Lohmann Information

Cuxhaven, October 2008

Prof. Dietmar Flock,
Editor

Editorial

While people across the world are worried about the financial crisis and trying to cope with rising food and energy prices, we should not forget the remarkable contributions of science to modern agriculture without which the increasing demand for animal protein of a growing world population could not be met. Public funding of research dedicated to efficient food production has been declining for years, and universities depend increasingly on donations from private individuals and/or the industry to continue adequate education and research progams so that today's students are prepared to develop better solutions to our current problems.

In this issue, we offer a combination of historical and current information as food for thought:

1. In his review **Jay Lush - reflections on the past, Dr. Louis Ollivier**, Jouy-en-Josas, France, pays tribute to the "father of modern animal breeding". Animal science students in many countries have learned animal breeding theory on the basis of the classic text book "Animal Breeding Plans", which has been aptly described as "a high impact book, even if not read".
   Readers of Lohmann Information may be interested to know that three former students of Prof. Lush became interested in poultry breeding after completing their PhD projects on dairy cattle and contributed to the layer breeding program of Lohmann Tierzucht: the late Dr. Max von Krosigk (1959-1970), Prof. Franz Pirchner (1962-1964) and the current editor (1968-1999).
2. Egg producers across the EU are in the process of replacing conventional cages by alternative management systems to meet EU regulations and increasing consumer demand for non-cage eggs. Based on a case study in Sweden reported at the 16th Finnish and Baltic Poultry Conference in Vantaa, Finland, **Prof. D.K. Flock** illustrates in his paper ***Adaptability of laying hens to non-cage environments*** that modern hybrid layers are quite capable to adapt to organic egg production, provided the husbandry is optimized to make use of the genetic potential.
3. Feed efficiency of laying hens has been improved gradually by a combination of genetic selection, feed formulation and management, but feed cost remains the major cost factor in egg and poultry meat production. Most nutrition research has focused on feed formulation to satisfy the birds' demand for energy, amino acids and other essential nutrients. In his paper ***Fiber in layer diets***, LTZ nutritionist **Robert Pottgüter** looks at fiber as an often overlooked feed component which deserves attention to optimize gut health, minimize environmental impact of production and even decrease cannibalism.
4. The control of diseases, an essential part of the modern poultry industry, would not have been possible without effective vaccines, for which SPF eggs are used. Lohmann Tierzucht, a major producer of SPF eggs, celebrated the 40th anniversary of the VALO department with a symposium in April 2008, at which **Dr. Egon Vielitz**, former head of the LTZ Veterinary Laboratory, reviewed ***The history of VALO SPF*** from its early beginnings in the 1950s.

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LOHMANN TIERZUCHT

5. Fertile eggs are widely used to produce vaccines for humans and animals. **Marcus Kock**, marketing director, and **Dr. Gerhard Seemann**, technical director of the VALO division of Lohmann Tierzucht, explain the difference between "Clean Eggs" and "SPF-Eggs" in their paper **Fertile eggs - a valuable product for vaccine production**. The total world market for vaccine eggs is almost 600 million eggs per annum, most of which are "Clean Eggs" for human vaccine production.
6. **Dr. Carmen Jungbäck** and **Dr. Andreas Motitschke** review ***The Importance of SPF-Eggs in Manufacturing and Testing of Poultry Vaccines*** from the perspective of the Paul-Ehrlich-Institute, the federal authority in Germany for the licensing of sera, vaccines and blood products for use in humans and animals. While attempts to find cheaper and/or more efficient alternatives to the use of SPF eggs continue, the authors conclude that SPF eggs will continue to be needed in the foreseeable future.
7. The last paper of this edition, ***Small and medium sized enterprises - winners of globalization?*** by **Prof. Feldmeier** and **H. Hansen** is based on a recent field study of the Institute for Management and Economics, University of Bremerhaven, Germany. Analyzing several success factors in business, the authors conclude that small and medium sized companies have excellent opportunities to benefit from globalization, especially if they have recourse to immigrants from the respective target countries which are acquainted with the cultures of the home as well as the host country.

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The editor also appreciates comments re. contents of this issue and suggestions for future topics.

With kind regards,

Prof. Dietmar Flock,
Editor

Jay Lush: Reflections on the past*

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It is my considered judgment that in animal breeding
the "endless frontier" is just as real as Vannevar Bush
has expressed it to be for scientific research in general
(Lush, Genetics and Animal Breeding, 1951a)

Introduction

Animal breeding is a human activity probably as old as humanity itself. Iconographic documents help us get an idea of how farm animal species have evolved since the early days of domestication, at least for most external traits. In contrast, the history of ideas and practice implemented by man to change his domestic animals is far more difficult to trace. Animal breeding has for a long time been a collection of recipes, before progressively evolving into an art and then becoming a science.
One American teacher, Jay Lush, in laying the foundations of scientific animal breeding, has contributed more than any other individual to the last step of this long evolution. Jay Lush taught animal breeding at Iowa State University (Ames, Iowa) from 1930 until his retirement in 1966 (see a brief biography by Chapman, 1991) His teaching and research resulted in a centre of animal breeding and genetics at Ames, that rapidly gained an international reputation and attracted students from all over the world. In this article I will try to summarise the contributions of Lush's ideas to the development of modern animal breeding and so I hope to explain the reasons why Lush's influence on animal breeding around the world has been so profound.
Belonging myself to the long list of Lush's students, I hope the reader will forgive my referring to some personal remembrances of the time I spent in Ames 51 years ago.

From Mendel's laws to scientific breeding

Jay Lush is universally recognised as the father of scientific animal breeding. These are indeed the very terms employed in his Wolf prize citation of 1979. As such he holds a place of its own in the history of genetics and its application to agriculture. Lush's position is rather unique at the interface between genetics and practical breeding. This may reflect contrasting situations between plant and animal breeding in the early days of mendelism. Plant breeding benefited much earlier than animal breeding from the rediscovery of Mendel's laws and a number of scientists were actively involved from the early days of the 20th century in trying to apply genetics to plant breeding. Scientific plant breeding indeed developed in parallel in many countries, through the efforts of many scientists and in very diverse contexts. As pointed out by Roll-Hansen (2000), in a remarkable article on the impact of Mendelism on agriculture, the impact of Mendelian theory on plant breeding varied from country to country (see also Allen, 2000). A good example has been the contrast between Swedish optimism and British pessimism on the prospects for increasing grain yields. The careers of Correns and Tschermak in German-speaking countries, Bateson in Britain, Nilsson-Ehle and Johanssen in Scandinavia, and the activities of institutions such as the Royal Horticultural Society of London (founded in 1804), the Svalöf Institute in Sweden (1886) and the American Breeders Association (1903) offer examples of the variety of approaches in the application of genetics to plant breeding. France may also be mentioned as an extreme example of resistance to mendelism until at least the early 1930s. Among various explanations, Gayon and Burian (2000) point out the lack of interaction between academic biologists and plant or animal breeders. In contrast to plant breeding, animal breeding had long been waiting for principles to be used in practice. Lush got his "first intriguing glimpses of genetics" around 1914 (Chapman, 1991). The animal breeding then taught in agricultural colleges went as follows, Lush recalled: "The first principle of animal breeding was: like produces like; while the second principle was: like does not always produce like!" (Lush, 1951a).

* adapted from a paper presented at the Lush Vision Symposium – Animal Breeding Plans, April 24-25, 2008, Iowa State University, Ames, Iowa, USA.

In this 1951 paper, abundantly commented upon 50 years later by a historian of science (Roll-Hansen, 2000), Lush exposed his "philosophy". To him the most significant contribution of genetics was to dispel confusion and to bring clarity. As he wrote, with genetics "it became clear" that (i) identical pedigree does not mean identical heredity, (ii) genetic and environmental variation are both present in the individual but have quite different consequences for its descendants, and (iii) mutations are not so important in practical animal breeding. In another paper of the same year he notes: "The psychological effect of having the mystery dispelled from animal breeding and knowing that one was struggling only to utilize natural laws, rather than against capricious, unknown and possibly hostile forces, must have been considerable although no way to measure it is apparent (Lush, 1951b).

The fundamental breeder's equation

Let us now ask ourselves: which contribution should we retain from Lush's work in genetics, if we had to retain only one among many contributions? Would it not be the "breeder's equation"? Lush himself, however, did not use that expression, neither was the equation even yet mentioned in the original 1937 edition of Animal Breeding Plans. I discovered the expression for the first time in the second volume of Lynch and Walsh's treatise (see Lynch and Walsh 2nd volume website[1]), and I was so pleased with the term that I included it in my revised edition of Eléments de génétique quantitative (Ollivier, 2002). But I wonder whether we should not perhaps better call it "LUSH's equation" and keep it in our records next to the well-known HENDERSON's equations.

Lush was essentially interested in changing things, through breeding plans based either on selection, relationship or somatic likeness. In fact, selection occupies more than half of the 17 chapters specifically devoted to breeding plans (Animal Breeding Plans, 3rd edition, 1945). There (page 148) he details the "increase expected in the population mean", after having defined the selection differential as the "superiority of the selected parents". In case all the genes combined their effects additively and the environmental variations did not affect the characteristic at all….. the expected increase in the population mean per generation would be equal to the selection differential. Actually the improvement of the population average will be only a fraction of the selection differential. That fraction has for its numerator the additive genetic variance and for its denominator the actual variance; i. e. the fraction is ó^2 G /(ó^2 G + ó^2 D + ó^2 I + ó^2 E) which for brevity we may call "heritability". This statement is immediately followed by an example about fleece weight, and, having previously defined generation interval as the average age of parents when their offspring are born, Lush goes on predicting annual increase in the flock average.

The breeder's equation in modern notation[2] usually goes as $R = ih^2$, where R is the response per generation expressed in standard deviation unit of the trait of interest, i being the intensity of selection, or standardised selection differential, and h^2 the heritability. This equation can be compared to the famous "fundamental theorem of natural selection" of R.A. Fisher (1930), and Lush's equation might thus be called the fundamental theorem of artificial selection. But I would like to point out another, considerably more far-reaching (if not extravagant) analogy, by moving to physics. We all know the famous equation promoted by Einstein's theory: $E = mc^2$. As noted in a recent book on scientific curiosities (Aydon, 2005), the message embodied in this "ominous equation" can easily be understood by anyone with even a modest scientific education, since E stands for energy, m for mass and c^2 for the speed of light. This equation – remarkably the only equation in Aydon's book: "it would not be a history of science if that one were left out" the author notes – tells us in simple terms the phenomenal amount of energy locked in the atom. One cannot help noting the "symbolic" similarity between $R = ih^2$ and $E = mc^2$: one capital letter on the left-hand side and two minuscules on the right-hand side, the first being a variable (i or m) and the second a positive constant (h^2 or c^2). And in both cases at the end much out of a little. A linguistic analogy can also be remarked since a breeder is a reactor in which breeding of fissionable elements takes place.

1 http://nitro.biosci.arizona.edu/zbook/NewVolume_2/newvol2.html
2 The equation of « genetic gain » is also given in Lush and Hazel (1942) as $\overline{G} = (z/p)g^2$

About the constancy of heritability (for a given trait), I should say that Lush was very cautious and he often insisted on the factors which could change h^2 (Lush, 1949), but he may have overemphasized the variability of this parameter. A long time ago, heritability of litter size in pigs – as estimated among many others by my colleague Legault (1970) – was 0.10. This remains the common figure that one can still find in the present day literature based on the most sophisticated tools of evaluation (Mérour et al., 2008). Alan Robertson and Oscar Kempthorne had a discussion at Ames in 1956, in a seminar where Alan was presenting the Edinburgh selection experiments and the derived concept of realized heritability. The discussion was about defining heritability in the narrow sense, in the broad sense, or in the "Edinburgh sense" (as John Wilson recalls). In this context it is worth noting that the way of measuring realized heritability is very precisely described, though not named as such, in chapter 8 of the 3rd edition of Animal Breeding Plans (Lush, 1945, p. 93). Being aware that we cannot do much to increase heritability, Lush found a way to "increase the speed of light" by combining individual merit and family merit (Lush, 1947). This 1947 paper, probably his most important single paper in his own words, is also a prototype for many of his papers. It illustrates how scientific knowledge can emerge from a very practical problem. Here the problem was to find how much attention should be paid to littermates when choosing boars and gilts for breeding (Chapman, 1991).

Changes

Lush was well aware of the really enormous possibilities of selection for changing things, given the slight changes to be expected in the rate of improvement predicted by the breeder's equation. One change he described and quantified was the "narrowing of gametic array" generated by selection[3] (Animal Breeding Plans, 1945 p. 142). This phenomenon, responsible for a decline in response, became later known as the Bulmer effect (Bulmer, 1971). Lush's guess that the decline in the rate of progress should be "very slow" (Animal Breeding Plans, 1945 p.152) has since been amply confirmed by selection experiments on many organisms. He also emphasized the contrast between our "considerable ability to forecast the rate of improvement possible in the immediate future" and the lack of "techniques for estimation the genetic limits for any characteristic in any population, unless one knows what genes are present and knows their effects and frequencies" (Lush, 1951a). Limits have later been extended well beyond where Jay Lush may ever have imagined himself. As we know, genetics has gone a long way towards exploring the limits of selection, owing to the pioneer work of Alan Robertson in a field which considerably developed after him. But we are still in doubt about the reality of the "endless frontier" he postulated, even though we now know much more about gene effects and frequencies. Selection experiments on laboratory animals have shown the crucial role of population size. The ratio R_{50} / R_1 (the selection response in generation 50 relative to generation 1) may be taken as a measure of deviation from linearity of response over a long period of time, and the value found in large experiments on Drosophila, $R_{50} / R_1 = 40$, is not far from expectation when due account is taken of the Bulmer effect (Hill, 2008).

Changes in the productiveness of animals were already well documented for many traits in many countries over periods of times extending far beyond the start of genetics, though the "taking of adequate and unbiased data is a distinctly modern development" (Lush, 1951a). Lush took as a first example of unbiased data the average weight of fleece per sheep in Australia, which showed an unmistakable upward trend, with a nearly doubled fleece weight over a period of 65 years (Figure 1A). As we can see, this trend has now been confirmed by a 5-fold increase in fleece weight over one and a half century (Figure 1B). In the US an increase of about 40 per cent of the production of farm animals was observed over the period 1920-1950, revealing quite an impressive steadiness (Lush, 1951a). But it was difficult to separate the trends observed into their genetic and environmental components. The first attempt to estimate genetic trends from field data may have been the study of production records from the Holstein-Friesian herd of ISC covering the period 1938-1949, shown in Figure 2 (Lush, 1951a). We have now fairly reliable estimates of genetic trends and genetic progress for most production traits in the main farm animal species over long periods of time (see the broiler example

3 I am indebted to Etienne Verrier for pointing it out to me

of Figure 3). Some decline in fitness traits has generally been observed, but genetic variation still remains and examples of improvement programmes show that unfavourable trends may be reversed by subsequent selection (Hill, 2008).

Figure 1A: Trends in fleece weight of Australian sheep

Average fleece weight (in kg), by five-year period, for all sheep in New South Wales from 1881 to 1946 (adapted from Lush, 1951a)

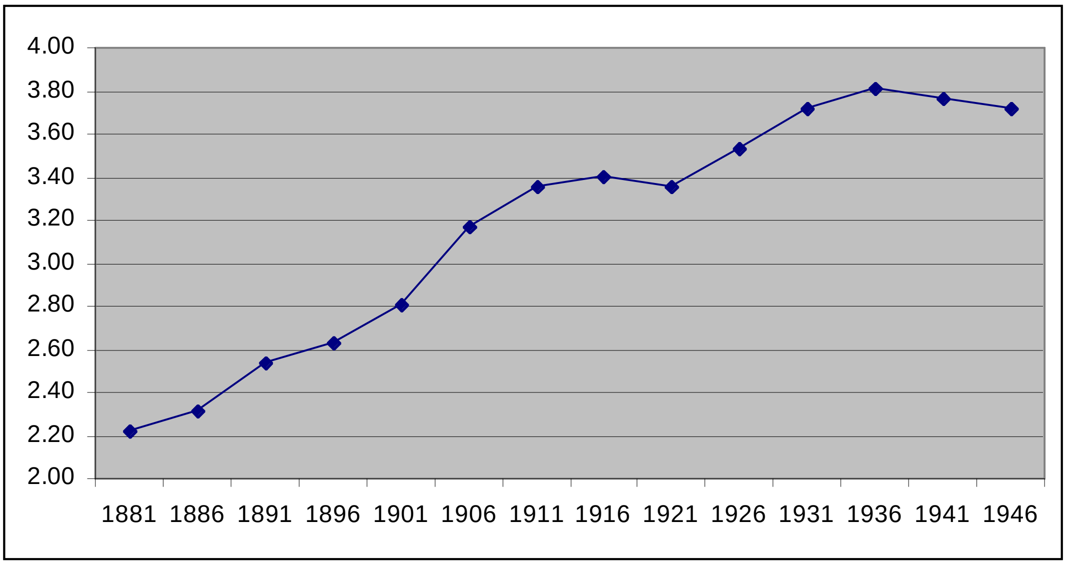


Figure 1B: Trends in fleece weight of Australian sheep (kg greasy per head) from 1850 to 2000 (from Rowe and Atkins, 2004; courtesy of Kevin Atkins).

