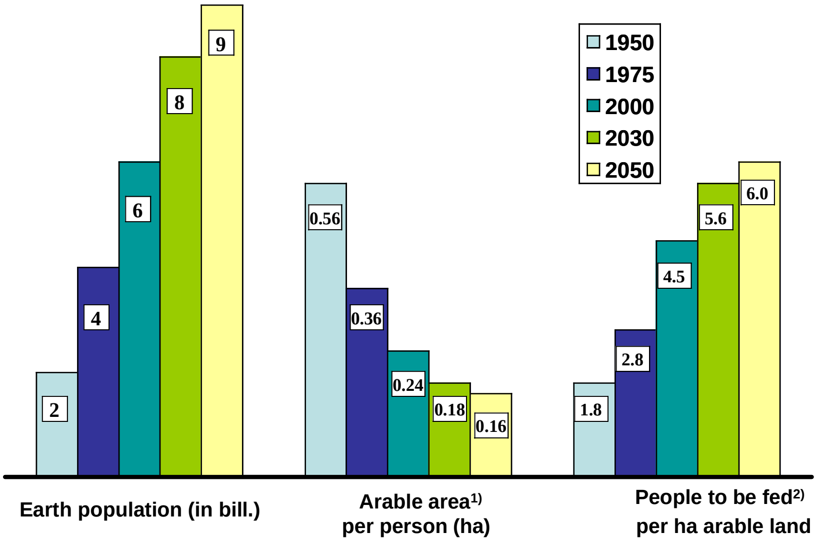
Introduction

The production of high amounts of phytogenic biomass with high quality or high bioavailability of valuable nutrients is one of the most important challenges to meet future demand (SCAR 2008; Flachowsky 2008; The Royal Society 2009). The world population is predicted to grow from presently 7 billion to about 9 billion in 2050, and the demand for food of animal origin may double (Steinfeld *et al.* 2006; Godfray *et al.* 2010), driven by increasing income from productive employment (Keyzer *et al.* 2005) and preference for “Western style of life” in many developing countries. Food of animal origin like poultry meat and eggs contributes to meet the human requirements in amino acids and many trace nutrients. The production of food of animal origin requires vast resources (e.g. Flachowsky 2002, 2011) especially in terms of arable land for feed production. Figure 1 shows the effects of population growth on the availability of arable land per person and the number of people to be fed per ha arable land during the time from 1950 to 2050.

Furthermore, feed/food production causes emissions with greenhouse gas potential such as carbon dioxide (CO_2) from fossil fuel, methane (CH_4) from the enteric fermentation (esp. ruminants) and from the excrement management as well as nitrogen-compounds (NH_3, N_2O) from the protein metabolism in the animals (see DEFRA 2006; Flachowsky and Hachenberg 2009, FAO 2010; Grünberg *et al.* 2010; Leip *et al.* 2010).

Additional arable land will be needed to produce biofuel and material for the industry, competing with land use for feed production. Therefore plant breeding and cultivation are the focal points for global

Figure 1: Population growth, arable land area available per person and number of people to be fed per ha(according to FAO yearbooks)



[1)] about 1.5 bill. ha are available presently
[2)] Number increases when area used to produce renewable resources increases

feed and food security in the years ahead. High yielding plants with low external inputs of limited natural resources should be the main goals of plant breeding in the future. So-called “Low Input Varieties” should use unlimited resources such as sunlight or sun energy, nitrogen (N_2) and CO_2 as plant nutrients from the atmosphere to the highest possible level and should use limited resources such as agricultural area, water, fossil energy, phosphorus etc. as effectively as possible (see Table 1).

The biodiversity of microorganisms, plants and animals offers an extremely large gene pool which has been already used by traditional plant breeding and which could be used more intensively in the future. Apart from traditional breeding, plant biotechnology apparently has a potential to contribute to the objective of “Low Input Varieties”. The cultivation of GMP increased worldwide from about 1.7 (in 1996) to nearly 148 million ha (in 2010), representing about 10% of arable land (James 2011). In % of the global GM area, the most important GM-crops are currently soybeans (60), corn (24), cotton (11) and canola (5) (Figure 2).

Table 1: Potentials to produce phytogenic biomass and their availability per inhabitant with increasing of population (Flachowsky 2010)
↑ Increase, ↓ Decrease, ↔ no important influence)

Plant nutrients in the atmosphere (N_2, CO_2)	↑↔
Sun energy	↔
Agricultural area	↓
Water	↓
Fossil Energy	↓
Mineral plant nutrients	↓
Variation of genetic pool	↑

In addition to previous reviews by Clark and Ipharraguerre (2001; 2004), Aumaitre *et al.* (2002), Chesson and Flachowsky (2003), Flachowsky *et al.* (2005, 2007), CAST (2006), Alexander *et al.* (2007), Flachowsky and Wenk (2010), and Flachowsky (2011), this contribution informs about the present stage of genetic modifications of plants and their nutritional assessment for poultry nutrition.

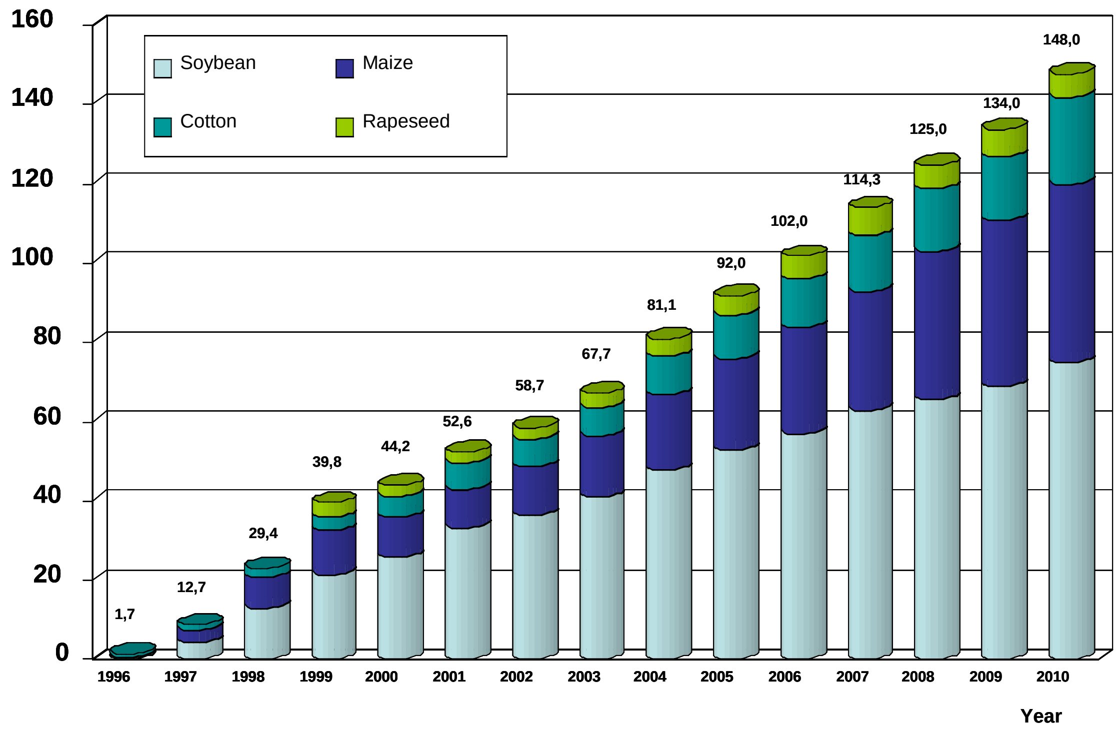
Definitions

The most important objectives for plant breeders are:

- High yields with low external inputs (Low Input Varieties) of limited resources (see Table 1)
- Lower concentrations of anti-nutritive (toxic) substances such as secondary plant products, mycotoxins, toxins from anthropogenic activities or inhibitors (e.g. phytate, lignin)
- Higher concentration of the components determining nutritive value such as nutrient precursors, nutrients, enzymes, prebiotics, essential oils etc.

Presently, most of the Genetically Modified Plants (GMP) are modified for agronomic traits (see Figure 2) such as increased tolerance against insects or higher resistance against insecticides or pesticides. Such plants are characterized by so-called input traits (GMP of the first generation) without substantial changes in composition and/or nutritive value. Such plants can be considered as substantially equivalent to their isogenic counterpart (OECD 1993).

Figure 2: Global area of transgenic crops (James 2011)



GMP of the second generation (with output traits) should contain more nutrients or less anti-nutritive substances. Such plants (feeds) are not substantially different in composition from their counterpart. GMP offer a wide range of application in animal nutrition. Seeds and by-products from food and biofuel industry are the most important feedstuffs for poultry.

Based on the present (public) situation animal nutritionists are to address the following aspects:

- Nutritional and safety assessment of feed from the 1st generation of GMP
- Nutritional and safety assessment of feed from the 2nd generation of GMP
- Influence of GM-feed on animal health and quality of food of animal origin
- Studies on the behaviour/degradation of newly expressed (novel) proteins, foreign DNA, side effects etc.

In Europe the safety of GMP for humans, animals and the environment is assessed by the Panel for Genetically Modified Organisms (GMO-Panel) of the European Food Safety Authority (EFSA, located in Parma; Italy), based on various Guidance documents (e.g. EFSA 2006, 2008). The EU-Commission is responsible for the risk management.

Compositional analysis

Composition analysis of feeds from GMP is the starting point for nutritional assessment. There are different recommendations for compositional analysis of GMP for feed groups (e.g. concentrates, forages etc.) and for animal groups (e.g. ruminants and non-ruminants), as shown for non-ruminants in Table 2. Between 60-100 ingredients of transgenic, isogenic and commercial varieties will be determined to compare the composition of plants and feeds from plants. In addition the newly expressed protein(s) and their degradability (mostly in vitro) will be determined.

No additional animal studies are recommended (EFSA 2006, 2008) if the GMP are substantially equivalent to their isogenic counterpart in the case of GMP of the 1st generation. Nevertheless many feeding studies with feeds from GMP of the 1st generation have been carried out during the last few years. Incidentally, all these studies can contribute substantial information to feed science, which has been dramatically neglected during the last 30 years.

Table 2: Examples for recommendations of compositional analysis of feeds from GMP, isogenic counterparts and commercial varieties for non-ruminants (see ILSI 2007 and OECD 2001-2005)

Crops/Grains/Byproducts	Livestock Type	Analyte[1]
Grain: maize, wheat, barley	Non-ruminants	DM, CP, EE, ADF, NDF, Ca, P, Mg, K, S, Na, Cl, Fe, Cu, Mn, Zn, ash, starch, lysine, methionine, cystine, threonine, tryptophan, isoleucine, arginine, phenylalanine, histidine, leucine, tyrosine, valine, fatty acids, vitamins
Oilseed meals: soybean, linseed, cottonseed, canola meal, full-fat oilseeds	Non-ruminants	DM, CP, EE, ADF, NDF, Ca, P, Mg, K, S, Na, Cl, Fe, Cu, Mn, Zn, ash, starch, lysine, methionine, cystine, threonine, tryptophan, isoleucine, arginine, phenylalanine, histidine, leucine, tyrosine, valine, fatty acids, vitamins

[1] ADF, acid detergent fiber; ADIN, acid detergent insoluble nitrogen; ADL, acid detergent lignin; ADICP, acid detergent insoluble crude protein; CP, crude protein; DM, dry matter; DNDF, digestible neutral detergent fiber; EE, ether extract (crude fat); NDF, neutral detergent fiber; NDICP, neutral detergent insoluble protein; NDIN, neutral detergent insoluble nitrogen, NPN, non-protein nitrogen