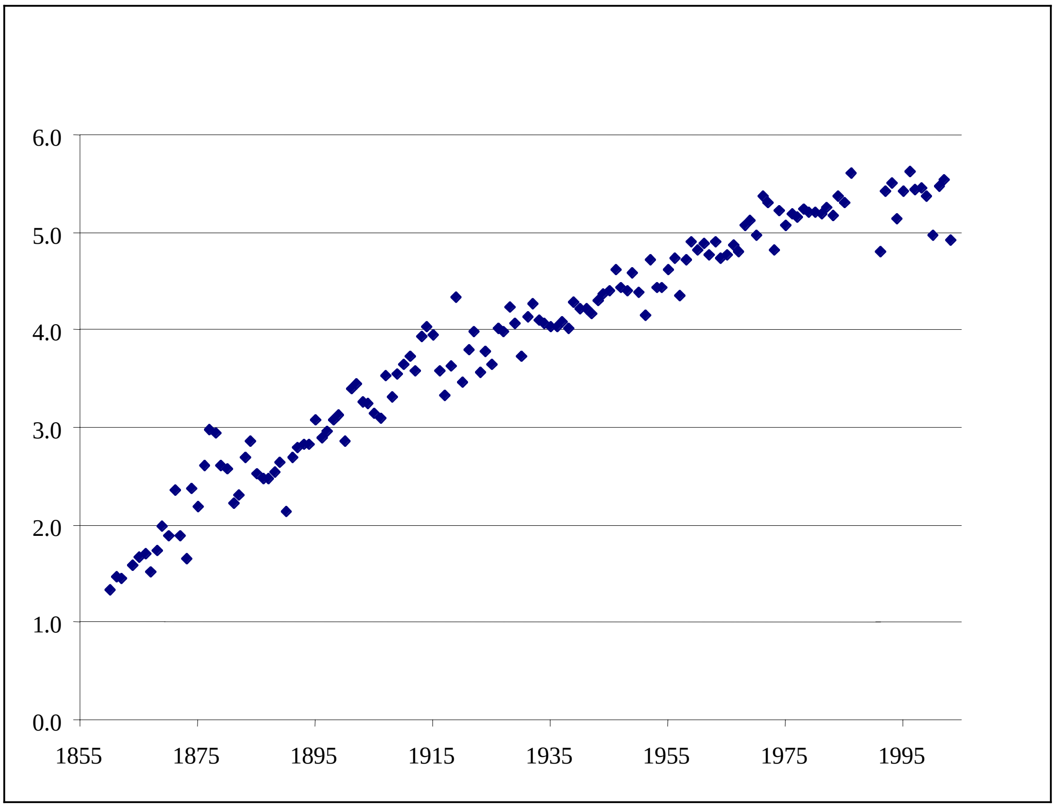
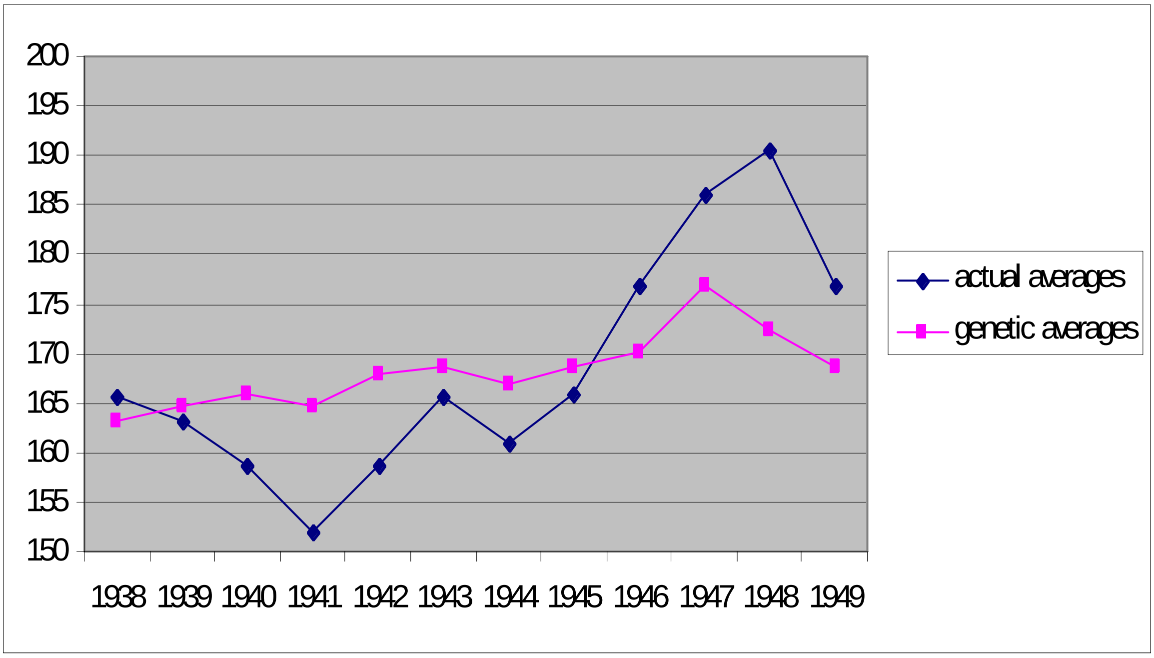
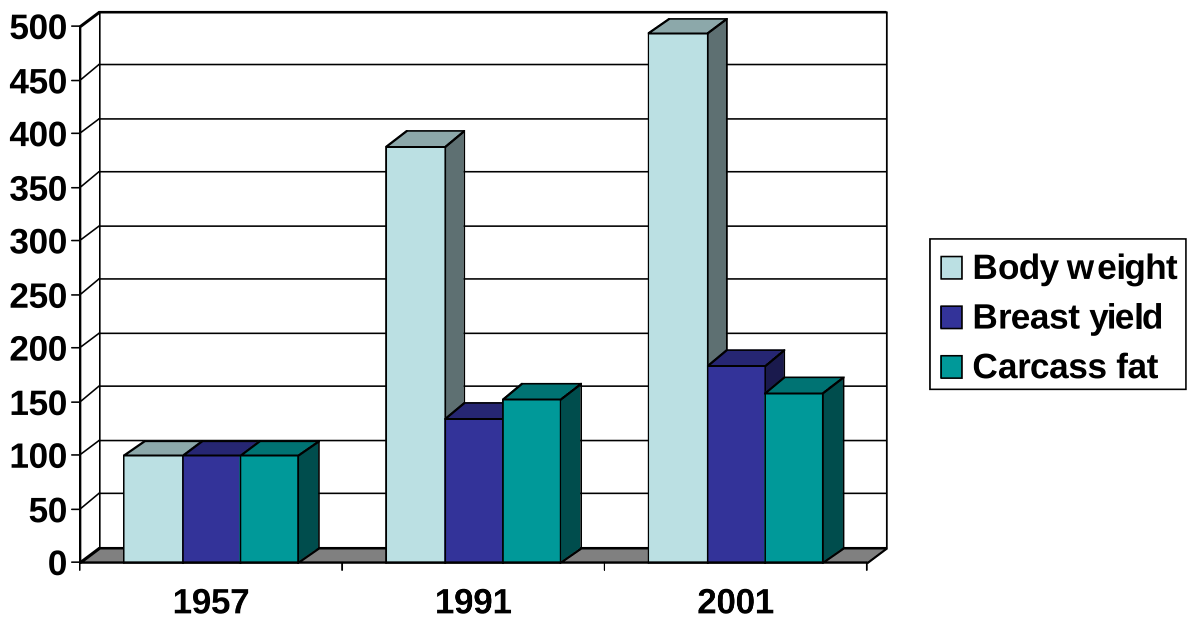


Figure 2: Phenotypic and genetic trends in 8-month fat production (kg) in the Holstein-Friesian herd of Iowa State College over the period 1938-1949 (adapted from Lush, 1951a)



The blue line in figure 2 connects the actual averages and shows a trend of 2.7 kg/year. The red line connects the annual averages corrected by "fitting constants" for year-to-year changes in environment and shows a trend of 1.1 kg/year.

Figure 3: Genetic changes since 1957. The broiler example (adapted from Hill, 2008)



Lush's legacy

The enormous impact of Jay Lush on the development of animal breeding internationally should again be recalled. The two essential ingredients behind his success are well known, (i) a famous book (Animal Breeding Plans, 1937, re-edited in 1943 and 1945, and translated in several languages) and (ii) a renowned teaching, based on mimeographed notes posthumously published (Lush, 1994). The link with the industry has been established through a sort of "human chain" made of his 279 students coming from 42 States of the Union and 32 foreign countries (Willham, 1999). Lush's views on teaching and the balance he recommended to keep between research and teaching may be rather clearly perceived in the following quotation, which also, I believe, highlights his modest overall approach to science and the extreme precaution he always took before issuing scientific statements: "Immediately on completing my PhD degree, I did research for more than 8 years, with almost no interruption for teaching. I'm glad it happened that way. If I had taught the same course as much as three times in succession, using the available texts and my graduate notes and all the rest of what I thought I knew, I would surely have come to believe those things myself so firmly that the errors among them could scarcely have been corrected by any amount of subsequent experience...Having no papers to grade or class rolls to call, I listened... Usually the animals were saying something like: Most of the things you think you know may be true in principle but you have many of them out of all proportion to their actual importance…Trying to solve apparent inconsistencies drove me in the direction of measuring more accurately the factors in the problems..." (Lush, 1973).

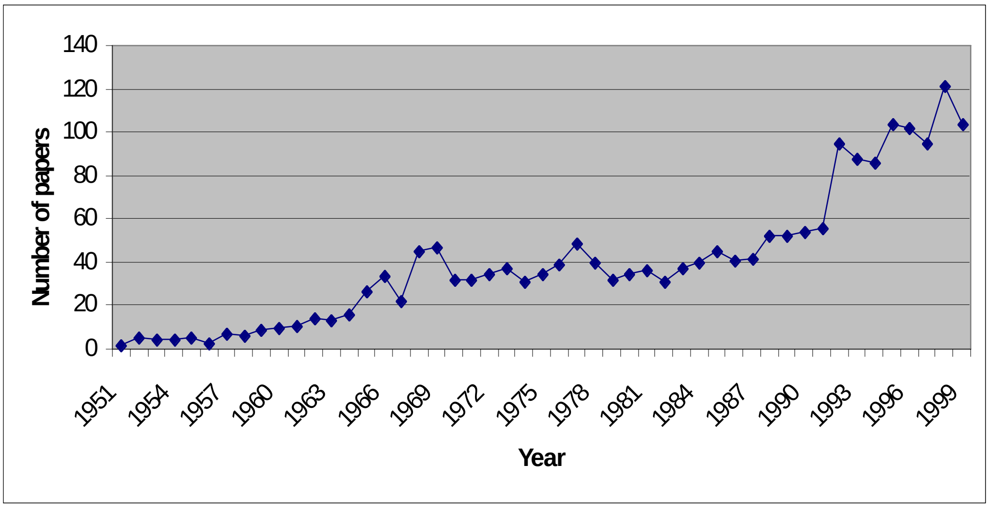
France may serve as an example of the development of animal breeding in Europe after World War II. France, however, presents some idiosyncrasies as to its relation to genetics, as it offers an example of a sort of "genetic lag". We have already mentioned the resistance of the French biologists to mendelism. The first chair of genetics in a French university was indeed created at the Paris Sorbonne after World War II, whereas several European countries had already created chairs of genetics in the years 1910-1930 (Gayon and Burian, 2000). Research in animal breeding started in the early 1950s at the Institut National Agronomique in Paris under the leadership of Jacques Poly, who eventually founded the Department of Animal Genetics of INRA (in 1963) and later became Director General of this research institution (created in 1946). As Jean Boyazoglu recalls, Jay Lush enjoyed many visits to INRA as well as riding across the narrow roads of the French countryside, humorously commenting on the dangers they entailed. Lush also had INRA in great esteem, as Tom Sutherland recalls from his decision to go on sabbatical to Jouy-en-Josas following Lush's recommendation. Owing to an inventory initiated by Jean-Jacques Lauvergne (Hutin and Lauvergne, 1964), the French scientific production in animal breeding has been thoroughly monitored ever since its beginning in 1952. Between 1952 and 2000, the annual number of scientific papers increased from two to 104 (Fig. 4A), the total count of contributing authors from three to 434 (Fig. 4B). The seemingly exploding number of authors (Fig 4B) reflects the general evolution in animal breeding research towards more international involvement and a corresponding number of authors per publication.

Hazel, Kempthorne and some others

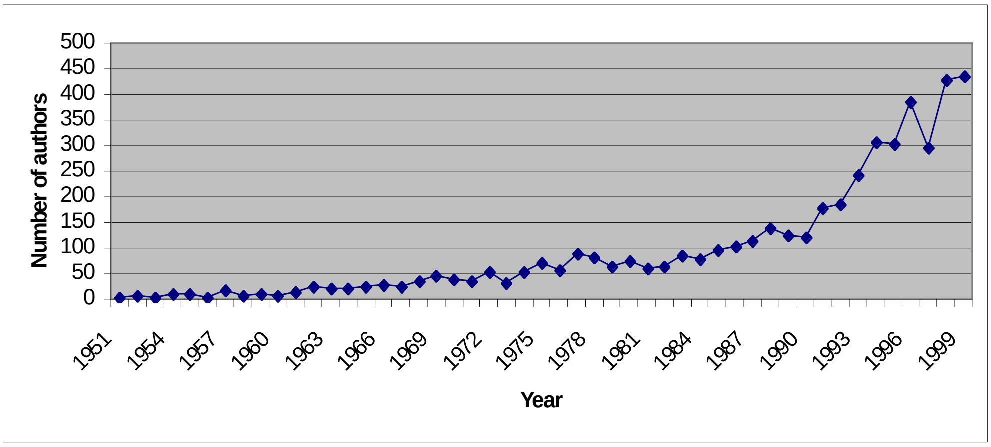
Lanoy Hazel deserves a special recognition by the animal breeders' community. Who else did ever produce three so fundamental papers over the course of only three years? His most famous 1943 paper on selection index (Hazel, 1943) came one year after a basic study of multivariate response to selection (Hazel and Lush, 1942), and was followed one year later by what may be seen as the first attempt at manipulating selection intensity, selection accuracy, and generation interval in order to maximise annual genetic response (Dickerson and Hazel, 1944). Hazel will also be remembered of course for being the inventor of the "mechanical measurement of carcass value on live hogs" using a backfat probe (Hazel and Kline, 1952). I later imported the method in France, which eventually allowed recommending a more efficient "performance testing" of pigs in lieu of the then popular progeny-testing, copied on the Danish model. This was like reversing the title of Dickerson and Hazel's paper of 1944 by relying on the "effectiveness of early culling as a substitute to selection on progeny performance". Incidentally, the year of Hazel's discovery of the backfat probe happened to be that of

Figure 4: French scientific publications in animal breeding from 1951 to 2000

A: number of papers in peer-reviewed journals



B: number of authors



the construction by INRA of the first Danish-type pig progeny-testing station. It is hard to realise to-day the amount of skepticism that the method received from the French pig industry in the early 60s, before it became widely accepted.

I must pay tribute to the teaching of several outstanding ISC professors besides Lush and Hazel in animal breeding. Many of them were recognised "stars" in the related fields of statistics and "pure" genetics. Oscar Kempthorne certainly deserves a special mention. I still remember his warm welcome when I started my graduate work in September 1956, as he let me know straightaway how much he admired the French geneticist Gustave Malécot. Kempthorne actually introduced me to Les mathématiques de l'hérédité (Malécot, 1948), a small book that promoted an elegant theory of inbreeding and correlation between relatives from the concept of gene identity. The book, however, remained unnoticed by most geneticists until the publication of Kempthorne's classical Introduction to Genetic Statistics. What Kempthorne said about the work of Malécot (Kempthorne, 1957, p. 72) applied, I believe, to his own teaching. Kempthorne's guiding principle was indeed to "lay bare the crucial ideas untrammelled by unnecessary assumptions". In his preface to Introduction to Genetic Statistics Kempthorne acknowledged the "tremendous inspiration" that Fisher's writings had been to him. Nevertheless, he expressed his indebtedness "to Wright for his work on inbreeding and population genetics" and mentioned he was "also highly stimulated by mimeographed notes on population genetics by J.L. Lush". Kempthorne's course thus appeared as a most welcome complement to Lush's teaching, essentially based on Wright's work, though Lush actually benefited from personal contacts with both Fisher and Wright[4]. A detailed account of the exchanges between Sewall Wright and Jay Lush, which started by a letter of Lush to Wright in 1918, is presented in the book of Provine (1986) Sewall Wright and Evolutionary Biology.

Let me also mention George Snedecor, whose Statistical Methods (Snedecor, 1956) I have religiously kept in my scientific library as a source of invaluable numerical examples for implementing standard statistical tests. John Gowen made me discover an astonishing laboratory beast, called Drosophila melanogaster. Gowen was a firm believer that most of the genes hypothesised to govern quantitative traits would one day be perfectly identified. As Tom Sutherland recalls, animal breeding graduate students of the time saw this contention as extravagant if not on the verge of insanity. The flourishing business of "gene hunting" which has steadily developed since the 1980s, and has now evolved into "genomic selection", appears to have vindicated his belief. Gowen is also known as the editor of Heterosis (Gowen, 1952), a much quoted book ever since it came out in 1952. Among many remarkable papers, the book contains an article by Charles Henderson (ISC Ph.D. 1948) which extends Hazel's selection index theory to a quite general method of breeding value estimation now known as BLUP, and even extends it to the "animal model" (Henderson, 1952, p. 359-361).

Conclusion

Going back to those 1956-57 days in Lush's graduate school, I cannot help remembering the friendly atmosphere which reigned among the students then present around Professor Lush. Let me mention a few names: Chris Plato from Cyprus – so surely Plato was familiar with Lush's thinking even though the reverse remains to be established – Niti Bohidar from India, Mohammed Gazzi from Egypt, Franz Pirchner from Austria, Werner Hartmann from Germany, Per Jonsson from Denmark, Tom Sutherland and Charlie Smith from Scotland, John Wilson from Northern Ireland, and Americans from many states in the Union. This geographic diversity was a reflection of Jay Lush's principle not to have more than two graduate students originating from the same country. Let me particularly recall the memory of Charlie Smith, who has provided the field of animal breeding with so many new and exciting ideas. Lush's influence on his students has been aptly summarised by Touchberry, quoted by Chapman (1991):"Dr Lush was highly respected and admired. He was firm without being threatening and he got his point and message across without raising his voice or using profanity. He was a warm and friendly person with a tremendous respect and tolerance for students".
The tradition of international openness that Jay Lush exemplified during his whole career at Iowa State has been continued ever since and is now enhanced with the launching of the Jay Lush Chair in Animal Breeding and Genetics, officially put in the hands of Dorian Garrick on 25 April 2008. All my best wishes go to the success of this initiative.

Zusammenfassung

Erinnerungen an Jay Lush

Im April 2008 fand an der Iowa State University in Ames ein Symposium „Lush Vision – Animal Breeding Plans" aus Anlass der Einrichtung eines permanenten Lehrstuhls für Nutztiergenetik in seinem Namen statt. In dieser Übersicht wird die Persönlichkeit und wissenschaftliche Leistung von Professor Jay L. Lush (1896-1982) als „Vater der modernen Tierzüchtung" gewürdigt. Sein Lehrbuch „Animal Breeding Plans" wurde in mehrere Sprachen übersetzt, gilt als Klassiker auf diesem Gebiet und wurde einmal als „bedeutend, selbst für die, die es nie gelesen haben" charakterisiert. Prof. Lush und seine Schüler in aller Welt haben durch Lehre, Forschung und Anwendung der wissenschaftlichen Erkenntnisse in allen Nutztierpopulationen maßgeblich dazu beigetragen, dass die Produktion von Lebensmitteln tierischen Ursprungs mit dem Bedarf einer wachsenden Weltbevölkerung schritthalten konnte.

4 In a letter of 1951 to Helen Turner Fisher recalls his visits to Lush at Ames in 1931 and 1935 and presents Lush as having done all his learning "at the feet of Sewall Wright in Chicago" (John James, personal communication)

Acknowledgements

It is a pleasure to acknowledge the advice and help received from many friends and colleagues during the preparation of this paper. Let me mention my fellow students in Ames, Tom Sutherland (Fort Collins) and John Wilson (Belfast), to whom I should add Max Rothschild (Ames), Bill Hill (Edinburgh), John James (Sydney), Jean Boyazoglu (Menton) and Jean-Louis Foulley (Jouy-en-Josas). But needless to say, the personal views expressed in this paper are only my responsibility.

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Videos of all talks presented at the Lush Vision Symposium were recorded and are available on the web at http://www.ans.iastate.edu/events/Lushsymp/?pg=videos

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Adaptability of laying hens to non-cage environments*

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Introduction

Since the decision to ban conventional cages in the EU by 2012, individual countries have passed laws for the transition period. Many egg producers are still undecided whether to invest in new facilities compatible with legal limitations or to give up egg production. Until a few years ago, most egg producers and poultry scientists agreed that cages were acceptable as a compromise between the needs of laying hens and the interests of producers and consumers.

Unresolved problems with non-cage management of laying hens have been pointed out repeatedly in the past (e.g. Flock, 1982; Flock et al., 2003), but we need to take a fresh look at this issue in view of the fact that conventional cages will be completely phased out in Germany a year from now. In the very near future, potential investors have to find answers to three questions:

(1) If they invest in enriched cages (or "Kleingruppenhaltung", a German version with more wellness for the hens than the EU minimum requirements), can eggs from these facilities be marketed with a sufficient profit margin?

(2) If they invest in a non-cage system, will they be able to provide the advanced management required for predictable results and recover the higher cost with a premium price?

(3) To what extent are differences between strains apparent and relevant for theses decisions, and are results from small groups in Random Sample Tests repeatable in large groups on production farms?

General review of alternative management systems

In his plenary lecture at the World Poultry Congress in Brisbane, Webster (2008) reviewed the development of theoretical and applied animal welfare in a historical context and from different points of view. As shown in table 1, hens and consumers may differ in their perception of different production systems:

Table 1: The welfare of laying hens in different production systems as perceived by the hen and by the people (Source: Webster, 2008)

	Conventional cage	Enriched cage	Free range
Hens	Unacceptable	Meets most hen needs	Acceptable if husbandry and environment are satisfactory
Consumers	Cheap and wholesome	"It is still a cage"	Increasingly popular
Farmers	No added value when it becomes standard	No added value	Added value

According to Webster, essential needs of the hens are met in "enriched" cages: much more space and opportunity to move around, dark nests, a dust bath and perches at different levels. With the term "Kleingruppenhaltung", German producers of eggs and equipment for the egg industry have tried to avoid the term "cage" and focus on the advantages of small groups in terms of behaviour and reduced risk of cannibalism and feather pecking. Not unexpectedly, opponents of non-cage systems

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* based on a paper by Flock and Norrman, presented at the 16th Baltic and Finnish Poultry Conference, on 3rd October 2008 in Vantaa, Finland.

launched a campaign against this system and it is not clear whether the egg industry will succeed in its attempts to get away from the current labelling (3 = cage production) which does not distinguish between conventional cages and enriched cages. At least two major discounters have decided that they will not list eggs from any cage system – ignoring the fact that many consumers prefer to make their own decisions on the basis of "value for money". The outcome of this dispute is still open, and egg producers must try to stay in business by keeping up with all relevant information.

Comparisons of Cage vs. Floor in German Random Sample Tests

In view of the expected ban of conventional cages in the EU, three out of five random sample testing (RST) stations in Germany discontinued their activities several years ago. Only two stations remain: Kitzingen in Bavaria changed to floor management in 1998, Haus Düsse recently installed "Kleingruppenhaltung", a form of enriched cages with more space than EU specifications.

Data comparing RST cage results from Haus Düsse with floor results in Kitzingen were presented 5 years ago at the Baltic Poultry Conference in Sigulda (Flock, 2003). Highly significant differences in mortality, hen-housed egg mass, feed conversion ratio and egg income minus feed cost were documented, with repeatable strain differences in three years. In the meantime, more data from 5 tests each (ending in 1999 – 2004) were analyzed and are presented in Table 2.

Table 2: Least squares means for major traits from cages (Haus Düsse) vs. floor (Kitzingen, with and without beak treatment); 5 tests each (1999-2004)

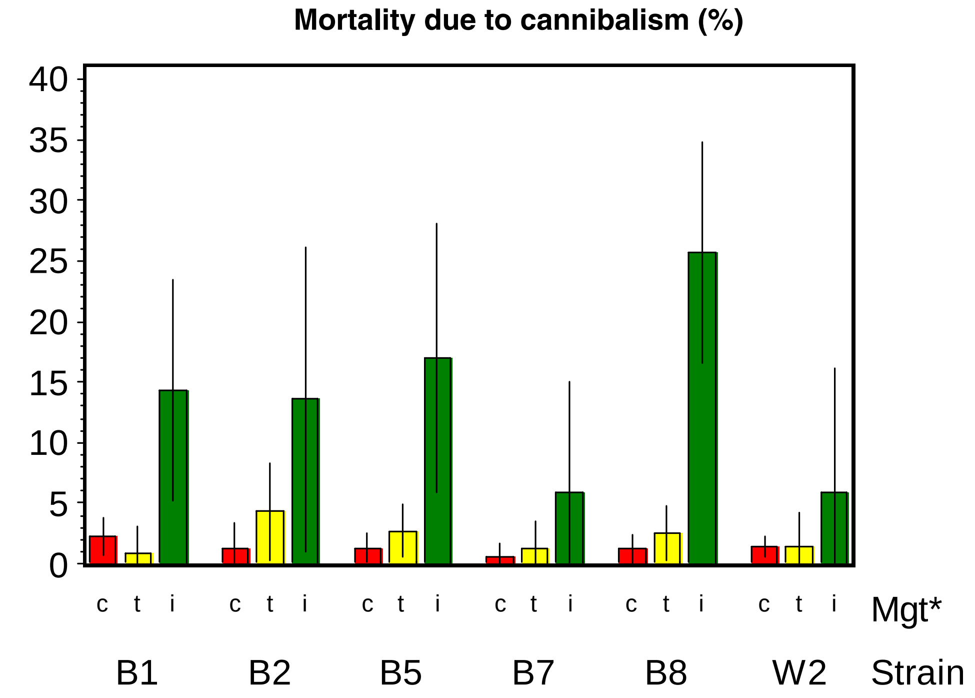
Management System	% Mortality		Egg Number		Egg Wt.	Egg Mass	F.C.R.
	Cannib.	Other	H.H.	H.D.	g	kg/HH	kg/kg
Battery cages, beaks trimmed	1.4	5.1	307.7	315.8	64.4	19.82	2.08
Floor, beaks trimmed	2.4	0.6	285.4	292.8	63.0	17.99	2.24
Floor, untreated beaks	14.0	0.5	266.2	288.9	63.4	16.87	2.36

Two results are immediately obvious: higher mortality due to cannibalism if pullets are not beak treated, and negligible mortality due to "other" causes under floor conditions. It is not known to what extent the lower egg production under floor conditions is due to uncollected eggs (e.g. dropped through the slats or eaten by the hens?). Similar differences were observed for some strains almost 40 years ago in German RSTs during the change from floor to cage testing, when strains were tested in both management systems.

The variability of results within and between strains is illustrated in Figures 1-5 for five traits of major interest: (1) mortality due to cannibalism, (2) egg number per hen housed, (3) average egg weight, (4) feed conversion ratio and (5) egg income over feed cost.

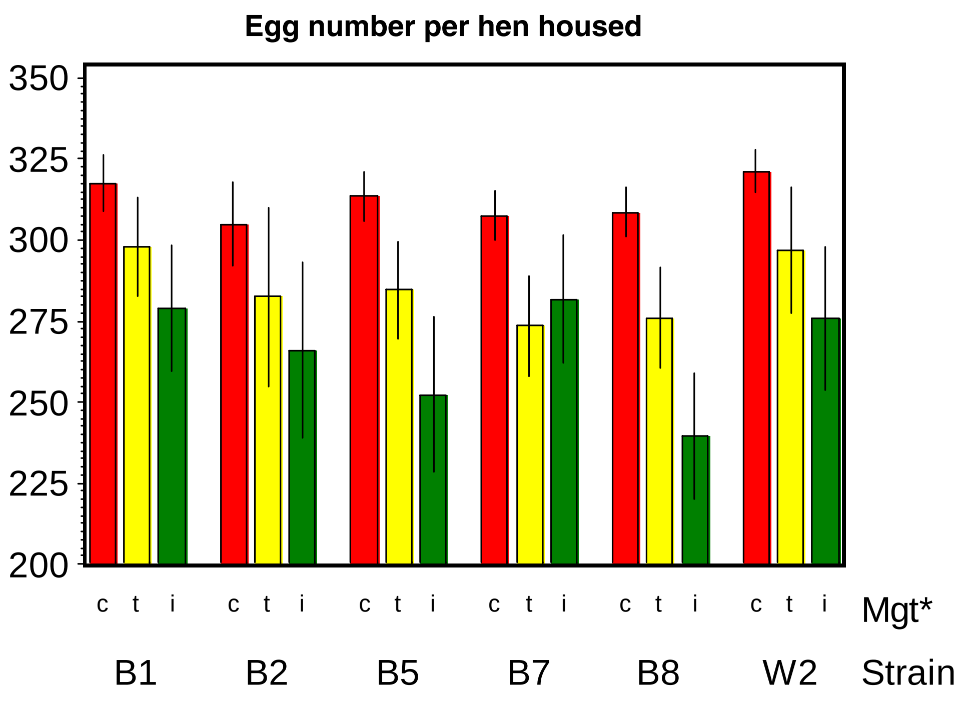
As can be seen from the graphs, there are substantial differences among brown-egg strains in their susceptibility to cannibalism and correlated production traits. Only one out of five strains (B7 = Lohmann Tradition) has similarly low mortality as the only white-egg strain (W2 = LSL) represented with sufficient frequency in these tests to be included in the statistical analysis.