Feeding studies

Types of studies

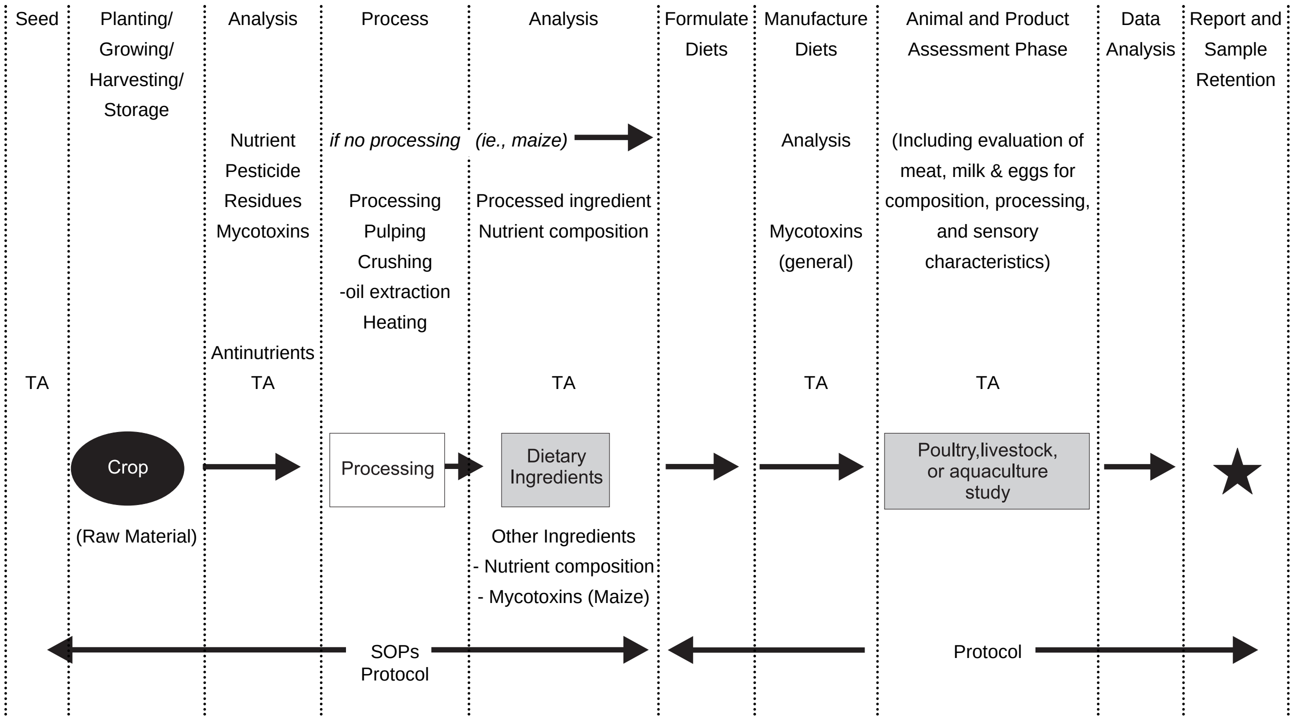
Details of sampling for animal feeding studies, handling of samples and preparation of samples for animal feeding studies are described by ILSI (2007) and are shown in Figure 3.

Feeding studies with laboratory animals and with food producing (target) animals can be done with various objectives to answer different questions (Table 3; see also Flachowsky and Wenk 2010).

Many studies were done with laboratory animal models for toxicity testing of single substances (single dose toxicity testing, repeated dose toxicity testing, reproductive and development toxicity testing, immunotoxicity testing etc.; EFSA 2008). Laboratory animals were also used for the safety (and nutritional) assessment of the whole GM-food and feed (in general 90-day feeding studies to detect unintended effects, sub-chronic animal tests, allergenicity tests; for margins of safety etc.; EFSA 2008; 2011; OECD 1995).

Studies with target animals are more of nutritional concern. The type of study depends on the type of genetic modification in plants, the availability of GM-feed and further factors (see Tables 3 and 4).

Figure 3: Flow diagram for animal feeding studies (by ILSI 2007)



TA = biotech Trait Analysis
SOP = Standard Operating Procedure
[1] Product quality studies may be desirable an a case by case basis, after the animal phase

Table 3: Important types of feeding studies with animals for safety and nutritional assessment of feed from GMP

Type of studies	Laboratory Aninimals	Target Animals
Testing of single substances (28 day study)	X	
90-day rodent feeding study	X	
Long-term feeding study	X	X
Multigeneration feeding study	X	X
Determination of digestibility/availability	X	X
Efficiency study (see Table 4)		X
Tolerance study		X

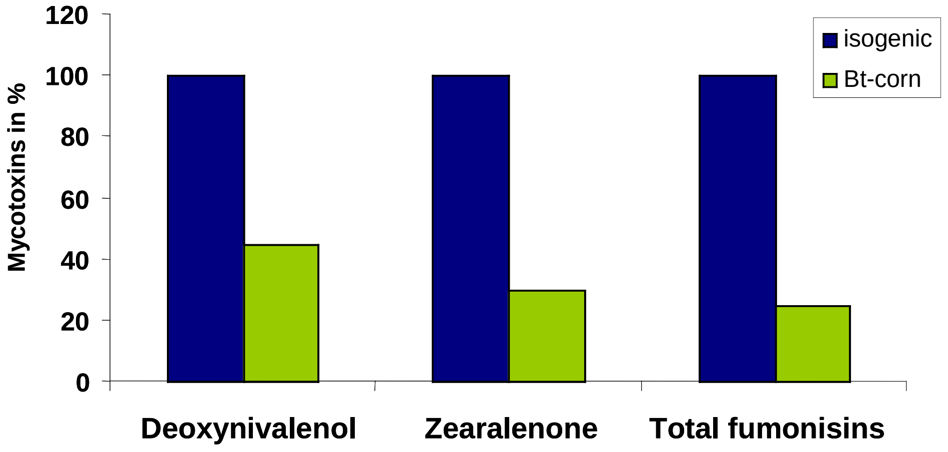
Table 4: Examples of life spans for poultry in efficacy studies
(in days; adapted from ILSI 2003, 2007)

Animal species/categories	Conventional/More intensive	Organic/More extensive
Chickens (broilers)	30 - 42	56 - 84
Turkeys for fattening	56 - 168	70 - 112
Laying hens		
- Growing (Pullets)	120 - 140	140 - 160
- Laying	300 - 360	360 - 720

Results of feeding studies with GMP of the 1st generation

In previous studies the authors compared only the composition and the nutritive value of one feed (e.g. transgenic origin) with another one (e.g. isogenic counterpart) and neglected the considerable biological range described e.g. in the OECD-consensus documents (OECD 2001a, 2001b, 2002a, 2002b, 2003, 2004a, 2004b, 2004c, 2005) or other feed value tables. In general GMP´s of the first generation were essentially equivalent to their isogenic counterparts. Under some cultivation conditions the mycotoxin contamination of GMP feed was lower than in feed from non-GM plants. For example, Bt maize is less severely attacked and weakened by the European corn borer and might have a greater resistance to field infections, particularly to Fusarium fungi, which produce mycotoxins. Evidence of reduced mycotoxin contamination in GMP has been demonstrated in some, but not all studies, as summarized by Flachowsky *et al.* (2005a). In long-term studies, numerous researchers investigated the influence of levels of corn borer infestation of isogenic and Bt hybrids on mycotoxin contamination. Most researchers reported a lower level of mycotoxin contamination in the transgenic hybrids, over a considerable geographical and time range of observations (Figure 4).

Figure 4: Mycotoxins in isogenic (100 %) and Bt-corn (% of isogenic corn; Sources: Bakan *et al.* 2002, Cahagnier and Melcion 2000, Munkvold *et al.* 1999, Pietri and Piva 2000, Reuter *et al.* 2002, Valenta *et al.* 2001)



In early feeding studies with food producing animals, feeds from GMP of the first generation were only compared with their isogenic counterparts to demonstrate equivalence (OECD 1993). Later studies included three or more commercial varieties to measure also the biological range of various measurements. In recent years about 150 feeding trials with food producing animals were reported in peer reviewed papers and summarized in several reviews (see above).

The inclusion of commercial varieties in such studies as recommended by ILSI (2007) and EFSA (2008) may contribute to a more biologically relevant assessment of the results of animal feeding studies (e.g. Lucas et al. 2007; McNaughton et al. 2007; see Table 5).

Table 5: Effect of GM maize DAS-59122-7 (53 to 70% maize in the diet) on broiler performance compared to the near isogenic control and three non-GM hybrids
(McNaughton *et al.*, 2007; 120 broilers per treatment)

Criteria	Control	DAS-59122-7	Confidence interval (95%)
Final 42-day weight (g)	1918	1916	1675 - 2144
Feed: gain (g/g)	1.88	1.87	1.70 - 2.03
Post-chill carcass weight (g/kg live weight)			
♂	708	713	626 - 792
♀	705	707	622 - 791
Relative kidney weight (g/kg body weight)			
♂	20	20	8.5 - 33.2
♀	20	21	8.2 - 33.2
Relative liver weight (g/kg body weight)			
♂	35	36	20.5 - 50.6
♀	34a	37b	19.5 - 51.0

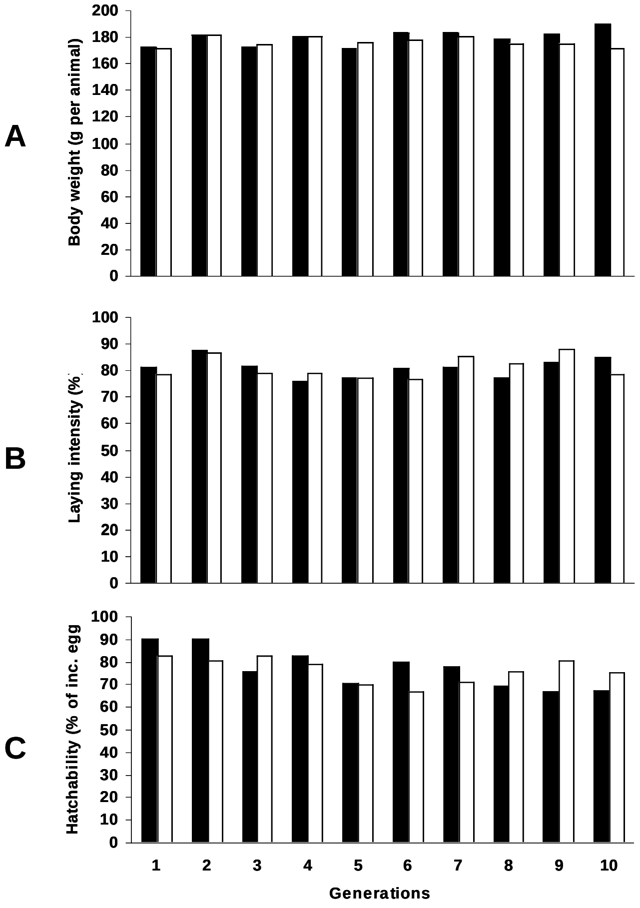
Apart from a statistically significant small increase in relative liver weight ($p<0.05$) of female broilers, no relevant differences between transgenic maize (DAS-59122-7) and its isogenic counterpart were found in this feeding trial. The inclusion of several commercial non-GM-varieties in the field and in animal feeding studies should help to avoid wrong conclusions from experimental data.

Long term feeding studies cover a very long period of the life or the whole lifespan of the animals. Results from such studies and multi-generation studies may include not only the animals´ growth performance, but also their health and reproductive performance (BEETLE 2009) in response to being fed high amounts of GM-feed. In laboratory studies, no negative effects on reproductive traits were found in rodents fed with Bt-corn, glyphosate tolerant soybeans or GM-potatoes compared with their conventional counterparts (Brake and Everson 2004; Kilic and Akay 2008; Rhee *et al.* 2005).

The results of two multi-generation studies at our Institute with laying hens (Halle et al. 2006) and quails (Figure 5) showed no differences in production and reproduction performance between laying quails fed diets containing 50% Bt maize vs. diets containing 50% isogenic maize

Table 6 summarizes results from feeding trials with different poultry species and categories, comparing feeds of GMP of the first generation (plants with input traits) with their isogenic counterparts. The absence of biologically relevant adverse effects in poultry studies is not surprising in view of the compositional equivalence between feeds from isogenic and transgenic plants and the general observation that GMP of the 1st generation are comparable with plants from traditional breeding.

Figure 5: **(A) Body weight of female quails (age: 6 weeks), (B) laying intensity and (C) hatchability of quails fed with isogenic (black columns) and transgenic (Bt, white columns) maize in a 10 generation experiment (Flachowsky *et al.* 2005b)**



Overall means
(Range of generations)

Isogenic	**Transgenic**
180.1 **(172.0 – 190.1)**	**176.9** **(171.9 – 181.7)**
Isogenic	**Transgenic**
81.3 **(75.9 – 87.8)**	**81.4** **(77.1 – 88.4)**
Isogenic	**Transgenic**
77.4 **(66.8 – 90.5)**	**76.7** **(67.0 – 83.2)**

Table 6: **Published comparisons of feeds from first generation GMP (mainly maize, soybeans, cotton, canola) of various constructs with their isogenic counterparts**

Poultry species/category	Number of experiments	Nutritional assessment
Broilers Laying hens Other poultry	48 12 1	No unintended effects in feed composition; only lower mycotoxin concentration in Bt-plants. No significant differences in digestibility of feed and poultry health. No biologically relevant effects on performance of birds and quality of poultry meat or eggs.

Results of feeding studies with GMP of the 2nd generation

During the last few years much attention has been spent to develop GMP, in which significant intended alterations in composition have been achieved in order to enhance the nutritional properties or health benefits. Examples of nutritionally improved GMP are given in Table 7.

Table 7: Examples of GMP with improved characteristics intended to provide nutritional benefits (EFSA 2008)

Plant/Species	Altered characteristic	Transgene/Mechanism
Maize	Improved amino acid profile ↑ Vitamin C ↑ Bioavailable iron ↑ Fumonisin ↓	Various enzymes Dehydroascorbate reductase Ferritin and Phytase De-esterase and de-aminase
Potato	Starch ↑ Solanine ↓	ADP glucose pyrophosphorylase Antisensesterol glycotransferase
Rapeseed	Vitamin E ↑ ß-Carotene ↑ Linoleic acis ↑	Gamma-Tocopheryltransferase Phytoene-Synthase Various desaturases
Rice	ß-Carotene ↑ Iron ↑	Phytoene-Synthase and - desaturase, Lycopene cyclase Ferritin, Metallothionein, Phytase
Soybean	Oleic acid ↑ Stearidonic acid ↑	Suppression of desaturase Various desaturases

New experimental designs are necessary for nutritional assessment of GMP of the 2nd generation (Flachowsky and Böhme 2005; ILSI 2007; EFSA 2008, 2011; Flachowsky and Wenk 2010) to test the significance of higher concentrations of valuable substances such as nutrients or nutrient precursors or lower concentrations of undesirable ingredients. An experimental design to demonstrate the bioavailability of a nutrient precursor is shown in Table 8.

Table 8: Examples for nutritional assessment of 2nd generation GMP (GM-plants with output traits, e.g. higher concentration of the vitamin A precursor ß-carotene (EFSA 2008)

Groups[3]	Composition of diets	Measurements; endpoints
1[1]	Balanced diet with typical amounts of the isogenic counterparts (unsupplemented control)	Depends on genetic modification of plants, e.g.: Concentration of specific substance(s) in target organ (e.g. vit. A in the liver)[2]
2	Balanced diet with adequate amounts of the transgenic counterpart (e.g. rich in ß-carotene)	Further metabolic parameters such as depots in further organs or tissues, activities of enzymes and hormones
3	Diet of Group 1 with ß-carotene supplementation adequate to Group 2	
4	Diet of Group 1 with vitamin A supplementation adequate to expected ß-carotene conversion into vitamin A	

[1] Adequate feed amounts for all animals; depletion phase for all animals before experimentation
[2] Up to the steady state in the specific target organ
[3] Four or more groups fed with commercial/isogenic control feed to find out the biological range of the parameter(s)

Table 9 shows an example to determine the ß-carotene conversion from maize into vitamin A in Mongolian gerbils.

Table 9: Experimental design to assess the conversion of β-carotene into vitamin A in Mongolian gerbils (60% maize in diets; n = 10, depletion phase: 4 weeks, feeding: 8 weeks; Howe and Tanumihardjo 2006)

	Unsupplemented control (Maize poor in carotene)	Carotene rich maize	Control + β-carotene	Control + vitamin A
ß-Carotene (nmol/g)	0	8.8	8.8	4.4
Theoretical retinol intake (nmol/d)	0	106	106	106
Retinol in serum (µmol/l)	1.23 ± 0.20	1.25 ± 0.22	1.23 ± 0.20	1.22 ± 0.16
Retinol in liver (µmol/g)	0.10^a ± 0.04	0.25^b ± 0.15	0.25^b ± 0.08	0.56^c ± 0.15

a, b, c Means with different letters differ ($p < 0.05$)

Adequate studies are necessary to demonstrate the effects of other newly expressed nutrients or higher levels of nutrients such as amino acids (Lucas *et al.* 2007), fatty acids (Meja *et al.* 2010), non-essential substances like enzymes or essential oils (Zhang *et al.* 2000).

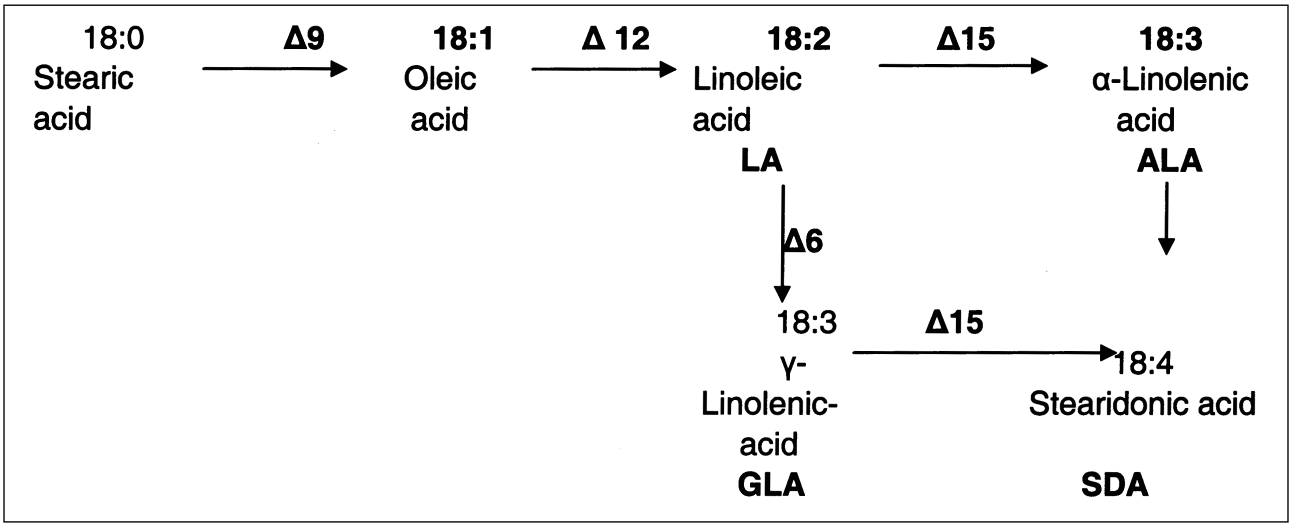
The introduction of new gene fragments may trigger the expression of new substances, which were never before in such plants. A recent example is the introduction of genes which express two desaturases in soybeans with the consequence to synthesize C18:4 n-3 octadecatetraenoic acid, also known as stearidonic acid (SDA; see Figure 6). This long-chain omega-3 fatty acid is one of the precursors for the formation of the long chain omega-3 polyunsaturated fatty acids 20:5 n-3 eicosapentaenoic acid (EPA) and 22:6 n-3 docosahexaenoic acid (DHA) which are essential for human and animal nutrition and have potential health benefits (Gebauer *et al.* 2006, Ursin 2003; Harris *et al.* 2008, Whelan *et al.* 2009).

The SDA-content of such soybean oil may vary between 20 and 30%. Rymer *et al.* (2011) added 45 (grower) and 50g (finisher) soybean oil containing 24% SDA to broiler feed and confirmed results from lactating cows (Bernal-Santos et al. 2010): increased concentration of SDA, EPA and DHA in various meat samples, compared to conventional soybean oil. Even higher EPA and DHA concentrations were achieved with fish oil supplementation, but the fishy taste was not acceptable. Gibbs *et al.* (2010) suggested the introduction of SDA in broiler feed as a possibility to increase the long-chain n-3 PUFA intake of humans.

Fate of transgenic DNA and newly expressed proteins

The intake of feeds from GMP results in the ingestion of transgenic DNA and newly expressed protein(s). Several studies were conducted to trace their fate during food/feed processing and when passing through the gastrointestinal tract of animals, and the extent to which transgenes or their products may be incorporated into animal tissues. Table 10 shows the influence of various processing conditions on some DNA fragments of rapeseed. Higher temperatures and extraction contributed to the degradation of DNA fragments. There is agreement among authors (Mazza *et al.* 2005, Sharma *et al.* 2006, Alexander *et al.* 2007) that recombinant DNA would be processed during feed treatment (ensiling, extraction etc.; see Table 10) and in the gut in the same manner as genetic material from endogenous feed, as shown in feeding studies with non-ruminants at our Institute (see Table 11) and

Figure 6: **Synthesis of Stearidonic acid (C18:4n) in genetically modified soybeans and the effects of various desaturases (from Ursin 2003 und Whelan 2009)**



several other institutions. Small DNA fragments from isogenic and transgenic plants could be detected in blood, spleen, liver and kidney (Mazza *et al.* 2005).

Table 10: **Processing of rapeseed for oil production and DNA fragments determined in final products of isogenic (i) and transgenic (t) rapeseed (Berger *et al.* 2003)**

Treatment		1	2	3	4
Processing		Crushing	Crushing	Crushing	Crushing
		-	-	Conditioning (96°C, 20 min)	Conditioning (103 - 111°C, 30 min)
		Pressing (69°C)	Pressing (95°C)	Pressing (95°C)	Pressing (95°C)
		-	Extraction	Extraction	Extraction
		-	Desolventizing-Toasting (105°C)	Desolventizing-Toasting (105°C)	Desolventizing-Toasting (105°C)
Rape-final products					
Determined DNA-fragments (bp)					
21000 bp (intact DNA)	i t	+ +	- -	- -	- -
248 bp	i	+	+	+	-
970 bp	i	+	-	-	-
194 bp	t	+	+	-	+
680 bp	t	+	-	-	-
1003 bp	t	+	-	-	-

+ detected, - not detected

Table 11: Studies of the Institute of Animal Nutrition, FLI, on transfer of DNA fragments in food producing animals