Figure 1: Strain x Management Interactions in German RST



* Management: c = cages; t = floor, beaks trimmed; i = floor, beaks intact

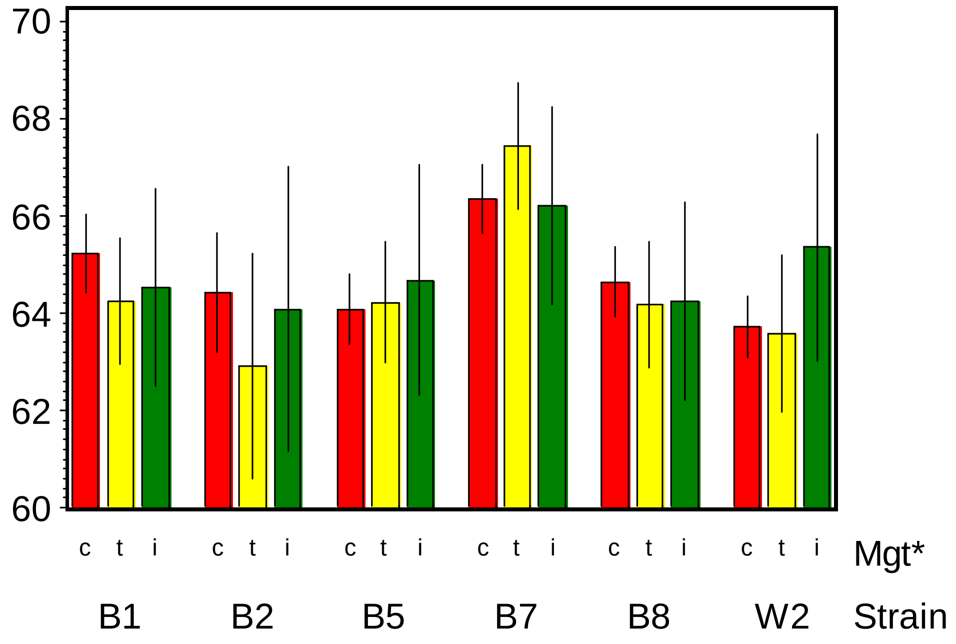
Figure 2: Strain x Management Interactions in German RST



* Management: c = cages; t = floor, beaks trimmed; i = floor, beaks intact

Figure 3: Strain x Management Interactions in German RST

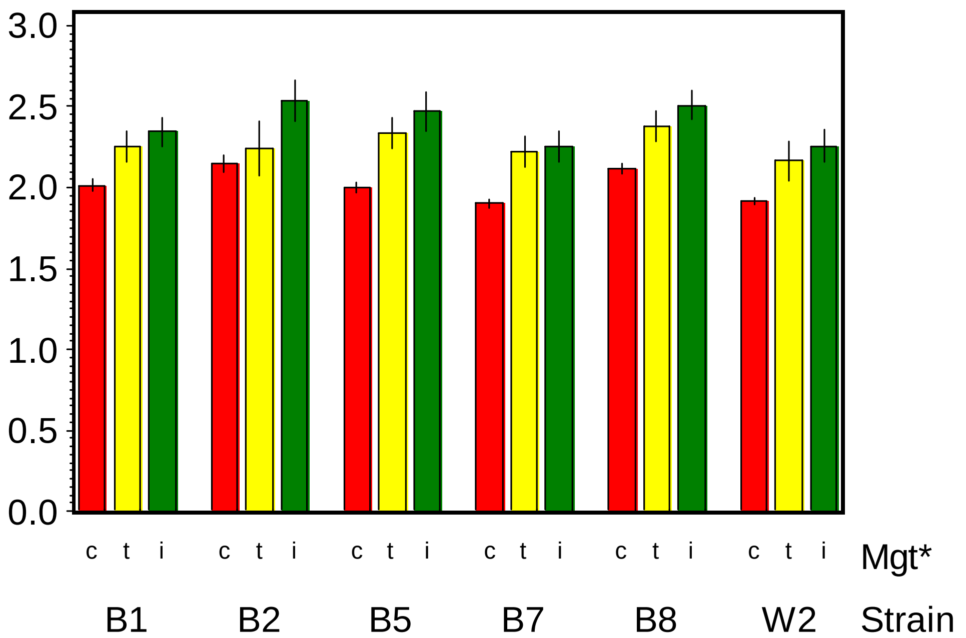
Average egg weight (g)



*Management: c = cages; t = floor, beaks trimmed; i = floor, beaks intact

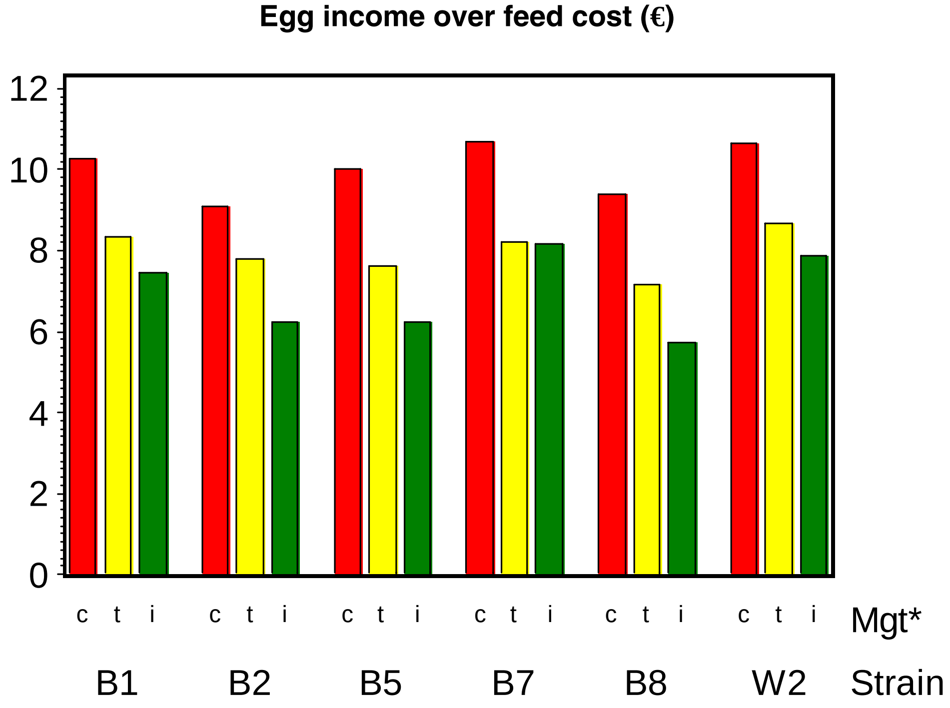
Figure 4: Strain x Management Interactions in German RST

Feed conversion ratio (kg/kg)



* Management: c = cages; t = floor, beaks trimmed; i = floor, beaks intact

Figure 5: Strain x Management Interactions in German RST



* Management: c = cages; t = floor, beaks trimmed; i = floor, beaks intact

Data from commercial egg production farms in Germany

A detailed analysis of field records from egg production farms in Germany was published by Bergfeld et al. (2004), based on a sample of 34 flocks from 17 farms, exclusively with floor management, varying between 500 and 20.000 in size. The results were evaluated in terms of economics, nutrition, product quality, poultry health and environmental impact (emissions and condition of free range after repeated use). The main conclusions were:

a) variation between flocks in all criteria studied indicates a high risk for producers

b) free range management is the most risky form of management

c) beak treatment is still necessary to limit risks of cannibalism and feather pecking

d) hygienic egg quality is effectively improved by slats, separating hens from litter

e) rearing conditions must correspond to the equipment in the laying unit; information on feeding, vaccination, lighting etc. must be made available at housing of pullets.

Strain differences are not documented in detail, but two findings are of special interest in the context of the present paper:

> white-egg layers averaged 89.4% rate of lay vs. 77.0% for brown-egg layers
> mortality averaged 11.8%, but ranged between 3.3 and 36.8%!

In Table 3 results of a study by Kreienbrock et al. (2004) are summarized based on 172 flocks in cages and 134 in floor systems. Average mortality in different floor systems ranged from 12.9 % to17.8 % - compared to 8.2 % in conventional cages - and slightly higher with free range than without access to free range.

Table 3: Laying mortality in different housing systems (Source: Kreienbrock et al., 2004)

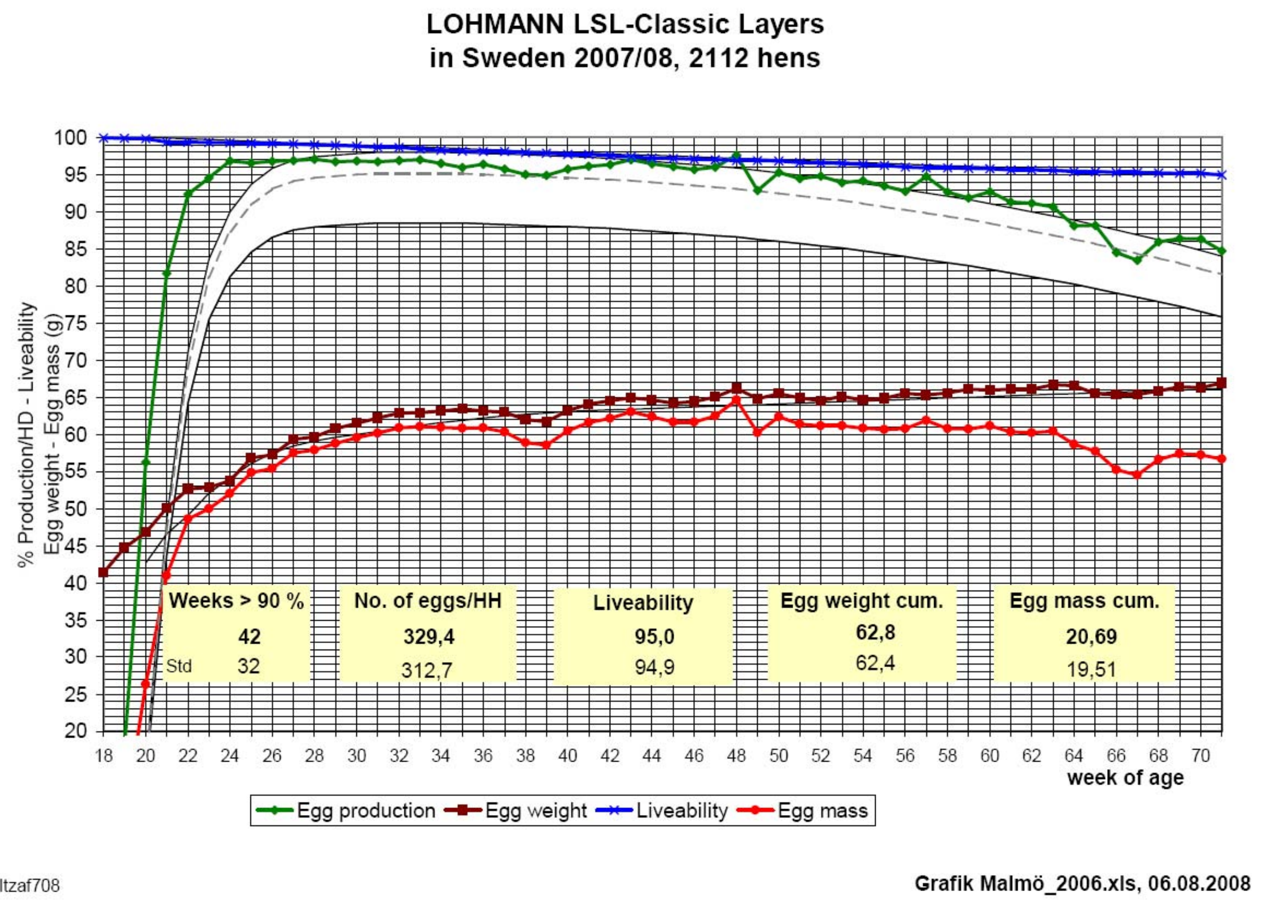
	Floor		Aviary		Cage
	Without range	Free range	Without range	Free range	
No. flocks	46	50	8	30	172
Mean	12.9	14.0	15.1	17.8	8.2
Best 10%	4.6	6.1	2.3	7.2	3.6

Although egg production is obviously less risky in cages and therefore more attractive for producers, consumers will eventually decide how eggs are produced. Therefore we must focus on the variation of results within systems, analyze repeatable causes of variation and learn from the best flocks.

A case study in Sweden: organic egg production with LSL hens

My career as geneticist started with the HNL breeding program 40 years ago, when we were still keeping our elite stocks exclusively on the floor and tested pedigreed crosses under floor and single cage conditions. Therefore I was curious to find out whether the current generation of LSL White Leghorns still copes well with floor management. I am happy to share with you results recently obtained from Lars Norrman in Sweden, who started to produce organic eggs a few years ago, after working 40 years in production and customer service for a company.

The results shown in Figure 6 are from an LSL flock on his farm in Southern Sweden, which recently completed a laying period to 71 weeks of age.



The excellent results shown in figure 6 were achieved by not only following strictly the general management recommendations for non-cage environments, but learning from own observations how to optimize the environment "from the birds' point of view". It is unlikely that similar results can be achieved if husbandry practices are decided in an office and carried out by farm personnel with limited knowledge and incentive to understand the needs of chickens.

The following recommendations may be used as a checklist to compare practices on other farms with the experience gained by Lars Norrman on his farm in successive flocks.

1. **The management of the laying flock must start from the day of hatch.**
   Get all relevant information from the rearing farm: vaccination schedule, feed source and quality, body weight; uniformity should be at least 80%.

2. **The rearing farm must have similar equipment as the laying unit.**
   Perches should be available from the beginning and will be used from one week of age. For organic egg production, a strict protocol must be followed.

3. **Transfer the pullets to the laying house early enough.**
   Most egg producers plan to house the flock at about 18 weeks when the vaccination program is finished. Close to the onset of lay, the pullets are curious to discover the new environment and to find the nests. Norrman got the best results from hens housed already at 14 weeks, two weeks before the critical time (16 to 18 weeks) when major hormonal changes take place.

4. **Proper light source and lighting program for open housing.**
   Windows are required for organic egg production, i.e. the lighting must take natural daylight into consideration. Lights must be gradually turned on and off. Conventional light bulbs are preferred over "energy-saving" tubes, which have been associated with nervousness. Consult experts for best light systems.
   Hens can be trained to return from free range with the sound of shutters before the end of the light day.

5. **Consistent feed quality is the most critical factor.**
   A good working relationship with the feed supplier is essential. Keep samples from each batch of feed to be analyzed by an independent laboratory in case of suspected deficiencies. An unbalanced amino acid profile is a common risk factor of organic feed.
   The feed structure in the rearing and laying farm should be similar. Prevention of selective feeding is especially important in floor housing systems. Sufficient crude fibre contributes to healthy guts and dry manure and may also reduce the risk of feather pecking and cannibalism (Pottgüter, 2008).

6. **Litter quality and air quality have to be optimized.**
   With cage management in closed houses, it is relatively easy to maintain good air quality, and there is no litter problem. In floor houses, wood shavings are preferred over straw and easier to keep in good condition. Solar energy can be used and is sufficient most of the time, wood pellets may supplement heating on cold days.

7. **Observe your birds daily, use veterinary help to diagnose problems.**
   Use your eyes, nose and ears to convince yourself that the hens are healthy and happy! Monitor water and feed intake daily. The first signal of feed quality problems or infections may be reduced water intake. By the time rate of lay and/or egg weight drops, it may be too late to correct the situation. Call for help of an experienced veterinarian to diagnose the situation if necessary.

8. **Keep accurate records and focus on utilization of the genetic potential!**
   Try to combine the highest genetic potential with the best possible husbandry under your specific conditions. Without knowing what a given strain of layers can achieve in terms of liveability, egg production and feed efficiency and corresponding "goals", it is impossible to assess the potential for further improvements. Avoid repeating the same mistakes and focus on what you can improve yourself instead of expecting solutions from others.

Discussion and conclusion

The management of random sample tests has to follow a given protocol to assure unbiased results and will be unable or reluctant to interfere if cannibalism starts in one group. Due to the small number of replicates, large differences between strains in traits like mortality are often not "statistically significant" and may be misleading. Primary breeders have additional information from many flocks around the world, enabling them to assess the relative risk of cannibalism in different strain crosses more reliably. Market shares of specific products reflect a combination of genetic potential, back-up with management recommendations and actual management on each farm. Primary breeders have been selecting against cannibalism for many years (Preisinger, 2001), and egg producers should monitor progress actually achieved with different strains while focusing on optimal management in their farm.

Assuming that the results from different management systems in RSTs shown in table 2 reflect field conditions, we can make the following rough calculation: 464 Mio people in the EU-25 consume on average 13.3 kg egg mass, i.e. 6.17 Mio tonnes of egg mass. If all these eggs were produced in cages under conditions like in Haus Düsse, 311 million hens would have to be housed, 20 million of which would die. To produce the same egg mass under floor conditions without beak trimming, 365 million hens would have be housed, 53 million of which would die (mainly due to cannibalism). An additional 54 million pullets would need to be reared and 1.7 million tonnes of feed would be required to cover the less efficient feed conversion. In view of the growing competition between food, feed and fuel, this point should not be ignored in a balanced assessment of different options.

Differences between strains in their adaptability to specific management systems are relevant for the choice of the most promising strain for a given management situation. To maximize family income, the goal should be to combine the best strain with best management. The market will eventually decide from which hens in which system eggs are produced. Farm management should make use of information on strain differences to minimize hen mortality and thereby improve hen welfare.