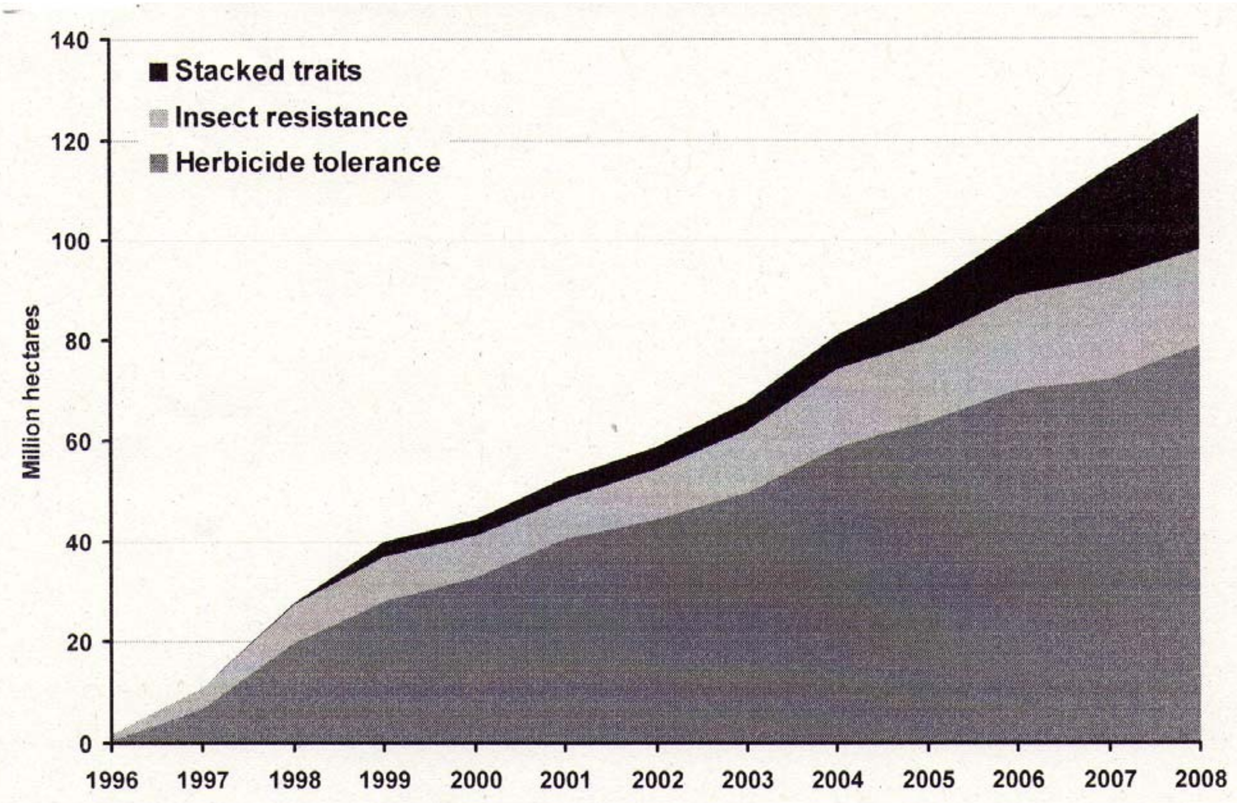
DNA source	Animal species	Results		
		Detection of transgenic DNA	Detection of “foreign” nontransgenic DNA	References
Bt-maize-grain and silage	Broilers Layers Growing bulls Dairy cows	No transgenic DNA in animal tissues	Plant DNA fragments in muscle, liver, spleen, kidneys of broilers and layers, not in blood, muscle, liver, spleen, kidneys of growing bulls, in eggs and feces of broilers and layers and in feces of dairy cows	Einspanier et al. (2001)
Bt-maize-grain	Pigs	Transgenic DNA fragments up to 48 hrs up to the rectum, not in blood, organs and tissues	Plant DNA fragments in the gastrointestinal tract, in blood, organs and tissues	Reuter and Alrich (2003)
Bt-maize-grain	Broilers	Transgenic DNA in the gastrointestinal tract, no transgenic DNA in blood, organs and tissues	Plant DNA fragments in the gastrointestinal tract, in blood, organs and tissues	Tony et al. (2003)
Bt-maize-grain	Quails (10 generations)	Transgenic DNA fragments (211 bp) in the stomach and whole gastrointestinal tract, no transgenic DNA fragments in muscle, liver, stomach, spleen, kidney, heart and eggs	Plant DNA fragments in the gastrointestinal tract	Flachowsky et al. (2005)
Bt-potato	Broilers	No transgenic DNA in muscle, liver, kidney and spleen	Plant DNA fragments in muscle, liver, kidney and spleen till 8 h after feeding	El Sanhoty (2004)
Gt-soybeans	Pigs	No transgenic DNA in muscle, liver, kidney and spleen	Plant DNA fragments in the gastrointestinal tract	Aulrich et al. (2002)
Inulin-potato-silage	Pigs	Transgenic DNA fragment (104 bp) in the stomach, no transgenic DNA fragments in animal tissues	Plant DNA fragments in the gastrointestinal tract, no plant DNA fragments in animal tissues	Broll et al. (2005)

Newly expressed proteins show similar chemical and physiological properties, including microbial and enzymatic degradation (Hammond 2008), as native plant proteins (Alexander *et al.* 2007).

Future tendencies

Presently many GMP containing stack events are being developed and already in cultivation (Figure 7). That means for example, the plants are resistant against insects and tolerant against insecticides. There are already plants in the pipeline containing up to eight stacks. In the future we may expect GM-plants with changed composition (2^{nd} generation of GMP), more resistant against biotic and abiotic stressors such as drought and saline soils and more efficient in using limited natural resources (Low Input Varieties; see Table 12).

Figure 7: Global area cultivated with the main GM traits



Source: Based on data from James (2008 & previous years).

Table 12: Present situation and future tendencies in global cultivation of GMP (Stein and Rodriguez-Cerezo, 2009)

Trait category	Commercial in 2008	Commercial pipeline	Regulatory pipeline	Advanced development	Total by 2015
Insect resistance	21	3	11	22	57
Herbicide tolerance	10	4	5	13	32
Crop composition	0	1	5	10	16
Virus resistance	5	0	2	3	10
Abiotic stress tolerance	0	0	0	5	5
Disease resistance	0	0	1	3	4
Nematode resistance	0	0	0	1	1
Fungus resistance	0	0	0	1	1
Other	2	0	0	11	13

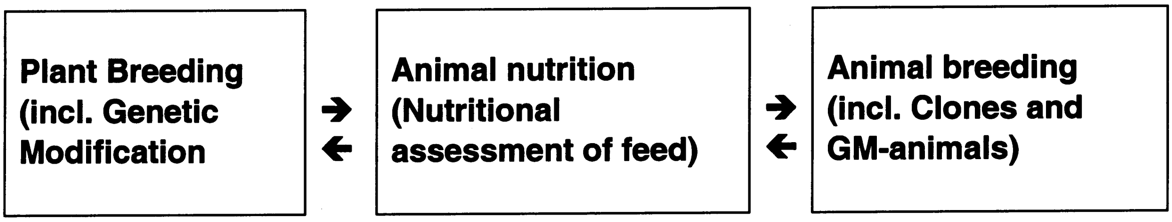
Note: The number of trails can exceed the number of GM crops

Conclusions

“Green” biotechnology should be considered as a method of plant breeding. Presently, the breeders improve resistance and tolerance of plants against insects, herbicides and/or insecticides (plants of the 1st generation) or influence the composition of GMP by increasing valuable nutrients and/or decreasing anti-nutritive substances (plants of the 2nd generation). Many new developments, including changes in composition, are in the pipeline by different companies. Furthermore, GMP´s are being developed to improve their agronomic properties such as drought resistance and salt tolerance (abiotic stressors; see Table 12).

Assessing the nutritive value and the safety of feeds from plant breeding and dealing with GM-animals are real challenges for animal nutritionists in the future (Figure 8). Various types of studies are necessary to answer all the questions and to contribute to a better public acceptance of such plants and animals (see Tables 3, 4, 8 and 9).

Figure 8: Animal nutrition (nutritional assessment of feeds) between plant and animal breeding



Presently, 10% of the global arable land is cultivated with GM-plants of the first generation, which have been tested in about 150 feeding studies with food producing animals.

No biologically relevant effects have been described in peer reviewed papers where the authors compared feed from GMP with their isogenic counterpart and commercial varieties if fed to broilers or other food producing animals.

GMP for more efficient use of limited resources such as water, arable land, fertilizers etc. are under development (see Table 12), but not yet in cultivation. Development of such plants is a real challenge for plant breeders all over the world for substantial contributions to global food security (Table 13). Safety and nutritional assessment of GMP and feeds from GMP are a substantial prerequisite for feeding such products to food producing animals and for a better acceptance in the society.

Table 13: Assessment of present modifications of plants from the view of food safety and food security

Objectives	Present significance	Contributions to	
		Food safety	Global food security
More resistant against herbicides	⇑ ⇑ ⇑	⇑	⇑
More resistant against insects etc. (e.g. Europ. corn borer)	⇑ ⇑	⇑	⇑
More valuable ingredients	⇑	~	(⇑)
Less undesirable ingredients	(⇑)	⇑ ⇑	⇑
More efficient use of resources (water etc.)	(⇑)	⇑	⇑ ⇑ ⇑

⇑ ⇑ ⇑	extremely high
⇑ ⇑	very high
⇑	high
~	not important

Zusammenfassung

Geflügelfutter aus gentechnisch veränderten Pflanzen

Der Anbau von gentechnisch veränderten Pflanzen (GMP) stieg weltweit von 1.7 (1996) auf etwa 148 Mio. ha (2010) an, was etwa 10% der global verfügbaren Ackerfläche entspricht. Die wichtigsten angebauten Kulturen sind Sojabohnen, Mais, Baumwolle und Raps. Sie sind überwiegend tolerant gegen Pflanzenschutzmittel oder resistent gegen Insekten. Zur ernährungsphysiologischen und Sicherheitsbewertung von Futtermitteln aus GMP existieren in verschiedenen Ländern Richtlinien.

Die ernährungsphysiologische Bewertung beginnt mit der Analyse der Inhaltsstoffe. Verdauungs- und Fütterungsversuche, vor allem mit Geflügel (Broiler), schließen sich an. Studien wurden auch zum Abbau der Erbsubstanz (DNA) sowie der neu ausgeprägten Proteine durchgeführt. Bisher wurden die meisten Versuche mit Futtermitteln aus Pflanzen durchgeführt, die keine wesentlichen Veränderungen in den Inhaltsstoffen aufwiesen (Pflanzen der ersten Generation).

Die Untersuchungen zeigten keine wesentlichen Unterschiede in der Zusammensetzung sowie im ernährungsphysiologischen Wert von gentechnisch veränderten Pflanzen der ersten Generation im Vergleich zu isogenen Ausgangsvarianten (außer einem geringeren Gehalt an Mykotoxinen). Die transgene DNA und die neu ausgeprägten Proteine zeigten bei der Futteraufbereitung und im Tier kein anderes Verhalten als native Pflanzen-DNA und Proteine.

Andere Versuchsansätze sind zur ernährungsphysiologischen und Sicherheitsbewertung von Futtermitteln aus Pflanzen mit substantiellen Veränderungen (GMP der 2. Generation) erforderlich.

References

Alexander T.W., Reuter T., Aulrich K., Sharma R., Okine E. K., Dixon W.T., McAllister T.A. (2007): A review of the detection and fate of novel plant molecules derived from biotechnology in livestock production. Anim. Feed Sci. Technol. 133: 31-62.

Aulrich, K., Reuter, T., Flachowsky, G. (2002): The fate of foreign DNA in farm animals fed with genetically modified plants. Proc. Soc. Nutr. Physiol. 11: 187-188.

Aumaitre A., Aulrich K., Chesson, A., Flachowsky, G., Piva, G. (2002): New feeds from genetically modified plants: Substantial equivalence, nutritional equivalence, digestibility, and safety for animals and the food chain. Livest. Prod. Sci., 74, 223-238.

Bakan, B., Melcion, D., Richard-Molrad, D., Cahagnier, B. (2002): Fungal growth and fusarium mycotoxin content in isogenic traditional maize and genetically modified maize grown in France and Spain. J. Agric. Food Chem. 50: 728-731.

BEETLE (2009): Long-term effects of genetically modified (GM) crops on health and the environment (including biodiversity). Executive Summary and Main Report. Federal Office of Consumer Protection and Food Safety (BVL), Berlin, 132 p., + 6 Annexes

Berger, B., Aulrich, K., Fleck, G., Flachowsky, G. (2003): Influence of processing of isogenic and transgenic rapeseed on DNA-degradation. Proc.Soc.Nutr.Physiol. 12: 108 (Abstract)

Bernal-Santos B., O´Donell S.M., Vicini J.L., Hartnell G.F., Bauman D.E. (2010): Hot topic: Enhancing omega-3 fatty acids in milk fat of dairy cows by using stearidonic acid-enriched soybean oil from genetically modified soybeans. J.Dairy Sci. 93: 32-37.

Brake, D.E., Everson, D.P. (2004): A generational study of glyphosate-tolerant soybeans on mouse fetal, postnatal and adult testicular development. Food Chem. Toxicol. 42: 29-36.

Broll, H., Zagon, J., Butschke, A., Leffke, A., Spiegelberg, A., Böhme, H., Flachowsky, G. (2005): The fate of DNA of transgenic inulin synthesizing potatoes in pigs. J. Anim. Feed Sci. 14, Suppl. 1: 337-340.

Cahagnier, B., Melcion, D. (2000): Mycotoxins de Fusarium dans les mais – grains a la recolte: relation entre la presence d'insects (pyrale, sesamie) et la teneur en mycotoxins. Proc. 6th Int.. Feed Proc. Conf., 27-28 November, Piacenca: 237-249.

CAST (2006): Safety of meat, milk, and eggs from animals fed crops derived from modern biotechnology. No 34, 8 p.

Chesson, A., Flachowsky, G. (2003): Transgenic plants in poultry nutrition. World´s Poultry Sci. J. 59: 201-208.

Clark, J.H., Ipharraguerre, I.R. (2001) Livestock performance: Feeding biotech crops. J. Dairy Sci. 84: Suppl. E9-E18, 237-249.

Clark, J.,H., Ipharraguerre I.,R. (2004): Biotechnology crops as feeds for livestock. In Agricultural Biotechnology challenges and Prospects by M.K. Balgat *et al.* (eds.), American Chem. Soc., Washington D.C., 177-198.

DEFRA (2006): Dtermination the environmental burdens and resource use in the production of agriculture and horticulture commodities. Defra project report 205, Cranfield, Univ. Silsoe Inst., http://www.cranfield.ac.uk.

EFSA (2006): Guidance document of the Scientific Panel on Genetically Modified Organisms for the risk assessment of genetically modified plants and derived food and feed. EFSA Journal 99, 1-100.

EFSA (2008): Safety and nutritional assessment of GM plant derived food and feed. The role of animal feeding trials. Food and Chemical Toxicology 46, 2-70.

EFSA (2011): Guidance on the safety assessment of genetically modified animal-derived food and feed (in preparation)

Einspanier, R., Klotz, A., Kraft, J., Aulrich, K., Poser, R., Schwägele, F., Jahreis, G., Flachowsky, G. (2001): The fate of forage plant DNA in farm animals:

A collaborative case-study investigating cattle and chicken fed recombinant plant material. Eur. Food Res. Technol., 212: 129-134.

El Sanhoty, R.M.E.S. (2004): Quality control for food produced by genetic engineering. Diss., TU Berlin, 155 pp.

EU (2000): Weißbuch der Lebensmittelsicherheit. Brüssel, 12.01.2000, ISSN 0254-1467, 66 S.

FAO (2010): Greenhouse gas emissions from the daity sector. A life cycle Assessment, Food and Agriculture Organisation of the United Nations. Rome, 90 p.

Flachowsky G. (2008): What do animal nutritionists expect from plant breeding? Outlook on Agriculture. 37: 95-103.

Flachowsky, G. (2010): Global food security: Is there any solution? (in German), NovoArgumente 105: 64-68.

Flachowsky, G. (2011): Feed from genetically modified plants in poultry nutrition. Proc. 18th European Symp. on Poultry, 31.10.-04.11.2011; Cesme/Izmir; Turkey, (in press).

Flachowsky G., Aulrich K., Böhme H., Halle I. (2007): Studies on feeds from genetically modified plants (GMP) Contributions to nutritional and safety assessment. Animal Feed Science Technology 133: 2-30.

Flachowsky G., Böhme H. (2005): Proposals for nutritional assessments of feed from genetically modified plants. J. Anim. Feed Sci. 14: 49-70.

Flachowsky G., Chesson A., Aulrich K. (2005): Animal nutrition with feeds from genetically modified plants. Archiv Anim. Nutr. 59: 1-40.

Flachowsky, G., Hachenberg, S. (2009): CO_2-footprints for food of animal origin – Present stage and open questions. J. Consumer Prot. and Food Safety 4, 190-198.

Flachowsky, G., Halle, I., Aulrich, K. (2005b): Long term feeding of Bt-corn - a ten generation study with quails. Arch. Anim. Nutr. 59: 449-451.

Flachowsky G., Wenk C. (2010) The role of animal feeding trials for nutritional and safety assessment of feeds from genetically modified plants – Present stage and future challenges Journal Animal Feed Sciences 19: 149-170.

FSANS (2007) The role of animal feeding studies in the safety assessment of genetically modified foods. Rep. Workshop of Food Standards Australia New Zealand, 15th June 2007, Canberra, 19p.

Gebauer S.K., Psota T.L., Harris W.S., Kris-Etherton P.M. (2006) n-3 Fatty acid recommendations and food sources to achieve essentiality and cardiovascular benefits. American Journal Clinical Nutrition 83(Suppl.) 1526S-1535S.

Gibbs, R.A., Rymer, C., Givens, D.I. (2010): Long-chain n-3 PUFA intakes in the UK and the potential of a chicken meat prototype to increase them. Proc. Nutr. Soc. 69, 144-155.

Godfray, H.C., Beddington, J.R., Crute, I.R.,, Haddad, L., Wawrence, D., Muir, J., Pretty, J., Robinson, S., Thomas, S.M., Toulmin, C. (2010): Food security: The challenge of feeding 9 billion people. Sci. 327: 812-818.

Grünberg, J., Nieberg, H., Schmidt, T. (2010): Treibhausgasbilanzierung von Lebensmitteln (Carbon Footprints): Überblick und kritische Reflektion. Landbauforschung – vTI Agriculture and Forestry Research 60, 63-70.

Halle, I., Aulrich, K., Flachowsky, G. (2006): Four generatios feeding of GMO-corn to laying hens. Proc. Soc. Nutr. Physiol. 15: 114 (Abstr.).

Harris W.S., Lemke S.L., Hansen S.N., Goldstein D.A., DiRienzo M.A.,Su H., Nemet M.A., Taylor M.L., Ahmed G., George C. (2008): Stearidonic acid-enhanced soybean oil increased the omega-3 index, an emerging cardiovascular risk marker. Lipds 43, 805-811.

Howe J.A., Tanumihardjo S.A., (2006): Carotenoid-biofortified maize maintains adequate vitamin A status in Mongolian Gerbils. J. Nutr. 136, 2562-2567.

ILSI (2003): Best practices for the conduct of animal studies to evaluate crops genetically modified for input traits. International Life Sciences Institute, Washington, D.C. 62 p. http//www.ilsi.org/file/bestpracticescas.

ILSI (2007): Best practices for the conduct of animal studies to evaluate crops genetically modified for output traits. Int. Life Sci. Inst., Washington D.C.

James C. (2011): Global status of commercialised transgenic crops: 2009. ISAAA; Ithaca NY, http://www.isaaa.org.

Keyzer, M.A., Merbis, M.D., Pavel, L.F.P.W. van Wesenbeck C.F.A. (2005): Diets shifts towards meat and the effect on cereal use: Can we feed the animals in 2030 Ecological Economics 55: 187-202.

Kilic, A., Akay, M.T. (2008): A three generation study with genetically modified Bt-corn in rats: Biochemical and histopathological investigation. Food Chem. Toxicol. 46, 1164-1170.

Kok, E.J., Keijer, J., Kleter, G.A., Kuiper, H.A. (2008): Comparative safety assessment of plant-derived feeds. Reg. Toxicol.Pharmacol. 50: 98-113.

Kok, E., Kuiper, H. (2003): Comperative safety assessment of biotech crops. Trends in Biotechnology 21: 439-444.

Leip, A., Weiss, F., Wasenaar, T., Perez, I., Fellmann, T., Loudjami, P., Tuiello, F., Grandgirard, D., Monni, S., Biala, K. (2010): Evaluation of the livestock´s sector contribution to the EU greenhouse gas emissions – Final report, JRC, EU.

Lucas, D.M., Taylor, M.L., Hartnell, G.F., Nemeth, M.A., Glenn, K.C., Davis, S.W. (2007): Broiler performance and carcass characteristics when fed diets containing lysine maize (LY038 or LY038xMON 810), control or conventional reference maize. Poultry Sci. 86: 2152-2161.

Mazza, R., Soave, M., Morlacchini, M., Piva, G., Marocco, A. (2005): Assessing the transfer of genetically modified DNA from feed to animal tissues. Transg. Res. 14: 775-784.

McNaughton, I.L., Roberts, M., Rice, D., Smith, B., Hinds, M., Schmidt, J., Locke, M., Bryant, A., Rood, T., Layton, R., Lamb, I., Pelaney, B. (2007): Feeding performance of broiler chickens fed diets containing DAS-59122-7 maize grain compared to diets containing nontransgenic maize grain. Anim. Feed Sci. Technol. 132: 227-239.

Meja, L., Jacobs, C.M., Utterback, P.L., Parsons, C.M., Rice, D., Sanders, C.,Smith, B., Iiams, C., Sauber, T., (2010): Evaluation of the nutritional equivalency of soybean meal with the genetically modified trait DP-3O5423-1 when fed to laying hens. Poultry Sci. 89, 2634-2639.

Munkvold, G.P., Hellmich, R.L., Rice, L.G. (1999): Comparison of Fumonisin concentrations in kernels of transgenic Bt-maize hybrids and nontransgenic hybrids. Plant Disease, 83: 130-138.

OECD (1993): Safety evaluation of foods derived by modern biotechnology. Concepts and principles, OECD Paris, France.

OECD (1995) OECD Guidelines for the testing of chemicals. OECD Cons. Meeting, 02./03Nov.1995, Rome; OECD, Paris, France.

OECD (2001a): Series on the Safety of Novel Foods and Feeds No. 1. Consensus document on key nutrients and key toxicants in low erucic acid rapeseed (canola). OECD, Paris, France.

OECD (2001b): Series on the Safety of Novel Foods and Feeds No. 2: Consensus document on compositional considerations for new varieties of soybean: Key food and feed nutrients and anti-nutrients. OECD, Paris, France.

OECD (2002a): Series on the Safety of Novel Foods and Feeds No. 3: Consensus document on compositional considerations for new varieties of sugar beet: Key food and feed nutrients and anti-nutrients. OECD, Paris, France.

OECD (2002b): Series on the Safety of Novel Food and feed No. 4. Consensus document on compositional considerations for new varieties of potatoes: key food and feed nutrients and anti-nutrients and toxicants. OECD, Paris, France.

OECD (2002c): Series on the Safety of Novel Foods and Feeds No. 5: Consensus document on compositional for new varieties of maize (Zea mays): Key food and feed nutrients and anti-nutrients and secondary metabolites. OECD, Paris, France.

OECD (2003): Series on the Safety of Novel Food and feed No. 7. Consensus Document on Compositional Considerations for New Varieties of Bread Wheat (Triticum aestivum): Key Food and Feed Nutrients, Anti-Nutrients and Toxicants. OECD, Paris, France.

OECD (2004a): Series on the Safety of Novel Food and feed No. 10. Consensus Document on Compositional Considerations for New Varieties of Rice (Oryza sativa): Key Food and Feed Nutrients and Anti-Nutrients. OECD, Paris, France

OECD (2004b): Series on the Safety of Novel food and feed No. 11. Consensus. Document on Compositional Considerations for New Varieties of Cotton (Gossypium hirsutum and Gossypium barbadense): Key Food and Feed Nutrients and Anti-Nutrients. OECD, Paris, France.

OECD (2004c): Series on the Safety of Novel Food and feed No. 12. Consensus Document on Compositional Considerations for New Varieties of Barley (Hordeum vulgare L.): Key Food and Feed Nutrients and Anti-nutrients. OECD, Paris, France.

OECD (2005): Series on the Safety of Novel Food and feed No. 13. Consensus Document on Compositional Considerations for New Varieties of Alfalfa and other Temperate Forage Legumes: Key Feed Nutrients, Anti-nutrients and Secondary Plant Metabolites. OECD, Paris, France.

Pietri, A., Piva, G. (2000): Occurrence and control of mycotoxins in maize grown in Italy. Proc. 6th Internat. Feed Produc. Confer. 27.-28. Nov., Piacenca:226-236.

Reuter, T., Aulrich, K. (2003): Investigations on genetically modified maize (Bt-maize) in pig nutrition: fate of feed ingested foreign DNA in pig bodies. Europ. Food. Res. Technol. 216:185-192.

Rhee, G.S., Cho, D.H., Won, Y.H., Soek, J.H., Kim, S.S., Kwack, S.J., Lee, R.D., Chae, S.Y., Kim, J.W., Lee, B.M., Park, K.L., Choi, K.S. (2005): Multigeneration reproductive and developmental toxicity study of bar gene inserted intogenetically modified potato in rats. J. Toxicol. Environm. Health 68, 2263-2276.