In Germany, many consumers do not discriminate on shell colour or even prefer white-shelled eggs if they are offered in supermarkets. But non-cage eggs are usually associated with brown shells, and it would take a dedicated promotion to convince consumers that non-cage eggs can also be produced from White Leghorns, probably even more environment-friendly, because fewer hens and resources would be needed to meet consumer demands for eggs and egg products.

Zusammenfassung

Zur Anpassungsfähigkeit verschiedener Legehennenherkünfte an alternative Haltungdssysteme

Bis 2012 wird in der EU die konventionelle Käfighaltung von Legehennen beendet, in Deutschland muss die Umstellung auf alternative Haltungssysteme bereits bis Ende 2008 bzw. mit Übergangsregeln im Laufe des Jahres 2009 erfolgen. Es kommt jetzt darauf an, das Marktpotenzial für Eier aus der Kleingruppenhaltung auszuloten und die Umstellung auf Boden- bzw. Freilandhaltung durch positive Beispiele und entsprechende Managementempfehlungen zu unterstützen.

Ergebnisse aus deutschen Legeleistungsprüfungen zeigen ebenso wie Praxisdaten deutliche Vorteile der Käfighaltung, die sich auf die Kleingruppenhaltung übertragen lassen. Ob sich der Umstieg auf alternative Haltungssysteme rechnet, hängt für den einzelnen Betrieb von seinen Produktionskosten und dem zu erzielenden Preis ab. In jedem Fall sinnvoll ist eine gründliche Analyse der Varianzursachen mit dem Ziel, von den Betrieben mit den besten Ergebnissen zu lernen und eigene Fehler nicht zu wiederholen. Die Ergebnisse einer LSL-Herde in Schweden zeigen, dass die Produktion von Bio-Eiern bei entsprechendem Management auch mit Weißen Leghorn möglich ist, sofern die Kunden nicht auf braunschalige Bio-Eier fixiert sind. Dabei sollte nicht vergessen werden, dass bei der Produktion von Bio-Eiern wegen der extrem hohen Futterkosten jedes zusätzlich verkaufte Ei relativ mehr bringt als bei den geringen Margen konventioneller Käfighaltung.

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Fibre in Layer Diets

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Introduction

Fibre in poultry diets may sound like a rather odd topic. When I talk to egg producers about fibre from a nutritionist's point of view, I may get a puzzled smile. All poultry and egg producers know that fibre is important for feeding horses, cattle, sheep, rabbits and even monogastric pigs and some poultry species such as geese and ratites, but laying hens? Even among poultry nutritionists the subject of fibre in poultry nutrition may still raise a polite but slightly incredulous smile.

From the international literature (van Krimpen 2008, Esmail 1997, Neufeld 2008, Hartini, Choct, Hinch and Nolan 2003) and listening closely to colleagues from different countries I get the impression that this must be a very interesting subject. Research in poultry behaviour has produced a growing body of evidence showing a positive effect of crude fibre (roughage). There are also extensive indications from research and practical experience suggesting a positive effect on faecal consistency and litter quality.

A look at layer mixtures in international comparison reveals that the crude fibre content of the mixtures varies considerably among different countries, while performance levels tend to be consistently high across the board. It is also worth noting that oats, a high-fibre cereal, is being used in north-western Europe for feeding poultry, especially during the moulting, and evidently with positive results.

Restrictions on the use of raw materials with high fibre content in layer rations are more likely due to technological reasons and processes for optimising linear feed formulations rather than specific characteristics or components of these raw materials as such.

Compared with feed mixtures for cattle, pigs and other farm species, poultry diets are typically high-energy mixtures and, assuming appropriate raw materials are available, extremely high concentrations of fibre will not occur in any case.

Definition of crude fibre

In animal nutrition the terms 'crude fibre' and 'roughage' are often used as synonymous. The reason for this is that fibre is a term that has been in use for a very long time. The term 'crude fibre' originated from the science of feed analysis, more specifically the 'Weender Analyse' system of feed analysis founded back in 1864. With the `Weender' analysis, various feed components and ingredients can be compared to get a rough estimate of digestibility. The term 'crude fibre' describes different structural plant materials that are insoluble in diluted acids and lyes and form a diverse group of poorly digestible or indigestible feed constituents. This might be the reason why fibre has a fairly poor reputation in poultry nutrition.

Crude fibre comprises the roughage in feed raw materials, also referred to as structural carbohydrates. These plant structural carbohydrates are composed of cellulose, hemicelluloses (pentosans, hexosans) and indigestible materials, mainly lignin. The composition of crude fibre differs in each individual plant food. Structural carbohydrates are virtually impossible to digest enzymatically in the animals' small intestine. Only the gut bacteria can digest crude fibre through fermentation by forming short-chain fatty acids and methane among other things. The proportion of cellulose and lignin in the crude fibre fraction also determines the digestibility of crude fibre or its solubility in the intestine. High cellulose and lignin concentrations mean reduced digestibility and vice versa. Wheat and maize for example have comparatively good crude fibre digestibility in monogastric animals (pigs, poultry), while oats are poorly digestible. Ruminants are very efficient at utilising crude fibre via rumen bacteria. The so-called „caecal digesters" (e.g. horses and rabbits) can also utilise dietary fibre for energy. These animal species need fibre in their daily ration for stable and healthy digestion. By-products of cereal processing such as wheat bran, wheat middlings and oat hull bran are particularly high in fibre. Some cereal varieties such as wheat, rye and maize contain little fibre, whereas husky cereals like oats and barley have higher fibre contents.

All plant fibre materials are polysaccharides, with the exception of lignin, a polymer of phenylpropane. A chemical definition is: "Roughage is non-starch polysaccharides - NSP". Starch, also a polysaccharide and as the principal constituent in all cereal varieties the major energy source in poultry nutrition, is used here as reference. The term „insoluble NSP" is increasingly used internationally to denote roughage such as crude fibre. They differ from „soluble NSP" which, when present in high proportions in poultry diets, can cause the familiar problems of moist, sticky droppings and wet litter. This suggests that NSPs could reasonably be divided into „good NSPs – roughage / crude fibre" and „bad NSPs". When people talk about NSPs they usually mean the latter, where the use of so-called NSP enzymes is indicated to eliminate the problems mentioned. Extensive knowledge based on scientific research is available in this area and when using such raw materials in poultry diets the use of NSP enzymes has now become standard practice.

The acquisition of new knowledge in the area of "insoluble NSPs – roughage / crude fibre" on the other hand is still a relatively new endeavour which, following some highly promising initial results, still requires much research work and verification of these results in the field.

Origins of crude fibre

Fibre is present in all feed raw materials and passes into feed formulations more or less unavoidably. As crude fibre makes officially no contribution to the nutritional value of poultry feed, yet has to be declared as a maximum value in many countries, the crude fibre content is included in all feed calculations and optimisations as information. As a rule, crude fibre is not subject to a minimum requirement in poultry rations and a maximum value is merely designed to ensure that the declaration is not exceeded. With different raw materials the actual fibre content can therefore range from about 2.5% in a maize-soya based mixture to 6.0 – 7.0% in mixtures based on barley, extracted sunflower meal and cereal by-products such as bran.

As the fibre content is on the one hand related to the energy content of different raw materials and on the other hand deserves more attention in the formulation of poultry rations, some examples of raw materials conventionally used in various countries and regions in poultry diets are described below.

Maize

Maize, the standard raw material in poultry nutrition, has the highest energy content of all the commonly used cereal varieties. This is directly related to a low content of crude fibre of about 2 – 3%, depending on quality and origin, and a relatively low content of soluble NSP. Maize with its golden-yellow colour is regarded by poultry producers worldwide as a quality symbol for poultry feed.

Sorghum, millet

Sorghum and millet are most commonly incorporated in poultry diets in North and South America, where they are grown. Nutritional value and fibre content are similar to maize. Because of its cost effectiveness sorghum was also used at fairly high concentrations (up to 40%) in poultry feed in Northwest Europe in 2007/2008.

Wheat

Wheat was for a very long time the most important cereal variety for poultry feed in Northwest Europe. It has a slightly lower energy content than maize, the fibre content is similar to that of maize and the content of soluble NSP is variably higher than in maize, depending on origin and harvest year.

Rye, triticale

Rye and triticale (a cross of wheat and rye) have a slightly higher content of crude fibre than wheat, the energy content is slightly lower and the content of soluble NSP distinctly higher. The use of these two cereals in poultry feed is regionally restricted to the areas where they are grown and the inclusion of suitable NSP enzymes is indicated if they make up a significant proportion of the mixture.

Barley, oats

Barley and oats are also called ‘husky cereals’ and, as the name suggests, have a much higher fibre content than the cereal varieties described so far: barley about 4.5 – 7.0% and oats about 10% crude fibre. Their energy content is low and both cereal types have considerable proportions of soluble NSP. When used in poultry diets the inclusion of suitable NSP enzymes is generally recommended. Barley and oats are used in large amounts in poultry diets in the countries where they are grown, significantly increasing the crude fibre content of the mixtures. Depending on availability and cost effectiveness they are highly suitable for increasing the crude fibre content of the feed formulation.

Cereal by-products, brans

Depending on the milling degree of the original cereal, all by-products of cereal milling have fairly high fibre contents ranging from about 10 to over 20%. Concentrations – including levels of other nutrients – can fluctuate widely and regular analytical checks and adjustment of the raw material matrix is an essential prerequisite for their use in poultry feed. The energy content is significantly lower than that of the original cereal because starch in particular is extracted as flour in the mill. On this basis these raw materials can provide attractive sources of nutrients and fibre, especially if low-energy mixtures are desired, e.g. for pullets during developer phase or broiler breeders. These by-products of cereal processing are unfortunately not available on the normal raw material market in all countries, but if available and cost effective, they are ideal sources of crude fibre for poultry diets formulated for specific purposes.

Soya, extracted soybean meal

Soya beans and their processing by-products are the most important protein source in the nutrition of all farm animals worldwide. This is due to their numerous advantages compared with other oilseeds, resulting in extensive cultivation and a worldwide trade in soya products. Extracted, toasted soybean meal is widely used in feed mixtures all over the world, on a regional level also whole toasted soybeans. Soybean meal in particular has many advantages in poultry nutrition: a high protein content, a fibre content of about 3-7% depending on quality and a higher energy content than other oilseed meals. The protein and crude fibre contents of soybean meal fluctuate in opposite direction depending on quality, i.e. the higher the protein content the lower the fibre content and vice versa, and the energy content varies accordingly. An analysis of the soybean meal quality used in any ration is highly recommended as a routine measure of feed quality control.

Rape, sunflowers

After soya, rape (and canola) and sunflowers are the most widely grown oilseed crops worldwide, and consequently so are their by-products: extracted rapeseed and sunflower meal. To a lesser extent, the various expellers or cakes with variable residual oil contents are also available regionally as feed raw materials. The available processing by-products of rapeseed and sunflower seeds show very wide variability across the world and regular analytical checks and adjustment of the raw material matrix are an imperative prerequisite for using these raw materials, especially analyses for crude fibre content, which is significantly higher (7 to over 20%) than in soya meal. Therefore they provide a readily available source of fibre. Since the crude fibre content is negatively correlated with the energy content, it deserves attention for that reason alone.

Dried grass meals, lucerne, alfalfa

Dried grass meals are used regionally, especially in layer rations. This is mainly due to their content of natural yellow pigments and the achievable effects on yolk colour. The content of crude fibre varies depending on quality, ranging from 15-30%, and the remaining nutrients can also fluctuate considerably. If available and cost effective, dried grass meals and similar raw materials can provide a very good source of dietary crude fibre. In processed form they are spread in the litter and have shown a positive impact on poultry behaviour.

Lignocellulose

Crude fibre products of lignocellulose are already well established in some areas of farm animal nutrition, including poultry diets, where promising initiatives have been undertaken in the field and in research. Lignocellulose is defined as cellulose and hemicelluloses with lignin deposits, i.e. it is lignified (woody) plant material. The advantages of these products are the standardised crude fibre content of about 50-65% depending on the product, the absence of mycotoxins and the thermal hygienisation in the manufacturing process.

It is beyond the scope of this paper to describe all raw materials that are successfully used in poultry nutrition worldwide. Animal by-products are not considered here because they are not used in many countries and also tend to have a very low fibre content. But it has become clear that there is an urgent need for all raw materials used in formulating feed mixtures for poultry to be regularly analysed for their content of crude fibre (and nutrients), on the one hand to gather information about the current situation and on the other hand to be able to exploit the positive effects of crude fibre effectively, as outlined below.

Table 1: Content of crude fibre and different NSP fractions in selected feedingstuffs in g/kg DM (source: AWT, 2005)

Feedingstuff	Crude fibre	Beta-glucans	Pentosans	Total NSP
Wheat	20 - 34	2 - 15	55 - 95	75 – 106
Rye	22 - 32	5 - 30	75 - 91	107 – 128
Triticale	30	2 - 20	54 - 69	74 – 103
Barley	42 - 93	15 - 107	57 - 70	135 – 172
Oats	80 - 123	30 - 66	55 - 69	120 – 296
Maize	19 - 30	1 - 2	40 - 43	55 – 117
Wheat bran	106 - 136	*	150 - 250	220 - 337
Soybean meal	34 - 99	*	30 - 45	180 - 227
Rapeseed meal	109 - 159	*	*	187
Fodder peas	56 - 72	*	*	156

* no data available

How does crude fibre pass into the feed formulation?

Crude fibre, roughage and insoluble NSP pass automatically into every feed formulation, especially via plant-derived raw materials. Any animal nutritionist responsible for designing poultry feed formulations is therefore well advised to learn as much as possible about crude fibre in different feed components and their effects on the animals. Where crude fibre (also described as insoluble NSP in a different form) is currently not present as a matrix value, the first thing to do is to set up an appropriate database of all raw materials. Once this is done the crude fibre content will automatically flow into all calculations and optimisations and differences between different feed compositions can be identified. The question whether any conclusions are then drawn from this information in terms of modifying feed formulations depends on many factors, such as the availability of fibre carriers as raw material, the cost effectiveness of these raw materials and also the need or desire for targeted intervention by manipulating the crude fibre content of the mixture.

Cost effectiveness is of central importance in ration formulation and evaluation of raw materials as costs must always be considered. Cost effectiveness denotes the value of a raw material e.g. in Euros or Dollars at which it is initially included in the formulation during feed optimisation with a view to reducing the overall cost of the mixture. The cost effectiveness of a raw material is determined by its nutrient content and its absolute price within a specific formulation in competition with alternative raw materials. Cost effectiveness in this context is completely different from a high or low absolute price of a raw material and can ultimately only be determined by using an optimisation program.

As already indicated in the description of individual raw materials, if maize and soybean meal are the only basic raw materials available for a feed formulation, the result will be a relatively low fibre content of about 2.5 – 3%. In this situation there is virtually no prospect of achieving a higher fibre content, which is a disadvantage when formulating an optimal developer feed for example. Faced with this situation it is advisable to check again whether any other raw materials might be available, e.g. DDGS, a raw material with a significant crude fibre content of approximately 5-10% depending on origin and quality which accrues as a by-product of bioethanol production. By introducing a minimum restriction for crude fibre in the optimisation it is possible to test the possible extent of increasing the fibre content.

In other countries and regions, such as Scandinavia or Spain, the ready availability and cost effectiveness of barley, in Scandinavia also oats, automatically results in crude fibre contents of about 4.5 – 6.5% in layer rations. If these raw materials are available, perhaps with additional cereal by-products, the desired fibre content can easily be achieved via ration optimisation. In countries where different raw materials with varying nutrient and fibre concentrations are usually available, cost effectiveness is the main factor in deciding whether or not to include the raw materials in the formulation, thus enabling the experienced nutritionist to achieve a specific crude fibre content in the ration.

A recent example from Western Europe may illustrate this point. During the period from mid-2007 to about mid-2008 changes in the cost effectiveness of corn and wheat resulted in layer rations almost entirely based on maize and soya, following several decades with wheat and soya as main components. Without setting a minimum restriction for crude fibre in optimisations, the fibre content in the finished feed would decline markedly.