Rymer C., Hartnell G.F.,Givens D.I. (2011): The effect of feeding modified soyabean oil enriched with C18:4n-3 to broilers on the deposition of n-3 fatty acids in chicken meat. Brit. J. Nutr. 105: 866-878.

SCAR (EU Commission – Standing Committee on Agricultural Research; 2008) New challenges for agricultural research. Climate change, rural development, agricultural knowledge systems. The 2nd SCAR Foresight Exercise, Brussels, Dec. 2008, 112p.

Sharma, R., Damgaard, D., Alexander, T.W., Dugan, M.E.R., Aalhus, J.L., Stanford, K., McAllister, T.A. (2006): Detection of transgenic and endogenous plant DNA in digesta and tissues of sheep and pigs fed roundup ready canola meal. J. Agric. Food Chem. 54: 1699-1709.

Stein A.J., Rodriguez-Cerezo E. (2009) The global pipeline of new GM-crops. JRC/ipts, EUR 23496 EN, 102p.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Haan, C. (2006): Livestock´s long shadow, Environmental issues and options. FAO Rome, 406 p.

The Royal Society (2009): Reaping the benefits: Science and the sustainable intensification of global agriculture. RS policy document 11/09, issued Oct. 2009 RS 1608, ISBN: 978-0-85403-784-1.

Tony, M.A., Butschke, A. Broll, A., Zagon, J., Halle, I., Dänicke, S., Schauzu, M., Hafes, H.M., Flachowsky, G. (2003): Safety assessment of Bt 176 maize on broiler nutrition: degradation of maize-DNA and its metabolic fate. Arch. Anim. Nutr. 57: 235-252.

Ursin V.M. (2003): Modification of plant lipids for human health: Development of functional land-based omega-3 fatty acids. Journal Nutrition 133, 4271-4274.

Valenta, H., Dänicke, S., Flachowsky, G., H. Böhme (2001): Comparative study on concentrations of the Fusarium mycotoxins deoxynivalenol and zearalenone in kernels of transgenic Bt-maize hybrids and nontransgenic hybrids, Proc. of the Soc. of Nutr. Physiol. 10: 182 (abstr.)

Whelan J. (2009): Dietary stearidonic acid is a long chain (n-3) polyunsaturated fatty acid with potential health benefits. Journal Nutrition 139, 5-10.

Zhang, Z.B., Kornegay, E.T., Radcliffe, J.S., Denbow, D.M., Veit, H.P., Larson, C.T., (2000): Comparison of genetically engineered microbial and plant phytase in young broilers. Poultry Sci. 79, 709-717.

Author’s address:

Prof. Dr. Gerhard Flachowsky
Institute of Animal Nutrition
Friedrich-Loeffler-Institute (FLI)
Federal Research Institute for Animal Health
Bundesallee 50
38116 Braunschweig, Germany

eMail: gerhard.flachowsky@fli.bund.de

Recommendations for energy and nutrients of layers: a critical review*⁾

Heinz Jeroch, Warmia and Mazury University Olsztyn, Poland

Introduction

The first monograph with recommended energy and nutrient requirements (as percentage or units per kg of diet, amounts required per hen daily) of poultry was published in 1944 by the US National Research Council (NRC). These standards were based on the substantial knowledge available at that time in North America on energy and nutrient requirements of laying hens and other poultry as well as contents (energy, nutrients) of feedstuffs used in poultry diets. The tables were updated in subsequent editions (9th edition published in 1994).

Europe followed in 1963, with recommendations for energy and nutrient requirements, published by the Agricultural Research Council (ARC) in the UK. In Germany, the Committee for the development of energy and nutrient standards published the first recommendations for energy and nutrient requirements of layers and broilers and for the concentration of energy and nutrients in rations in 1999, for fattening turkeys in 2004 (GfE).

As shown in table 1, several national research groups worked on this subject and published recommendations, and H. VOGT of the Poultry Research Center in Celle coordinated a project of the WPSA Working Group Poultry Nutrition to work out recommendations for Europe. Recommendations for minerals were published in 1981 and followed for macro-elements for growing and adult poultry in 1984 and 1985; recommendations for trace elements and vitamins were planned, but never published.

The American monographs on poultry nutrition cover energy and nutrient needs extensively. In his book „The Scientific Feeding of Chickens“, TITUS (1st edition 1941, 4th edition 1961) already lists relevant information on energy and nutrient content in poultry feed. SCOTT, NESHEIM and YOUNG treated energy and nutrient requirements in their book „Nutrition of the Chicken“ (1st edition 1969) in great scientific detail and depth. This tradition is continued in the 4th edition of „Scott`s Nutrition of the Chicken“, edited by LEESON and SUMMERS (2001). H. VOGT (1987) followed the factorial approach and contributed an extensive chapter on energy and nutrient requirements of poultry in „Geflügel“ (SCHOLTYSSEK).

Recommended energy and nutrient contents in whole rations and concentrates have also been published by companies specialized in feed additives (e.g. Evonik), by trade associations (e.g. AWT for amino acids and vitamins) and by primary poultry breeding companies (e.g. Lohmann Tierzucht).

The following discussion refers primarily to recommendations for laying hens published by scientific organisations (table 1) or authors of books. Recommendations are based on the daily nutritional needs of laying hens depending on age and current production, expressed in terms of contents in complete rations.

Scientific recommendations and safety margins

The requirements determined under experimental conditions are not always sufficient in practice, for various reasons listed in table 2, and the rations should be supplemented to provide necessary safety margins. How much to supplement cannot be derived from experimental results and needs experience and judgment on the part of the producer; excessive levels of nutrients may also be detrimental.

---

*⁾ based on an invited paper, presented at the annual meeting of the German WPSA Branch, March 15-16, 2011, at the University of Hohenheim.

Table 1. Recommendations published by scientific organisations

Source	Country	Year	Recommendations for
Agricultural Research Council (ARC)	UK	1975	Chickens, turkeys, ducks, geese
Gesellschaft für Ernährungsphysiologie (GfE)	D	1999	Laying hens, broilers
		2004	Turkeys
Council of Agriculture Taiwan (CAT)	T	1991	Water fowl
Institut National de la Recherche Agronomique (INRA)	F	1981	All poultry species
National Research Council (NRC)	USA	1994	All poultry species
Normenkommission der Forschungskooperation TE	GDR	1983	Laying hens, Broiler breeders
Polish Academy of Sciences (PAN)	PL	2005	All poultry species
World Poultry Science Association (WPSA)	Europe	1984/85	Macro-elements for all poultry species

Table 2. Reasons for recommended additions/allowances to scientifically determined requirements (energy, nutrients)

Energy/nutrients	Reasons why safety additions/ allowances are necessary in practice	Margin added (%)
Metabolisable energy (AMEN)	Variable contents in feed components, Genetic differences in efficiency of conversion, Management conditions, temperature	5-10
Crude protein, Amino-acids	Variable contents in feed components, Differences in ileal (prececal) digestibility, damage of components during processing, antinutritive factors (ANF), differences in utilization, protein bound/ free amino acids	10-15
Macro-elements	Source, differences in digestibility and utilisation, antagonistic effects, age effects, ANF, structure	~10
Trace elements	Variable contents in feed components, form of binding, utilization of trace elements from feed and feed additives, variation in net demand, interactions among trace elements and with other feed components, ANF	10-20
Vitamins, essential fatty acids	Variable contents in feedstuffs, losses, environmental effects, feed effects, antagonists, availability, unspecific recommendation, increasing performance	20-100

Energy requirement and supply

Energy in poultry feed is expressed world-wide (in Germany since the early 1960s) in terms of apparent metabolisable energy, N-corrected (AME_N). Contents of components and complete diets and recommendations for daily intake are commonly expressed in kJ or MJ (occasionally still in kcal).

The energy requirement for laying hens in table 3 has been derived by the factorial method described by GfE (1999). The daily energy needs are the sum of requirements for maintenance and for production. The maintenance requirements are primarily determined by metabolic body mass of the hens. Additional factors are activity (more in barn and free range systems than in cages), ambient temperature, condition of feather cover and genotype.

The energy requirements for production are primarily determined daily egg mass output, body mass increase between sexual maturity and mature weight and regrowth of feathers. Table 3 shows the suggested energy demand from several published sources for layers with 1.8 and 2.2 kg body mass, producing 55 or 60 g egg mass per day.

All recommendations for laying hens in conventional cages, with the exception of the 1975 ARC figures, are in close agreement. The latter assume higher energy requirements for maintenance, which accounts for 60 % of total energy needs, while only 40 % are used for production.

The GfE recommendations assume 10 % and 15 % more maintenance energy for activity in barn egg and free range systems compared to cages, but so far insufficient experimental results are available to confirm these rough figures. Additional energy will also be needed for dissipation of body heat in case the house temperature exceeds the thermo-neutral optimum. This would be a frequent problem in subtropical and tropical regions, occasionally also during hot summers in moderate climate zones like central Europe and therefore justifies more research.

Additional energy is also needed if the ambient temperature drops below 15 °C. The GfE (1999) recommendations assume 7 kJ/kg $W^{0,75}$/d more energy for each °C lower temperature. Loss of feathers has to be compensated with more energy to maintain body temperature, especially in case of induced molting. More experimental results quantifying the actual effect of different degrees of feather loss on energy demand are needed.

Table 3. Recommendations for energy requirements of laying hens at peak production under conditions of thermo-neutral temperature

Source	Live weight kg	AMEN requirement	(MJ/hen/day)
		55 g daily egg mass	60 g daily egg mass
GfE (1999)	1.8	1.28[1]/1,35[2]/1,39[3]	1.33/1.40/1.44
	2.2	1.40/1,49/1,53	1.45/1.53/1.58
ARC (1975)	1.8	1.60	-[4]
	2.2	1.67	-
LEESON and SUMMERS (2001)	1.8	1.22	-
	2.2	1.38	-
NRC (1994)	1.8	1.31	-
	2.2	1.45	-
VOGT (1987)	1.8	1.31	1.35
	2.2	1.39	1.44

[1]cages; [2]barn; [3]free range; [4]no data

The recommendations for optimal energy supply (in AME_N/kg diet) are in reasonable agreement (table 4), with the exception of the ARC (1975) experts, who assumed that laying hens can adjust their daily energy intake by increased feed consumption, provided a minimum of 9.6 MJ/kg feed is assured. Although we agree that hens tend to adjust their feed intake to some degree on the basis of energy content, our own results suggest that 9.6 MJ/kg would be too low for today's highly efficient layers, who are unlikely to increase their feed intake accordingly.

Table 4. Recommendations for energy content of laying hen diets

Based on	Source	MJ AME_N/kg feed (88 % DM)
Scientific experiments	ARC (1975)	min. 9.6
	JEROCH AND DÄNICKE (2010)	approx.11.4
	LARBIER AND LECLERCQ (1994)	11.3-12.1
	LEESON AND SUMMERS (2005)	11.7-12.1
	NRC (1994)	approx.11.9
	PAN (2005)	11,1-11,7
	VOGT (1987)	11.0-11.5 (range 10.5-12.5).
Practical experience	Lohmann Tierzucht	11.4-11.6
	DLG Standards (1992)	10.4-11.4

Adequate energy supply at high ambient temperatures is always a challenge. With increasing temperature, laying hens reduce their daily feed intake and thereby energy and nutrient intake. In older literature it has been suggested to increase energy density at high temperature to compensate for reduced feed intake. At high temperature, when the daily intake is already low, the hens will reduce their intake less in response to increased energy concentration of feed, with the net effect of increased energy intake, as shown in table 5.

The energy concentration of layer diets can be increased by added fat or oil, which has the additional advantage of improved feed structure and reduced metabolic heat production compared to other feed components. While these relationships are commonly understood in commercial feed formulation today, it would be highly desirable to verify the rather old results with modern hybrid layers to quantify the effects and fine-tune recommendations.