Other sources of crude fibre in poultry diets are the different oilseed meals, which are primarily incorporated into the mixtures to cover the protein requirement. While soybean meal (especially high-protein grades) bring little fibre into the formulation, the use of extracted sunflower seed meal and rapeseed meal results in significant amounts of crude fibre in the formulation. Here too, a specific, stable fibre content can be maintained via the optimisation program, provided the relevant raw materials are available and cost effective.

Without the availability and cost effectiveness of suitable raw materials, it may be virtually impossible to achieve a specific crude fibre content in the formulation. In this case an alternative solution would be products based on lignocellulose for optimising the crude fibre content, entirely with insoluble NSP, an approach which has already proved effective in practice and is discussed in more detail below. Due to their very high fibre content these products have the advantage of requiring relatively little space in the formulation in order to achieve a marked increase in the crude fibre content of a formulation. The same is true if the fibre content of more highly concentrated mixtures is to be increased, for example a nutrient-dense layer starter ration or broiler feed. If normal fibre carriers such as bran or extracted sunflower seed meal are included in the optimisation program in competition with a crude fibre concentrate, this may turn out to be highly cost effective and result in an overall cost reduction. Any modification or optimisation of the formulation to achieve a given crude fiber content should preferably be achieved without affecting the levels of the remaining nutrients in the ration, especially the energy content. If this is not achieved, adding a raw material with higher fibre content will educe the nutrient content of the ration, which may well result in performance reduction and reinforce traditional negative attitudes towards crude fibre. But with expert ration optimisation this is unlikely to happen. Modifying a layer ration to achieve a specific, slightly higher crude fibre content while maintaining the energy content can involve a slightly increased use of fats and oils. This is very welcome as it improves the acceptance of a meal-type feed for hens, binds dust and because a higher energy contribution from fat and oil provides numerous nutritional benefits for high-producing laying hens.

Table 2: Nutrient content of selected feedingstuffs (figures at 88% DM)

Feedingstuff	Crude protein %	Crude fibre %	Crude starch %	Energy ME MJ/kg
Wheat	12.1	2.6	58.3	12.78
Rye	9.9	2.4	55.6	12.24
Triticale	12.8	2.5	56.3	12.59
Barley	10.9	5.0	52.7	11.43
Oats	10.6	10.2	39.8	10.25
Maize	9.1	2.3	62.0	13.35
Sorghum (Milo)	10.1	2.1	62.0	13.03
Wheat bran	14.1	11.8	13.1	6.17
Soybean meal 48	46.8	4.3	4.0	9.9
Rapeseed meal	34.0	11.5	5.7	8.7
Fodder peas	22.1	5.9	42.1	11.03

Source: Jeroch & Dänicke 2008 and own calculations; energy according to ME estimation formula

Practical experience with fibre in layer diets

Looking at diets for laying hens in international comparison we find that fibre is not a negative element and has no adverse effect on layer productivity. Even though the majority of poultry kept for commercial purposes are fed maize/soya-based rations, there are still many countries with intensive poultry production where this is not the case. In these countries mixtures based on wheat, triticale, barley and even oats are formulated and protein sources, along with soybean meal, include extracted sunflower seed meal, rape or canola products, other legumes such as peas or field beans or other diverse plant-derived protein carriers such as dried grass meal. There is also a wide range of other raw materials that can potentially be used for feeding laying hens. The resulting mixtures may well contain up to 7% fibre in the classic sense, distinctly more than in the maize/soya mixtures. Allowing for the problem of soluble NSP, which require the use of NSP enzymes, and insoluble NSP (crude fibre), these diets are entirely equivalent to maize/soya-based mixtures in terms of productivity and egg quality of modern layer hybrids. Very often it is found that rations with higher fibre content, i.e. more than 3.5 – 4.0%, stabilise the gut, resulting in drier litter, especially in non-cage systems. Even in battery systems a more stable gut situation will reduce the proportion of dirty eggs.

Reports in the literature (Rezaei,Torshizi and Rouzbehan 2008) and practical experience in several countries suggest that layer rations with higher fibre content can reduce the ammonia concentration in the air. This has a positive effect on the health of the birds and improves working conditions in poultry houses. Excessive ammonia levels are a frequent problem especially in floor systems.

From my own practical experience, I can report that diets with higher fibre content have a favourable effect on laying hens in non-cage production systems. This observation has been confirmed by recent scientific studies (van Krimpen 2008; Hartini, Choct, Hinch and Nolan 2003) and should be taken into account as a contribution to ensure continued success of the egg industry when adapting production systems to consumer preferences for eggs from non-cage systems.

In the rearing of laying hens the dietary fibre content is also of key importance during the pullet or developer phase (approx. weeks 9 – 16). Provided the development of the chicks during the starter phase (up to week 8) was successful, a nutrient-reduced ration can and should be fed during the pullet phase in order to enable the pullets to grow slowly into physically and sexually mature laying hens. The nutrient reduction in the developer diet refers to the protein and amino acid content rather than the energy content. If available, raw materials with a lower nutrient density and higher fibre content could be introduced into the ration. In many countries these raw materials are also often more cost effective than cereal and soybean meal and can thus help to reduce feed cost in the pullet phase, the time of highest feed consumption during the rearing phase. A higher fibre content in pullet feed (e.g. above 5.5%) also helps the young birds to get used to eating a larger volume of feed. The inclusion of high-fibre components (e.g. cereal by-products) slightly reduces the specific weight of the feed, forcing the pullets to spend more time eating.

Training pullets for a high feed intake capacity during rearing is the key to adequate feed intake at the start of the laying period. At this critical time many flocks have an inadequate feed intake, leading to depressed productivity and failure to achieve peak performance. Undernourishment of hens during this phase may also cause poor performance and health problems later on, such as fatty liver syndrome. It has been shown in scientific trials (van Krimpen 2008; Harlander-Matauschek 2007) that an increased content of crude fibre (insoluble NSP) additionally has a favourable impact on behavioural characteristics of hens by reducing the tendency to aggressive pecking and cannibalism. As a rule, when efforts are made to increase feed intake the use of meal-type feed and feed with a higher content of insoluble NSP reduces the tendency towards abnormal behaviours or vices, an important consideration in terms of animal welfare. There is also a direct correlation between dietary fibre and maintenance of an intact plumage, which must be a fundamental aim of any commercial poultry operation. If a wide range of raw materials is available, it is relatively simple to optimise feed formulations by setting maximum and minimum levels for crude fibre. To what extent this is possible depends on many factors, not least the cost of the formulation, if crude fibre “is not calculating by its own”, as the nutritionist sitting at his optimisation computer tends to put it. Experiences gathered by animal nutritionists in many countries with formulations optimised for a higher crude fibre content should be an incentive to introduce it even in countries where it has not been practised previously. But it is not possible to give a generally valid recommendation as the availability of suitable raw materials and their relative cost effectiveness can differ significantly.

A question that is still entirely unresolved is the impact of fibre, if any, on the gut flora. It is well known that a healthy, species-specific gut flora is essential for stable digestion and efficient nutrient absorption. It is the basis of the body’s ability to fight infections and the competence of the gut as an inductive site for immune responses. We know from other species that the gut flora can be influenced by stabilising it through nutrition and diet, but very little research has been done in this area with poultry. The author has reports from the field suggesting that feed which has been optimised specifically for gut health via the crude fibre content might potentially have an effect on the clostridial problem. But further practical experiences and research work are required in this area.

It has already been mentioned that the options for accurately adjusting the crude fibre content in ration formulation are very limited if suitable raw materials are either unavailable or not cost effective. In this situation, the use of fibre carriers based on lignocellulose provides an alternative. Initial published results from the field on this subject in poultry are already available, following successful use of these products in the nutrition of pigs, rabbits and household pets. The impact of these fibre concentrates (50 – 65% crude fibre) on faecal stability and litter quality is usually instantly evident. Given the additional stabilisation of the gut and the resulting improvement in nutrient absorption, an effect on the animals’ performance is a logical consequence. Fibre concentrates offered on the market do not have the often wide fluctuations in the nutrient content found in normal fibre carriers (e.g. brans, dried grass meals) and provide guaranteed hygienic quality, such as absence of contaminants and mycotoxins. They require less space in the ration formulation to achieve a consistent increase in the fibre content of the diet. It may even be possible to achieve a cost advantage if a minimum restriction has already been incorporated in the optimisation program.

Table 3: Layer diets with different raw materials and varying content of crude fibre (and crude fat), optimised for constant nutrient content

Diet No.	1	2	3	4	5	6
Maize/corn %	60.8	-	-	-	-	57.3
Wheat %	-	64.3	36.4	38.0	44.1	-
Barley %	-	-	24.2	19.9	13.6	-
Oats %	-	-	-	-	-	-
Soya -48 %	24.1	12.5	13.5	8.4	4.6	23.1
Soya full -fat %	1.0	8.6	9.8	9.3	8.5	-
Sunflower meal -38 CP %	-	-	-	-	12.0	-
Rapeseed meal %	-	-	-	7.6	-	2.9
Fibre concentrate -65% CF %	-	-	-	-	-	1.0
Minerals, fat & oil, supplem. %	14.1	14.6	16.1	16.8	17.2	15.7
Nutrients, varying:						
Starch %	38.9	38.3	34.3	33.2	33.3	36.7
Crude fat %	5.3	5.5	7.5	8.0	8.0	8.0
Crude fibre diet %	2.8	2.9	3.5	3.9	4.2	3.8

Nutrient content all diets: ME 11.4 MJ/kg; 17% crude protein; 0.34% dig. methionine; 0.60% dig. lysine; 3.8% calcium; 0.33% av. phosphorus; 0.17% sodium; 1.8% linoleic acid.

Discussion

Fibre has no direct nutritive benefit in poultry nutrition and has until now been regarded as `useless roughage´. Diets based on maize and soya products predominate worldwide and are considered ideal for poultry. But many countries have had very good experience using other raw materials with higher fibre content (e.g. wheat, barley, oats, bran, rape products, sunflower seed products) in poultry diets. Compared to conventional maize/soya-based mixtures, these diets have a significantly higher content of crude fibre (insoluble NSP). This suggests that fibre is by no means harmful for poultry.

Many countries have had very positive results from using raw materials with higher fibre content. This has changed the perception of crude fibre in layer diets (and also in chick starters); it is no longer regarded as just roughage and is now deliberately incorporated into poultry rations via the optimisation process. The effects have generally been a positive impact on faecal consistency and litter and a reduced percentage of dirty eggs.

Results from commercial farms suggest that monitoring or deliberately manipulating the fibre content can be highly beneficial if the aim is to optimise the diet for `gut health´. There is mounting evidence that fibre has a positive effect on behavioural characteristics of poultry. Scientific studies on this subject are also increasingly appearing in the international literature. In view of the current trend in the EU and other countries to change from conventional battery cages to alternative systems for laying hens, it is important to determine to what extent diets with optimal fibre content can help to control aggressive pecking in non-beak treated hens in floor systems.

To what extent fibre is actually included in layer diets will depend on the availability of suitable raw materials. The options are limited where classic maize/soya diets are used. But awareness of the benefits of fibre might encourage animal nutritionists and feed manufacturers to actively search for raw materials not previously used, in an attempt to introduce these into established formulations. One such „new“ raw material is DDGS (dried distillers grains with solubles), a by-product of worldwide bioethanol production. Others include all by-products of cereal processing for food use such as brans and middlings and by-products of oil extraction from sunflower seed or rapeseed. Where these or similar raw materials are not available, the use of crude fibre concentrates based on lignocellulose provides an alternative. Products of this type are of standardised quality with a very high hygiene status and are free of undesirable contaminants such as mycotoxins.

Initial results on the use of lignocellulose-based products in broilers, turkeys and laying hens have recently become available. They confirm the basic findings obtained with conventional fibre carriers but also open up new possibilities, including cost-optimal formulation of layer diets.

Conclusion

Maize and soybean meal are considered worldwide to be the standard raw materials for laying hen diets. In many regions where these materials are either unavailable or not cost-effective farmers have been using alternative raw materials, which inevitably leads to a higher fibre content in layer diets compared with the standard maize/soya based formulation. The productivity of flocks fed these diets is at least equal, and in some cases even superior, to the maize/soya diets. Stabilisation of the digestion, resulting in drier droppings and improved litter, is often a welcome secondary effect.

Research results indicating a positive nutritional effect and a favourable impact on behavioural characteristics of laying hens by feeding diets with higher levels of crude fibre (insoluble NSP) are increasingly reported in the international literature (van Krimpen 2008; Harlander-Matauschek 2007; Hartini, Choct, Hinch and Nolan 2003). If conventional fibre carriers are unavailable or not cost effective for ration formulation the use of crude fibre concentrates based on lignocellulose provides an interesting alternative for adjusting the fibre content (insoluble NSP) of a feed formulation.

Practical experience with manipulating the fibre content of diets for laying hens and growing chicks have had the following results:

- Pullets learn sufficient feed intake to overcome the critical period of peak production
- Effect on the gut flora through `feeding for gut health´
- Stabilisation of digestion with a positive effect on litter condition and house climate
- Reduced percentage of dirty eggs due to sticky droppings
- Favourable impact on behavioural characteristics, such as aggressive pecking and cannibalism

Optimizing the fibre content is an important aspect of formulating diets of laying hens. Further research into the effect on poultry behaviour in general and the impact of the content of insoluble NSP (crude fibre) and the different crude fibre fractions on digestive physiology are required to verify the experience gained in the field.

Zusammenfassung

Rohfaser wurde bisher in der Geflügelernährung wenig beachtet. In diesem Beitrag wird deutlich, dass Rohfaser zwar keinen „Nährwert“ im klassischen Sinn hat, aber erwünschte Nebenwirkungen bei richtiger Dosierung haben kann: (1) die Entwicklung eines optimalen Verdauungstraktes in der Junghennenaufzucht hilft in der kritischen Phase der Legespitze, genügend Futter aufzunehmen; (2) eine stabilere Darmflora trägt zu einer besseren Kotkonsistenz bei und zeigt sich u.a. durch bessere Einstreu bei Bodenhaltung und weniger Schmutzeiern in allen Haltungssystemen; und (3) gibt es Hinweise, dass mit erhöhtem Rohfasergehalt die Neigung zu Federpicken und Kannibalismus verringert wird – vorausgesetzt, das Fertigfutter bleibt ausgewogen in allen essentiellen Nährstoffen, insbesondere limitierenden Aminosäuren.

Deutschsprachige Leser seien auf einen Beitrag des Autors im Geflügeljahrbuch 2009 hingewiesen, der nicht nur, aber auch das Thema Rohfaser im Zusammenhang mit der Auswahl von Rohstoffen für die wirtschaftlich optimierte Geflügelfütterung ausführlicher behandelt.

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The History of VALO SPF*

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Heinz Lohmann, the founder of our company, always admired Americans with their scientific approach to business. Between 1956 and 1958 he signed license agreements with American poultry breeders Nichols and Heisdorf & Nelson for die multiplication and distribution of broilers and layers, respectively. With these cooperations he established a basis for transferring knowledge from the USA to Germany between geneticists, nutritionists and veterinarians.

In the late 1950s, a close cooperation and personal friendship developed between veterinarians of the Lohmann Veterinary Laboratory (Drs. Landgraf, Vielitz and Kirsch), their colleagues at the H&N Veterinary Laboratory (Dr. Zander and others) and Prof. Roy Luginbuhl, virologist at the University of Connecticut.

While German veterinarians still knew only two or three typical poultry diseases - coccidiosis, pullorum and Marek's - Luginbuhl had recognized as early as 1958 that eggs used for multiplication of virus had to come from flocks free of latent infections (Luginbuhl *et al.*, 1967). Chicken embryos were first used for virus studies by Rous und Murphy (1911). It took twenty more years before Woodruff and Goodpasture (1931) used chicken embryos fort the multiplication of pox virus.

Beveridge and Burnet (1946) still stated: „there is no authentic report demonstrating that chicken embryos are viral vectors, and it is much easier in poultry to prevent the passage of viral diseases than in other free roaming species“. In his review of poultry diseases, Cottral (1952) listed 9 infectious agents which are transmitted vertically by chicken embryos: Leukosis, AE, ND, Infektious Sinusitis (Mykoplasmosis), Psittakosis, Tuberkulosis, Chicken Typhus and Parathyphus. In the following years Adeno virus was shown to be transmitted by hatching eggs, and several reports confirmed Cottral's earlier report. Significant developments were the discovery of „Resistence inducing factors“ (RIF) by Rubin (1960) to check for the presence of Leukosis virus and the Cofal test by Sarma (Sarma *et al.*, 1964) a complement fixation test to check for group specific Leukosis antigens. Kottaridis *et al.* (1966) developed a serological test to detect Leukosis antibodies.