Table 5. Effect of feed energy concentration (AMEN) on daily intake of feed and metabolisable energy at different temperatures[1]

Metabolisable Energy MJ/kg feed	18° C		30° C	
	Feed intake g/hen/day	Energy intake MJ/hen/day	Feed intake g/hen/day	Energy intake MJ/hen/day
11.95	127	1.52	107	1.28
12.79	118	1.50	104	1.34
13.58	112	1.52	102	1.38
14.42	106	1.52	101	1.46

[1] PAYNE (1967), quoted in LEESON and SUMMERS (2005)

Crude protein/ amino acid requirements and supply

The protein and amino acid (AA) requirements for laying hens have been the subject of extensive research in the past, based on the factorial method (GfE, 1999). Other estimates of requirements were derived from metabolic studies and performance trials.

As shown in table 6, the AA requirements published by GfE (1999) are in the range of other recommendations. With the exception of tryptophan, the NRC (1994) listed the lowest levels for all AA, while AWT (2000) advocates a higher lysine level than other sources. All figures refer to total amino acids.

Table 6. Daily requirements for crude protein and amino acids for a laying hen with 1.8 kg body mass and 60 g daily egg production

Reference	Crude protein g	Lys mg	Met mg	Met+Cys mg	Thr mg	Trp mg
GfE (1999)	19.8	729	363	635	520	169
LARBIER and LECLERCQ (1994)	17.7	731	342	-	572	177
LEESON and SUMMERS (2001)	17.0	700	370	640	630	150
NRC (1994)	15.0	690	300	580	470	160
VOGT (1987)	20.5	835	405	775	520	170
AWT (2000)	-	880	420	780	575	160

As an alternative to the factorial derivation of AA requirements, the calculations can also be based on the concept of ideal proteins, as described by GRAMZOW (2001) and others. With this approach, only the requirement for a reference amino acid, usually lysine has to be determined, either by the factorial method, in balance trials or in dose-effect feeding trials. Table 7 gives a summary of ideal AA profiles published by different authors; their effects were discussed recently by BREGENDAHL, (2009). From the known relationship to other AA, the requirements for all other AA can then be derived. Current recommendations of Lohmann Tierzucht follow LEMME (2009). Additional research is needed to generate input data in terms of standardized ileal digestibility (KLUTH and RODEHUTSCORD, 2009) to define the ideal AA profile and fine-tune the recommendations for modern laying hens.

Table 7. Ideal amino acid profiles derived by different authors for laying hens

Amino acid	NRC (1994)[2]	JAIS *et al.* (1995)[3]	GfE (1999)[4]	LEESON & SUMMERS (2005)[5]	ROSTAGNO (2005)[6]	BREGEN-DAHL (2009)[7]
Lysine[1]	100	100	100	100	100	100
Methionine	43	44	50	51	50	47
Met+Cystine	84	-	87	88	91	94
Threonine	68	74	72	80	66	77
Tryptophan	23	16	23	21	23	22
Arginine	101	82	91	103	100	<107
Isoleucine	94	76	91	79	83	79
Valine	101	64	100	89	90	93

[1] Lysine = 100% [2] based on total AA requirement [3] based on N-balance [4] based on factorial derivation of gross AA requirements [5] based on total AA requirement of layers at 32–45 weeks of age [6] based on requirements for digestible AA [7] based on requirements for true digestible AA for laying hens with maximal egg mass production at 28–34 weeks of age

When comparing the recommended CP and total AA levels between different sources in table 8, the corresponding feed energy content needs to be kept in mind. The GfE recommendations are based on the results of factorial method and were first calculated for 1 MJ AME_N and then for common energy levels. The levels listed by GfE and NRC (1994) are lower than those from other sources and take no safety limit into account.

For application in practice, about 10 % higher levels should be used (e.g. 6.9 g instead of 6.3 g lysine/kg feed with 11.4 MJ AME_N/kg). Results of a recent trial (HALLE *et al.*, 2005) comparing recommended GfE levels with 15 % higher or lower AA levels are shown in table 9. In this trial, higher concentrations did not improve performance, but lower levels of lysine and methionine had significant negative effects on egg output and feed conversion ratio.

In the past, recommendations were usually expressed in terms of total amino acids. More recently, AWT (2000) and Evonik-Degussa GmbH (LEMME, 2009) suggested to focus on true digestible AA for layers, which differs from the concept of standardized prececal (ileal) digestible amino acids (KLUTH and RODEHUTSCORD, 2009).

Table 8. Recommendations for crude protein and amino acid contents of complete layer feed (88 % DM) during early laying month and peak production

Source	Age or current production	CP g/kg	g/kg					AME_N MJ/kg
			Lys	Met	Met + Cys	Thr	Tryp	
GfE (1999)	60 g egg mass/day	161	6.3	3.1	5.5	4.5	1.5	11.4
ARC (1975)	90 % rate of lay	-	7.5	3.5	4.7	3.6	1.7	-
LEESON & SUMMERS (2005)	18-32 weeks of age	190	8.2	4.3	7.1	6.6	1.7	12.2
NRC (1994)	90 % rate of lay	147	6.7	2.9	5.7	4.6	1.6	11.9
PAN (2005)	>85 % rate of lay white hens	165-175	8.0	3.5	6.8	5.4	1.6	11.5-11.7
	>85 % rate of lay brown hens	155-160	7.2	3.4	6.3	5.1	1.7	11.3-11.5
AWT (2000)	-[1]	160	8.0	3.8	7.1	5.2	1.5	11.9

[1] not specified

Macro-elements requirement and supply

The requirements for macro-elements have been determined with the factorial method, like for energy, crude protein and essential amino acids (GfE, 1999). To calculate adequate phosphorus requirement is difficult, because the digestibility of phytate-P from plants and phytase concentration in plants vary considerably.

The requirement recommendations for this element are currently expressed in terms of available P (aP) or non-phytate-P (NPP), but this is not satisfactory (GfE 1999 und 2004); a new system is suggested, based on “usable” phosphorus.

Table 10 shows requirements derived by WPSA (1985) and GfE (1999), based on factorial calculations. Differences in the Ca recommendations result from the assumed utilization: GfE assumed 55 % (at peak production), WPSA 50 % (on average), and modern phase feeding assumes only 40 % toward the end of the laying period.

Table 9. Effects of reduced vs. increased lysine or/and methionine levels compared to GfE (1999) standards with phase feeding of commercial laying hens (Lohmann LSL-Classic)[1,2]

Experimental feed formulation	Feed g/hen/d	Prod. %	Egg mass g/d	Feed conversion	Body weight[3]
GfE standard	116	88	54	2,22	1919
GfE standard - 15 % Lys	108	82	47	2,32	1719
GfE standard - 15 % Met	113	85	51	2,26	1835
GfE standard - 15 % Lys+Met	102	73	42	2,46	1720
GfE standard + 15 % Lys	117	88	55	2,16	1919
GfE standard + 15 % Met	116	86	53	2,27	1941
GfE standard + 15 % Lys+Met	117	87	54	2,20	2025

[1] HALLE *et al.* (2005);
[2] layer mash based on maize, barley, wheat bran, wheat gluten, peas and soya oil, supplemented with lysine, methionine, minerals and vitamins; 11.4 AME_N/kg feed;
[3] final body weight at end of test, after 52 weeks of production.

Table 10. Requirement of macro-elements (g/hen/day) for different body weight and egg mass production

Source	Live wt. kg	Egg mass g/day	Ca	Non-Phytine-P	Mg	Na	Cl
GfE (1999)	1.8	55	3.65	0.35	0.047	0.11	0.15
		60	3.95	0.37	0.050	0.12	0.16
	2.2	55	3.65	0.37	0.048	0.12	0.15
		60	3.95	0.39	0.051	0.13	0.16
WPSA (1985)	1.8	55	4.15-4.80[1]	0.30	0.048	0.13	0.15
		60	4.50-5.20[1]	0.32	0.050	0.14	0.16
	2.3	55	4.20-4.83[1]	0.33	0.048	0.14	0.16
		60	4.55-5.25[1]	0.34	0.052	0.15	0.17

[1] last part of laying period

The recommendations for the contents of macro-elements in complete layer rations summarized in table 11 are based on the results of factorial experiments or trials focused on the response to increasing dosage of given elements. LEESON and SUMMERS (2005) present recommendations for specified hen age, energy content of feed and daily feed intake. The rather high Ca levels quoted by these authors are partly explained by the high energy level of typical feed formulation in the USA, with corresponding lower feed intake.

The NRC (1994) recommendations vary with feed intake, while PAN (2005) take strain of layer and rate of lay into account in addition to feed intake. In agreement with WPSA (1984) recommendations, both sources recommend increased Ca levels as the hens get older.

Table 11. Recommendations for macro-element contents in layer mash (88 % TS) during early laying months and peak production

Source	Ca	NPP	aP	Mg	Na	Cl	MJ AME_N/kg
GfE (1999)[1]	33.5	3.1	-	0.42	1.05	1.15	11.4
LEESON & SUMMERS (2005)[2]	42.0	-	4.0	-	1.6	-	12.0
NRC (1994)[3]	32.5	2.45	-	0.5	1.5	1.3	11.85
PAN (2005)[4]	35.0	-	3.7	0.5	1.5	1.6	11.3-11.5
WPSA (1984)[5]	36-426	3.0	-	0.4	1.3	1.2	11.25

[1] 1.8 kg live weight/hen, 60 g egg mass/day; 232-45 weeks of age;
[3] light strain of layer, 90% rate of lay, 100 g feed intake/day;
[4] brown-egg strain, > 85% rate of lay
[3-5] light strain of layer, 60 g egg mass/day; [6]toward end of laying period

The recommended levels for phosphorus appear excessive and are probably due to the uncertainties discussed above. In a recent trial, KOZLOWSKI and JEROCH (2011) demonstrated that much lower levels of non-phytate-P are adequate, provided the feed contains sufficient phytase (table 12). As an added benefit, the hens would excrete less P.

Table 12. Effect of added phytase on egg production, feed efficiency and shell strength (Lohmann Brown layers, 21-40 weeks of age) [1, 2]

Non-phytate-P g/kg feed	Added Phytase FTU/kg	Feed intake g/day	Rate of lay %	Egg weight g	FCR kg feed/ kg egg	Live wt. g	Shell strength N
2,5[2]	-	125	94.1[a]	62.1	2.16[a]	1997[a]	35.8
1,3	-	128	90.6[b]	61.0	2.33[b]	1820[b]	32.8
1,3	250	127	94.6[a]	61.5	2.20[a]	1922[a]	35.2

[1] KOZLOWSKI and JEROCH (2011); [2] 44 hens in single cages per treatment group [3] NRC-Norm (1994)

Supply with trace elements

The most important trace elements in layer rations are iron, copper, zink, manganese, iodine and selenium. No recommendations based on the factorial method have been published (reasons discussed by GfE, 1999). The recommended levels are exclusively derived from dose-effect feeding trials and show considerable variation (table 13).

With the exception of Fe, the NRC values are probably too low under commercial conditions. The GfE (1999) advocates levels of trace elements „which are optimal for the most productive and most efficient individual layers under commercial conditions”. Some authors recommend higher levels in breeder rations than in layer feed, but GfE considers the recommendations adequate for parent stock as well. The scientific support for such claims is, however, limited and perhaps outdated.

Table 13. Recommended levels of trace elements in layer rations (mg/kg feed with 88 % DM and normal AME_N)

Source	Fe	Cu	Zn	Mn	I	Se
GfE (1999)[1]	88	6	44	44	0.44	0.13
ARC (1975)	-	-	50[2]-60[3]	30-50	0-0.2	-
LARBIER & LECLERCQ (1994)[4]	60	10	50	40	0.3	0.1
LEESON & SUMMERS (2005)[5]	30	5	50	60	1.0	0.3
NRC (1994)	44[6]-59[7]	-	34-44	20	.034-0.1	0.06
PAN (2005)	40-45	5-8	50-60	60-80	0.7-1.0	0.15

[1] layers [2] layers in production; [3] parent stock in production; [4] layers and parent stock in production; [5] layers in production;
[6] layers in production; [7] parent stock in production

Additions of trace elements in feed supplements follow recommendations. However, in designing feed supplements, the trace elements contained in components are often ignored, and this may lead to overconsumption and excessive levels in excreta. Questions regarding the use of organic vs. inorganic compounds of trace elements have recently been discussed e.g. by SCHENKEL (2008). It has been demonstrated that some organic compounds of trace elements (especially Se) have a higher bio-availability than inorganic compounds in poultry as well. This means that lower levels in daily intake can reduce levels in excreta without sacrificing productivity and health. Experimental results for organic compounds of Zn-, Mn- and Cu are still inconclusive (review of literature, ref. SIMON, 2011). Additional experiments, especially with laying hens, are necessary in this area.