Luginbuhl started in 1963 to establish SPF chicken flocks at the University of Connecticut. He used Mount Hope White Leghorns, unfortunately not a very productive strain, and called the program „ SPAFAS“ (Specific pathogen free avian supply). According to the definition of the International Society for Laboratory Animals, SPF chickens are kept in flocks routinely monitored for specified pathogens, with negative results to date. Without specifying the pathogens, the label „SPF“ is not indicative of the quality of the eggs and their suitability for experimental purposes.

Following Luginbuhl's advice, we started in 1963 to reproduce and rear flocks of chickens in Cuxhaven under isolated conditions und to monitor their health status. Table 1 shows routes of infection in chickens, table 2 the plan for laboratory tests. From 1963 to 1965, we used HNL laying hens, then changed to stock imported from SPAFAS. We compared house type A with negative air pressure vs. house B with positive air pressure and filtered air (FAPP), as described by Drury *et al.* (1969). Results are shown in table 3.

The number of hens per house varied between 200 and 2.000, and the total volume tested between 1963 and 1970 was about 4.000 hens in house A, 14.000 hens in house B. In 1966 the cooperation between SPAFAS and Lohmann was formalized, the contract signed 20.09.1966.

In further trials we tested the effectiveness of air filters. The results shown in table 4 convinced us that FAPP conditions with special high efficiency filters are essential to maintain SPF flocks successfully with predictable results (Vielitz *et al.*, 1974). An important part of our learning process was to determine the optimal air pressure to combine zero disease risk with normal bird behaviour as an indicator of bird welfare (if air pressure is too high, birds may respond with extreme nervousness).

* Based on a presentation at the 40th VALO Anniversary, May 28-29, 2008, Atlantic Hotel Sail City - Bremerhaven.

Table 1: Routes of natural infection in poultry

Egg transmission (a) temporary (acute disease phase)	e.g. AE IB Influenza ND Gumboro Adeno viruses
(b) permanent (wthout clinical disease)	e.g. Leukosis viruses S. pullorum Mycoplasms
Horizontal spread via animal to animal contact dust, feed, litter insufficient sanitation caretaker, equipment	e.g. IB AE Marek Newcastle ILT Salmonella

Table 2: Monitoring scheme for SPF chicken flocks

Infection	Strain or antigen in test system	Type of test
Adeno viruses (e.g. Celo)	Celo-Phelps strain	agar gel precipitation
Avian encephalomyelitis (AE)	van Roekel strain (egg adapted)	embryo-susceptibility test
Fowl pox	a strain of virus producing specific AGP reactions	agar gel precipitation
Infectious bronchitis (IB)	a strain of virus producing specific AGP reactions, Beaudette strain, Mass. 41 strain	agar gel precipitation serum neutralization
Infectious laryngotracheitis (ILT)	a strain of virus producing specific AGP reactions	agar gel precipitation
Influenza (Typ A)	Wilson's strain fowl plaque virus	agar gel precipitation haemagglutination-inhibition
Newcastle disease (ND)	B_1 or F strain	haemagglutination-inhibition
Marek's disease	a strain of virus producing specific AGP reactions	agar gel precipitation
Infectious bursitis (Gumboro disease)	egg adapted strain	embryo-susceptibility test
Leukosis	RSV (type A + B)	serum neutralization: cofal test
Mycoplasma gallisepticum and synoviae	commercially available specific antigens	agglutination
Salm. pullorum	commercially available specific antigens	agglutination

Table 3: Infections occurring in SPF chicken flocks using different ventilation (1963 - 1970)

Housing type	Number of flocks	Infected flocks	
(a) Windowless houses security management negative prssure ventilation no air filtration	14	Celo AE IB Marek	2/14 3'/14 3/14 14/14
(b) Kept in isolated location maximum security management windowless houses psitiv pressure ventilation air filtration	7	Marek all other listed agents	4/7 0/7

Table 4: Prevention of Virusinfection by airfiltration
Transmission trials, exp. house Vet. Labor

Agent (excreted by disease birds)	Number	Filter	Exposure time (days)	Result	
Marek	20 20	without Astrocel*	49	14/20 0/20	seroconversion positive (AGP)
NDV	30 30	without Astrocel	18	30/30 0/30	mortality
IBV	20 60	without Astrocel	24	20/20 0/60	clinically IB-symptoms

* Arocel = Hepafilter, class S (Trial No 62/70, 80/70, 18/71)

In 1968 new FAPP houses were built in Großenhain near Bederkesa, and this reference date was chosen as the basis for the 40th anniversary we are celebrating this year. With the „all in" „all out" system, 2.000 day-old pullets and a corresponding number of cockerels are housed and kept in the same facilities to the end of the laying period.

The SPAFAS hens were soon replaced by more productive HNL White Leghorns. A small house (Farm Elbeck in Altenbruch) was equipped with individual cages, in which HNL hens were kept and subjected to rigorous tests for leukosis virus and other disease agents (Vielitz *et al.*, 1974). The third generation after confirmed 100% negative test results was used as source of hatching eggs to reproduce the first flock from HNL stock for the SPF farm in Großenhain.

In this region Lohmann had leased a large area of woodland in which broiler breeders were reared from 8 weeks of age under free range conditions. We first thought free range management should be beneficial for rearing breeding stock in fresh air with ample exercise, but soon learned that free range also involved high mortality (mainly due to parasitic diseases), resulting in poor development of the chickens – a fact rediscovered in our time, 40 years later, by many poultry people while changing from conventional cages to free range management of layers. Besides poultry diseases, foxes and birds of prey contributed to high losses.

Since 1968 we are using the trade name „VALO" (Vakzine Lohmann).

Several people contributed significantly to the success and increasing sales volume of VALO eggs during the first decades: production manager Widukind Ruttke, sales manager Hartwig Morrise and from the staff of the Veterinary Laboratory especially Dr. Helga Landgraf, Dr. Kirsch, Mrs. Holland-Letz and the author of this review.

The first scientist who used VALO SPF embryos as basis for human vaccines was Prof. Voß at the Robert Koch Institute in Berlin. Our collaboration started in the 1980s in connection with his development of yellow fever vaccines, and we owe many useful suggestions for our laboratory work to his advice.

The sale of VALO eggs was initially organized through TAD, while the Veterinary Laboratory of Lohmann produced and sold vaccines from VALO eggs. I reported on the establishment of SPF chicken populations and their use during an international symposium held at the Veterinary College in Hannover in November 1967. We also reported about our experience with the management of SPF chicken flocks at the 12th International Congress for Biological Standardization in September 1971 in Annecy, France (Vielitz and Landgraf, 1972).

To keep up with the growing demand for SPF eggs, we converted the floor houses to colony cages in the mid 1970s and thereby doubled the capacity.

The SPF status of our VALO flocks has been certified by State Veterinary authorities from the beginning while the Lohmann Veterinary Laboratory continued internal monitoring of all flocks.

In a joint project with the University of Giessen (Prof. Bauer, Dr. Fries), we tried to establish flocks free of endogenous provirus (chf - chicken helper factor), but this turned out to be very difficult. The productivity of chf-negative hens was very poor and no commercial demand for the product developed.

Another research project, in the late 1980s, was conducted in cooperation with the Free University of Berlin (Prof. Monreal, Prof. von Bülow) to establish a flock free of chicken anemia virus (CAV). This project was very successful and enabled Lohmann Tierzucht to produce CAV-free SPF eggs as the first company in the world. From CAV-free VALO eggs, we could then produce the first live CAV vaccine (Thymovac) for world-wide distribution.

VALO has been at the forefront of innovative research during its 40 year history, and SPF chicken embryos will remain essential for research and the production of poultry vaccines in the foreseeable future.

Zusammenfassung

VALO SPF: Erinnerungen an die Entwicklung der SPF-Eierproduktion in Cuxhaven

In diesem Referat wird an die Entwicklung von VALO SPF seit den ersten Anfängen Mitte der 1960er Jahre erinnert. Aus der anfänglichen Notwendigkeit, die eigenen Zuchttierbestände frei von übertragbaren Krankheiten zu halten, entwickelte sich im Laufe der vergangenen vier Jahrzehnte ein wichtiger, hoch spezialisierter Produktionszweig der Lohmann Tierzucht: die Erzeugung von SPF-Eiern für die Impfstoffproduktion. Der Import von Knowhow aus den USA setzte sich fort in eigener Forschungstätigkeit des LTZ Veterinärlabors und in der Zusammenarbeit mit europäischen Forschungseinrichtungen. Zu den herausragenden Beiträgen zur Gesundheit von Geflügelbeständen weltweit gehört die Entwicklung von CAV (Hühneranämie Virus) freien Beständen zur Produktion von Geflügelimpfstoffen aus CAV-freien SPF Bruteiern.

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Fertile eggs – a valuable product for vaccine production

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Since a long time, fertile eggs are being used as the preferred substrate for vaccine production. The total number of eggs used for this purpose is estimated at currently about 600 million eggs per annum. The market for fertile eggs, commonly called “vaccine eggs”, consists of different segments with specific requirements concerning production and quality.

Market segments for vaccine eggs

Generally speaking, there are two major categories of eggs for vaccine production: “Clean Eggs” and “SPF-Eggs”.

Clean Eggs: The largest volume of vaccine eggs is used for the production of human flu vaccines. These eggs are produced under conditions similar to parent flocks for the production of day-old commercial layer chicks. The same quality of eggs is the standard product to produce killed vaccines for veterinary use in Europe, whereas SPF-eggs are generally required for this purpose in the USA. The quality specifications for these so called “Clean Eggs” are laid down by the customers in co-operation with the producers. Main criteria are the cleanliness and the fertility.

The main reasons for using Clean Eggs instead of SPF-Eggs for human flu vaccine production are the huge quantities of eggs needed seasonally and the higher cost of producing SPF eggs. One fertile egg is needed to produce a single vaccine dose against a specific flu virus. Since normally the “flu shot” consists of a combination of flu viruses, for one shot up to 3 eggs are needed for production. If SPF-eggs were required, this would make flu vaccination unaffordable for many people, especially in low-income countries. As an example from the production of poultry vaccines, one SPF-Egg is good for the production of 17.000 doses of IB vaccine.

To meet specific requirements of customers, Clean Eggs can be produced without antibodies for specific disease agents by adjusting the vaccination program for the source flocks. The market volume for vaccine eggs is estimated to be 530 million eggs per annum.

SPF-Eggs: Specified Pathogen Free Eggs (SPF-Eggs) are produced under strictly isolated conditions to guarantee the absence of all disease agents and antibodies against these agents which are laid down in the European Pharmacopoeia. SPF-Eggs are generally used for all live vaccines and also for killed vaccines for veterinary use in some areas of the world, as mentioned above. The use for human vaccines is currently limited to four products and requires a limited volume of SPF-Eggs. The total volume of SPF-Eggs used world-wide is estimated to be 60 – 65 million. Only three major producers are active in this field world-wide who have the necessary know-how and experience to meet the high quality requirements.

Marketing of Eggs for Vaccine Production

Eggs for vaccine production are marketed in one of two forms: cold or pre-incubated. **Clean Eggs** are predominantly marketed pre-incubated. Since these eggs are needed in large quantities within a short period of time, the vaccine producers are negotiating delivery contracts on a yearly basis according to the anticipated volume of vaccine production. Pre-incubated eggs have the advantage of being candled before delivery. Only eggs with a developed and vital embryo are entering the site of vaccine production. This reduces not only the volume of eggs and labor requirement, but also the risk of contamination for the vaccine producer.

The production of **SPF-Eggs** is a highly specialized business with production facilities concentrated in a few locations mainly in Europe and the USA. On the other hand SPF-eggs are a necessary source material for world-wide vaccine production. It is therefore of utmost importance to secure the delivery of SPF-eggs also in the event of transport restrictions due to national, notifiable disease outbreaks.

Major producers like VALO have spread out their production units to different countries and are able to supply from this network in case of import restrictions from one of these locations. In co-operation with customers, SPF-egg producers are trying to get regulations that will allow free transport of SPF-eggs also in case of restrictions for ordinary hatching eggs. This could help the poultry industry especially at times when SPF-eggs are desperately needed for vaccine production.

Production of SPF-Eggs

As for the quality of SPF-Eggs some conditions for producing SPF-eggs are laid down in the European Pharmacopoeia. However, the consistent quality of SPF eggs depends more on the long-term experience of the whole staff involved in the production and processing chain than on studying manuals and text books in case problems are noticed. VALO, for example, has more than 40 years of experience in producing SPF-Eggs and developed a technology which enabled VALO to be first in producing SPF-Eggs completely free of chicken anaemia virus (CAV). Over the years, VALO had an impressive record of consistent quality, with rare failures in individual flocks, in which case customers were informed immediately and eggs used for less sensitive purposes or the flocks have been culled.

To achieve and maintain the SPF-status, all production steps must be under complete control. Products entering the production units must be safe and in case of a potential risk must be treated effectively before being used. Since SPF-Eggs for commercial purposes are produced by large flocks, the amounts of feed, water and air that have to be supplied in a safe way are staggering. A typical flock of 5000 hens will need about 200 tons specially treated feed, 400,000 liter water and 4-17 million m^3 of air during the life cycle. The caretaker will enter and leave the building 450 times, 42,000 egg flats must be delivered into the house and 1.25 million eggs, dead birds and 500 tons of manure must be removed from the house safely. How are these processes organized in the VALO organization?

Personnel

Generally speaking, access to the chicken houses is minimized. Ideally only the caretaker enters the house throughout the whole life cycle. To reduce the necessity of entering for repair and maintenance, all standard maintenance work is done during the service period when the house is empty. Important technical equipment is serviced routinely or will be replaced as a safety measure in the downtime of the house.

The caretaker enters the house through double barriers: the first barrier requires a change from street clothes and shoes into farm owned clothes and boots, the second barrier before entering the SPF-house requires a complete change to house specific clothes after a shower with hair wash. The house specific clothes remain within the house during the complete production cycle, which requires a washer and dryer for each house.

Feed consists of organic material and is therefore a potential carrier of all kinds of contaminants. To minimize the risk for all VALO flocks, the feed is produced in a company owned state of the art feed mill, using an effective heat treatment system. In this feed mill, finished feed is exclusively produced for the VALO SPF-flocks and elite breeding flocks and grandparents in the Cuxhaven area under the control of the Veterinary Laboratory of Lohmann Tierzucht. Only selected raw materials from proven sources are used. Currently the feed consists of corn, wheat, soybean meal, vegetable fat plus vitamin and mineral premixes. The decontamination treatment consists of heat (85°C for 6 minutes minimum) and the addition of an acid mix after cooling.

Fat and vitamins are added after the heat treatment and need to be decontaminated separately. Fat is kept in the storage tanks at a constant temperature of 70°C and is therefore clean when added to the feed. The vitamin premix is delivered in 25 kg bags which are irradiated with 15 kgy minimum dose prior to being transported to the mill. The bags are emptied into a container in the HEPA-filtered section of the feed mill through sterile stainless steel tubes. Fat and vitamins are added to the feed in the second mixer located in the overpressure ventilated area of the mill. This mixer serves as dryer and cooler as well as final mixer for the mash feed. The process air for drying and cooling and also the air to overpressure ventilate the cooling and finished feed storage bins is HEPA-filtered.

An important part of the feed supply concept is clean delivery. A dedicated tanker type vehicle is used to deliver the feed into a storage building close to the production sites on Monday or Tuesday just after the mill and the delivery vehicles have been thoroughly cleaned and disinfected during the weekend. Supply to the SPF-chicken houses is organized with farm own transport vehicles which never leave the farm area. All SPF houses are supplied with town water which is controlled very strictly by the state authorities. Regular tests are performed internally and by an independent laboratory.