Feed formulations for the production of designer eggs generally contain much higher concentrations of specific trace elements than recommended for normal functioning and egg production.

Supply with vitamins

Balanced poultry feed requires feed additives for most vitamins. A factorial determination of requirements is impossible for the same reason as for trace elements: lack of detailed information about basic data. The GfE and NRC recommendations shown in table 14 are based on dose-response feeding experiments. In some experiments, the effects of different dosage were not only related to egg production, but also to contents in liver and egg yolk as well as biochemical parameters.

It should be pointed out that the recommendations in table 14 are based on feeding experiments many years ago, when the rate of production was much lower and feed conversion ratio (FCR) higher (table 15). As demonstrated in table 16, the vitamin A intake per unit egg mass is reduced by about one third due to higher production, if the feed formulation follows the NRC recommendations (2930 IE/kg feed). According to LEESON (2007), the NRC figures are not adequate for today's highly efficient layers. The GfE recommendations should be updated, based on recent experimental evidence and with necessary safety margins.

Other authors recommend much higher vitamin levels than NRC (1994) and GfE (1999), especially for fat soluble vitamins. Relationships between increased vitamin intake and benefits of "designer eggs" for human health or benefits for the immune system of laying hens will not be covered here.

In feed formulation, vitamins contained in components are usually ignored. This is justified for vitamins A, D3 und B12 because today's commercial rations contain only plant components, which may contain only low concentrations of ß-carotine. Other vitamins are contained in sufficient, sometimes even excessive, concentration in feed components. The recommendations of WHITEHEAD (1998) take the contents of B vitamins in components into account.

Table 14. Recommendations for vitamin contents and additives per kg all mash layer feed with 88 % DM and normal AME_N content

Vitamin[1]	**GfE (1999)**	**NRC (1994)**	**Other sources[2]**	**Recommended for feed additives[3]**
Vitamin A	4000	2930	8000 - 11000	7000 - 12000
Vitamin D_3	400	295	1600 - 3500	2000 - 3500
Vitamin E_2	5-9	5	10 -50	7.5 – 30 (150–240)
Vitamin K_3	0.5	0.5	1 - 3	1 - 4
Vitamin B_1	1.5	0.7	1 - 2	0 - 3
Vitamin B_2	2.5	2.5	4 - 5	0 - 9
Vitamin B_6	2.5	2.5	1 - 3	0 - 6
Vitamin B_{12}	0.01	0.004	0.01 – 0.02	0.005 – 0.25
Niazin	19	10	20 - 40	5 - 80
Pantothenic acid	4.9	2	5 - 10	4 - 18
Folic acid	0.5	0.25	0.4 - 1	0 - 2
Biotin	0.1	0.1	0.1	0 – 0.3
Choline	500	1050	200 - 500	0 - 600

[1] vitamin E in mg or IE, all other vitamins in mg,
[2] PAN (2005), LARBIER & LECLERCQ (1994), LEESON & SUMMERS (2005),
[3] WHITEHEAD (1998), AWT (2001), DSM (2001, 2006)

Table 15. Development of egg production and feed efficiency in German random sample tests (conventional cages)

Parameter	**White-egg strains**		**Brown-egg strains**	
	1970/1971[1]	**2002/2004[2]**	**1970/1971[1]**	**2002/2004[2]**
Age at 50 % Prod., days	170	154	177	146
Egg number per HH	244	319	199	317
Average egg weight, g	60.3	64.3	62.4	66.2
Total HH egg mass, kg	14.7	20.5	11.8	21,0
FCR, kg feed/ kg EM	2.93	1.94	3.29	1.96
Live wt. at 504 days, g	2030	1847	2420	2204
Mortality, %	8.9	4.0	19.1	5.6

[1] FLOCK (1972); [2] Geflügeljahrbuch (2008)

Table 16. Comparison of vitamin A intake of laying hens if the same NRC (1994) standards were used in 1970/71 and 2002/04

Years of production	Egg number/hen housed	Vitamin A intake in IE	
		per 100 g EM	per 65 g egg
1970/1971	244	86 (100)	56
2002/2004	319	57 (66)	37

Summary and Conclusions

The above review of current recommendations for optimal layer nutrition leads to the following conclusions and demands for future research:

- The change from conventional cages to barn and free range management requires reliable estimates of additional energy needs for exercise, degree of feather cover and deviations from thermo-neutral temperature.
- Differences between hens (between and within strains) in their ability to adjust daily feed intake to variable temperature and energy content of feed should be analyzed with suitably structured data.
- Recommendations for amino acid contents in layer rations and daily intake should be developed for prececal (ileal) digestible AA. This requires analysis of digestibility of components under standardized conditions (KLUTH and RODEHUTSCORD, 2009) and derivation of recommendations on the same basis.
- The efforts to develop a new system to assess the availability of phosphorus should be intensified to improve the utilization of this limited resource and reduce waste in emissions.
- The recommendations for trace elements should be verified with focus on bio-availability from various sources, especially chelated compounds.
- Research to determine the optimal supply of vitamins, especially fat soluble vitamins, should include not only commercial hybrid layers, but also parent stock.

Zusammenfassung:

Versorgungsempfehlungen für Energie und Nährstoffe bei Legehennen kritisch hinterfragt

Der vorliegende Übersichtsartikel analysiert kritisch Versorgungsempfehlungen (Bedarf, Futtergehalte) für Umsetzbare Energie und Nährstoffe (Rohprotein, Aminosäuren, Mengen- und Spurenelemente, Vitamine) von Legehennen. Dabei werden vor allem die Empfehlungen der Gesellschaft für Ernährungsphysiologie, internationaler wissenschaftlicher Gremien (u.a. National Research Council, Polnische Akademie der Wissenschaften, World Poultry Science Association), Monografien zur Geflügelernährung (u.a. Leeson und Summers, 2005) sowie ausgewählte neuere Veröffentlichungen zur Thematik herangezogen. Es werden Schwachstellen aufgezeigt und daraus Hinweise für wissenschaftliche Aufgabenstellungen abgeleitet. Hierzu zählen insbesondere: Objektivere Einschätzung des zusätzlichen Energiebedarfs für Bewegungsaktivitäten, unterschiedliche Befiederung und für Umgebungstemperaturen unterhalb als auch oberhalb des thermoneutralen Bereiches, Futterverzehrsverhalten in Abhängigkeit vom Energiegehalt der Futtermischung in verschiedenen Bereichen der Umgebungstemperatur, AS-Versorgungsempfehlungen auf der Basis der standardisierten praeceacal verdaulichen Aminosäuren, neues Phosphorbewertungssystem, Bioverfügbarkeit der Spurenlemente aus organischen Verbindungen, Versorgungsempfehlungen mit fettlöslichen Vitaminen für Hochleistungshennen und begründete Sicherheitszuschläge.

Literature

Arbeitsgemeinschaft für Wirkstoffe in der Tierernährung (AWT) (2000) Aminosäuren in der Tierernährung, Agrimedia Verlag, Bergen/Dumme, 59 pp.

Arbeitsgemeinschaft für Wirkstoffe in der Tierernährung (AWT) (2001) Vitamine in der Tierernährung, Agrimedia Verlag, Bergen/Dumme, 78 pp.

Agricultural Research Council (ARC) (1975) The Nutrient Requirements of Farm Livestock, No. 1 Poultry, 153 pp.

Ausschuß für Bedarfsnormen der Gesellschaft für Ernährungsphysiologie (1999) Empfehlungen zur Energie- und Nährstoffversorgung der Legehennen und Broiler, DLG-Verlag, Frankfurt am Main, 145 pp.

Ausschuß für Bedarfsnormen der Gesellschaft für Ernährungsphysiologie (2004) Empfehlungen zur Energie und Nährstoffversorgung der Mastputen. Proceedings of the Society of Nutrition Physiology 13, 199-233.

Bregendahl K. (2009) Das ideale Aminosäurenprofil für Legehennen. AminoNews. 13 (01), 7-12.

Deutsche Landwirtschafts-Gesellschaft (1992): DLG-Mischfutterstandards, Teil 2 für Rinder, Schafe, Pferde, Kaninchen, Geflügel und Fische.

DSM (2006) Fortification Guidelines, DSM Nutrition Products Inc., Parsippany, NJ, USA.

Gramzow St. (2001) Untersuchungen zum idealen Protein schwerer männlicher Mastputen. Shaker Verlag Aachen, 152 pp.

Halle Ingrid, Dänicke S., Rauch H.-W. (2005) Untersuchungen zur Aminosäurenversorgung von Legehybriden. Archiv für Geflügelkunde 69, 167-174.

Jeroch H., Hoffmann L. (1983) Energie-, Protein- und Aminosäure-bedarfsnormen für Hennen der Legerichtung (Legehybriden) und der Mastrichtung (Broilerhennen). Institut für Geflügelwirtschaft Merbitz, Berichte zur Geflügelproduktion 14, 4-20.

Kozlowski, K.., Jeroch, H. (2011): Efficacy of different levels of Escherichia coli phytase in hens fed maize-soyabean meal based diets with a decreased non-phytate phosphorus content. Journal of Animal and Feed Science 20, 224-235.

Kluth H., Rodehutscord M. (2009) Standardisierte Futterbewertung auf der Basis der Aminosäurenverdaulichkeit beim Geflügel. Übersichten zur Tierernährung 37, 1-26.

Larbier M., Leclercq M. (1994) Nutrition and Feeding of Poultry. Nottingham University Press, Loughborough /GB, 305 pp.

Leeson S. (2007) Vitamin requirement: is there basis for re-evaluating dietary specifications? World`s Poultry Science Journal 63, 255-266.

Leeson S., Summers J.D. (2001) Scott`s Nutrition of the Chicken, 4th ed., University Books, Guelph, Ontario, Canada, 591 pp.

Leeson S., Summers J.D. (2005) Commercial Poultry Nutrition, 3rd ed., Nottingham University Press, UK, 398 pp.

Lemme A. (2009) Amino acid recommendations for laying hens. Lohmann Information 44, 21-32.

National Research Council (NRC) (1994) Nutrient requirements of poultry, 9th revised ed., National Academie Press, Washington, D. C., 155 pp.

Polnische Akademie der Wissenschaften (PAN) (2005) Nährstoffbedarf des Geflügels-Nährwert der Futtermittel und Fütterungsempfehlungen, 4th ed., Kielanowski-Institut für Tierphysiologie und Ernährung, Jablonna/Warszawa, 135 pp (in Polish).

Schenkel H. (2008) Verfügbarkeit und Verwertbarkeit von Spurenelementen aus unterschiedlichen Supplementen. In: Eder K. (Hrsg.) 10. Tagung Schweine- und Geflügelernährung, Halle (Saale), pp. 83-86.

Vogt H. (1957) Fütterung des Geflügels. In: Scholtyssek S. (Hrsg.) Geflügel, Verlag Eugen Ulmer, Stuttgart, pp 216-311.

Simon Annette (2011) Unpublished manuscript.

Whitehead C.C. (1998) Vitamin interactions and requirements in poultry. In: 7th International Symposium on Animal Nutrition, Kaposvar, Hungary, pp. 3-31.

WPSA (World`s Poultry Science Association) (1981) Mineral requirements for poultry/recommendations in european countries. World`s Poultry Science Journal 37, 127-138.

WPSA (World`s Poultry Science Association) (1984) Mineral requirements and recommendations for adult birds. World`s Poultry Science Journal 40, 183-187.

WPSA (World`s Poultry Science Association) (1985) Mineral requirements and recommendations for growing birds. World`s Poultry Science Journal 41, 252-258.

Authors address:

Prof. Dr. Dr. h.c. Heinz Jeroch
E-Mail: heinzjeroch@hotmail.com