Manure handling and removal

All VALO – SPF flocks are kept in family cages with manure belts. The manure is removed once or twice a week, using specially designed screw augers. These augers have a double shut-off system to ensure that there is no backflow of material into the house and that no rodents or other potential disease carriers can enter the house. This auger system can only handle wet manure which, from a management point of view, is sub-optimal. However, it is the safest system we know to handle the manure removal from the SPF houses.

Material transfer

All material brought into or taken out of a SPF-house is a potential risk for contamination. Our general policy is therefore to minimize the transfer of material. All material needed during a life cycle is brought into the house before final disinfection prior to the placement of day-old chicks. Other material, dead animals and eggs must pass a disinfection chamber with an effective fumigation procedure in place. All outgoing material is fumigated and the emptied chamber is fumigated again before the chamber can be opened again from the clean side.

Air

Dust can carry a substantial contamination load. All air delivered to a SPF-chicken house must therefore be filtered before entering the house. We currently use a system with three filter steps. The last step is a HEPA–filter which filters out 99.95 % of all particles in the air. To insure that all air passes through the filtration system, the technical equipment must be designed to avoid false air entering the house. This is possible by using a filtered air, positive pressure (FAPP) system. The FAPP system we are using also has active ventilation elements on the exhaust side to avoid wind pressure into the house and to keep off insects. All filters are exchanged before a new flock is placed and are checked for leaks with a particle counter.

Pest Control

Rats and mice are important carriers of diseases and contaminants. To keep them from entering a house, all walls are sealed properly and doors are protected by shields. An essential part of rodent control is to catch them outside the houses if possible. Therefore, all VALO – houses are equipped with rodent traps along the walls at a distance of only 3 m from each other. As soon as a house is depopulated, a very intensive pest control program must be carried out inside the house. Since no chicken feed is available for the rodents at this time, they can be caught more easily than while a house is populated with birds.

Grading, disinfection and final inspection

The final step before shipping SPF–Eggs to the customer is grading and disinfection. Although the eggs at VALO are fumigated during the transfer from the chicken house to the grading facility, the eggs may have been re-contaminated during handling and transport and are therefore disinfected again. The grading process consists of a visual inspection where soiled eggs and eggs with obvious shell defects are removed before the eggs pass through a crack detector unit and a weighing system. Eggs with shell defects, undersized and oversized grades are directed to separate packing lines and sold to an egg breaker. Saleable VALO SPF-eggs are sorted into three weight classes and packed into cardboard boxes. This process gives VALO customers a more uniform egg size and supports automatic processes in egg handling during the vaccine production. The first disinfection is by fumigation, the final disinfection before packing the eggs by spraying. For both processes, formaldehyde free products are used.

Quality control to confirm the SPF status

Besides the visible inspection of egg quality, the SPF status of each flock has to be guaranteed at all times during production to ensure the requirements of the European Pharmacopoeia. At present, the list of agents consists of 22 different diseases, of which absence of antibodies or antigens has to be demonstrated by validated, approved testing protocols. During the rearing period 5% of the birds have to be tested twice, during the production period 5% on a monthly basis (or 1.25% weekly). All this testing is done in the DIN ISO 17025:2005 certified Veterinary Laboratory of Lohmann Tierzucht.

All efforts in production, handling and marketing of VALO SPF–Eggs focus on the same goal: to supply the vaccine industry with a safe and reliable source material of high quality in line with the current and future product specifications of our customers.

Zusammenfassung

Bruteier als hochwertiges Ausgangsmaterial für die Impfstoffproduktion

Viele Impfstoffe für den Human- und Veterinärbereich werden unter Verwendung von Bruteiern mit definierten Eigenschaften produziert. Es ist zu unterscheiden zwischen Bruteiern, die im Humanbereich für die Produktion von Grippe-Impfstoffen verwendet werden (als „Clean Eggs“ oder „Serumeier“ bezeichnet) und Bruteiern für die Produktion von bestimmten Human- und Geflügelimpfstoffen („SPF-Eier“), für deren Produktion die Ausgangsbestände frei von einer langen Liste von Erregern und Antigenen gegen diese Krankheiten sein müssen.

In dieser Arbeit werden die Unterschiede zwischen diesen beiden Kategorien und die speziellen Produktionsbedingungen für SPF-Eier beschrieben.

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The Importance of SPF-Eggs in Manufacturing and Testing of Poultry Vaccines

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Introduction

SPF-eggs are used for the production and control of vaccines for humans and animals. This presentation describes the major areas in which embryonated SPF-eggs are used. Furthermore, the advantages and disadvantages of using these eggs in production and control of vaccines will be discussed in comparison to conventional eggs on the one hand and cell lines which are derived from SPF-eggs on the other hand. The following remarks will concentrate on the production and control of viral vaccines for poultry.

What is SPF?

First of all, it should be made clear what SPF means. SPF is the abbreviation of specified-pathogen-free. That means that SPF-flocks for the production of SPF-eggs are free from specific undesirable microorganisms. The antigens not accepted under SPF conditions as defined in the European Pharmacopoeia (Ph. Eur.), 6th edition are shown in Table 1.

Table 1: Current requirements for SPF eggs

SPF-eggs must be free of the following pathogens:	
Avian adenovirus, group 1	Egg drop syndrome virus
Avian encephalomyelitis virus	Infectious bursal disease virus
Avian infectious bronchitis virus	Influenza A Virus
Avian infectious laryngotracheitis virus	Marek‘s disease virus
Avian leucosis virus	Newcastle disease virus
Avian nephritis virus	Turkey rhinotracheitis virus
Avian orthoreovirus	Mycoplasma gallisepticum
Avian reticuloendotheliosis virus	Mycoplasma synoviae
Chicken anaemia virus	Salmonella pullorum

This list is updated whenever necessary. The actual list can be found in the current edition of the Ph. Eur.. It should be noted that chickens and eggs derived from SPF-flocks are free of the antigens listed; but that does not mean they are sterile. Everybody who uses chickens and eggs for manufacture, control and possibly research should bear this fact in mind, as the “substrates” derived from eggs and chickens may be contaminated by other antigens as those for which the source flocks are tested. This bio-burden may influence the quality of the vaccines and the control tests.

Virus Production

Three kinds of “substrate” derived from SPF-eggs are used for virus production: Embryonated and pre-incubated SPF-eggs, primary cells (e.g. chicken embryo fibroblasts) derived from pre-incubated embryonated SPF-eggs and chickens hatched from SPF-eggs.

Virus production in **embryonated SPF-eggs** has certain benefits compared to the production in cell lines: No additional culture medium is needed. Consequently, there is no risk of contamination with extraneous agents derived from media composed of substances of animal origin. As some extraneous agents cannot be excluded by specific tests (e.g. TSE) this benefit cannot be underestimated.

The harvest of fluids or embryos from incubated eggs can be processed directly. No additional manipulation such as trypsination and washing is necessary.

The purification step can be very simple if the allantoic fluid is harvested and processed directly as it is usually done for most of the avian viral vaccines. The purification procedure used in the production of human influenza is quite the opposite. Here, an intensive purification via different techniques is used (filtration, centrifugation, chromatography). The reasons for these differences are obvious: since purification is costly, purification of harvest material is seldom performed where low priced mass vaccination is needed (e.g. for poultry). Vaccines for other species, where local and systemic reactions against egg material have to be minimized, require purification. For poultry, most of the egg derived vaccines are administered via non-parenteral routes, which leads to less side effects than injection of the same non-purified material may cause.

It should not be forgotten that a prerequisite to virus production is that the virus is adapted to eggs. The harvest and purification of virus harvests requires manpower and special equipment even if some harvest steps can be automated. Negative impact from viral vaccines produced in eggs is derived from the bio-burden. As already mentioned, eggs, especially SPF-eggs, are free from a number of specified pathogens but not sterile. Some production procedures can help to ensure that the level of bio-burden can be kept as low as possible: disinfection of the egg shells, candling of eggs and discarding infertile eggs and eggs with dead embryos prior to harvesting, collecting of harvests in small vessels, discarding parts of the harvests which are too heavily contaminated, centrifugation, etc..

Virus production **in primary cells** derived from embryos has its advantages when viruses are adapted to cell cultures. One of these advantages is the easy access to a large number of cells without long term pre-culturing, splitting and maintenance as required by permanent cell cultures. On the other hand, the embryonated eggs have to be pre-incubated and the preparation of the cells requires more manpower than the propagation of cell lines. The harvest technique requires some knowhow but is easy in principle. It depends on the type of virus release, i.e. if the supernatant of the cells should be harvested or the cells themselves. Concerning further processing of the harvests, the procedures are similar to those used for virus harvests derived from embryonated eggs. Depending on the route of administration and the species to be vaccinated, the degree of purification is adapted to the final use of the vaccine.

Virus production **in chickens** is only used in exceptional cases, whenever the virus cannot be adapted to eggs or cells. As far as possible, this sort of virus propagation is avoided for a number of reasons: The maintenance of the chickens is demanding as the animals must be kept in isolators and the harvest requires killing of the chickens followed by a labour intensive extraction of organs. Positive aspects are the easy growth of the virus and the lack of media containing ingredients of animal origin. On the other hand, the bio-burden can be high and may require purification steps during production. Last but not least, the animal welfare aspect has to be mentioned which restricts the use of animals for virus propagation to an inevitable minimum.

Control or Testing of Vaccines

The “substrates” used for the control of vaccines (starting materials, in process controls and final product testing) are the same as for virus production: embryonated eggs, primary cell cultures derived from embryonated SPF-eggs and SPF-chickens.

For testing purposes it is inevitable to use SPF-eggs in order to avoid falsification of test results by contamination with other antigens.

As regards benefits and restrictions, testing in **embryonated SPF-eggs** is in some aspects similar to the virus production in eggs. Some additional aspects should be considered: Tests have to be validated according to Good Manufacturing Practise (GMP), Good Laboratory Practise (GLP) or Quality

Management (QM), depending on which laboratory is performing the tests. In any case, it must be demonstrated that the tests are reproducible. As eggs are much more complicated in their structure than cell cultures, validation principles of tests performed in eggs rely more on the principles used for the validation of in vivo tests than validation of in vitro tests.
The necessary equipment for the maintenance of the eggs such as incubators, the logistics concerning delivery/ transport quality, pre-incubation conditions, etc. require special knowledge and manpower. Furthermore, the individual variety of eggs (form, air chamber, size) creates additional obstacles for reproducible and robust testing. Embryonated SPF-eggs are mainly used for titration of live virus and testing for extraneous agents. In very rare cases, serum neutralisation tests are performed in eggs.

Testing in **primary cells** (Chicken Embryo Fibroblasts, CEF or Chicken Embryo Kidney Cells, CEN) resembles the procedures for virus production. Special attention should be paid to possible contamination of cells during extraction from the embryos. The validation of tests performed in cells follows the principle of in vitro tests. Primary cells derived from embryonated SPF-eggs are normally used for virus titration, testing for extraneous agents and serum neutralisation tests.

Testing **in chickens** is required for quality, safety and efficacy testing of vaccines. For quality purposes chickens are used for testing of extraneous agents. Strong efforts are currently made to replace these tests by in vitro tests. SPF-chickens are mainly used in laboratory tests on safety and efficacy. Especially safety and efficacy trials are inevitable in order to define the behaviour of the vaccine in target animals. Concerning validation and organisation of tests, the aspects already mentioned for production and use of eggs apply. For safety tests a number of tests has to be performed (overdose studies, spread of vaccine strain, reversion to virulence, etc.). The efficacy tests consist of serological and challenge trials in order to define the onset, level and duration of immunity.

Conclusion

Embryonated SPF-eggs are essential to the production and control of vaccines adapted to eggs. SPF-eggs are also the major source for primary cells or even live chickens. There is no biological substrate which is able to replace SPF-eggs. Even if the resources in personnel, logistics and equipment which are necessary for the use of eggs are demanding, the benefits for safe production and testing outweigh the overall costs of using this live system.

Zusammenfassung

Die Bedeutung von SPF-Eiern für die Herstellung von Geflügelimpfstoffen und die routinemäßige Qualitätskontrolle

Vorgebrütete SPF-Eier werden für die Produktion von Geflügelimpfstoffen und deren Überwachung gebraucht. Aus SPF-Eiern werden auch Primärzellen und lebende Küken produziert. Einen biologisches Substrat, das SPF-Eier ersetzen könnte, gibt es nicht. Der Kostenaufwand für Personal, Logistik und Material für die Produktion von SPF-Eiern ist beträchtlich, aber die Vorteile für die Qualitätssicherung von Impfstoffen und Laborergebnissen rechtfertigen den hohen Aufwand.

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The EDQM & Quality Assurance, www.edqm.eu /Quality Assurance Policy.

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Small and medium sized enterprises (SMEs) – winners of globalization?

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Introduction

The globalisation of markets is not only a challenge for large enterprises but also concerns more and more medium sized companies. Small and medium sized companies (SMEs) are more engaged today in the course of new technological developments, new markets and especially services than often assumed and recorded in statistics (Feldmeier, 2006). Especially because of their innovative drive SMEs are becoming an increasingly important factor in the competitiveness of national and regional economies. To overcome the limitations of regional markets, specialized SMEs are increasingly trying to position themselves on the world market.

Successful internationalization of SMEs – assessment of existing theories

From a microeconomic as well as from a macroeconomic perspective it is important to investigate the question of the concrete orientation of the internationalization of SMEs. A basic problem in this matter is that neither a comprehensive theory of internationalization of SMEs exists (Krämer, 2003), nor is there sufficient empirical evidence to justify the assumption that experience from large-scale enterprises can also explain the internationalization of SMEs. Attempts to explain internationalization refer to current theories, which are based on the internationalization of large and/or multinational companies which increasingly evade their national economies through their strategic location policy (internationalization).

According to this SMEs act in their processes and strategies of internationalization parallel to large scale enterprises and are in a complementary relationship with them in their foreign business. For example it is implied (in examining individual cases of internationalization)[1] that there is a significant correlation between the size of SMEs and the proportion of their exports (Krämer 2003). According to current theory, the forms of internationalization differ between large scale enterprises and SMEs and it is assumed that the former tend to direct investments, whereas SMEs, due to their low financial power, prefer (indirect) imports (N.N., 2005). In addition, it is often stated that SMEs mainly follow in the footsteps of great pioneers in their cultivation of foreign markets in order to earn "follower advantages" as their entourage.

Yet, numerous studies of individual cases concerning the behavior of internationalization of SMEs prove that SMEs not only differ fundamentally from large scale enterprises but also consciously seek alternative ways in the development and adaptation of foreign markets and the selected steps of internationalization respectively. Thus, conventional assumptions about the fundamental aptitude of SMEs for internationalization are apparently incorrect (EU Commission, 2003; Feldmeier, 2003). The traditional hypothesis: "The smaller an enterprise, the less its tendency to internationalization" is thus – as will be shown in detail – not tenable. It assumes that internationalization can only be successful with certain entrepreneurial resources and forms of internationalization, which imply a higher degree of resources bound abroad, entrepreneurial financing and management capacities, which are not available in most SMEs.

The size of enterprise is not the main factor which limits the competitiveness of SMEs but rather the restrictions related to it, such as e.g. a relatively high degree of specialization of the product range, a high degree of fixed cost charges and/or little (cost-critical) production quantities due to closely limited domestic markets, because SMEs mainly operate in tightly defined market niches. The size of the

[1] Forms of internationalization are especially indirect export, direct export, sales subsidiaries, licensing, joint ventures, production abroad and subsidiaries abroad.

enterprise is only of importance for the internationalization of SMEs as far as a minimum size represents a necessary prerequisite for the use of a competitive advantage. This is only achievable through a directed internationalization which reverses the causal relationship assumed to date. Not the already existing advantages of scale, but their development are essential for internationalization of many SMEs.

Most researchers so far take no account of qualitative factors of definition and success of SMEs independent of the size of enterprises, nor do they recognize the fact that SMEs are not categorically losers of globalization but establish their business on the strength of world market leadership ("hidden champions" through "first mover advantages"). SMEs differ from large scale enterprises inasmuch as they consciously choose alternative ways in the adaptation and development of foreign markets and the chosen steps of internationalization (Feldmeier, 2007).

Strategies for successful internationalization of SMEs

In this paper we will deduce strategic factors of success for the internationalization of SMEs based on case studies of a network research project[2].

The intention of this empirical investigation was to compile information on the internationalization of mid-sized enterprises and relevant factors contributing to their success. In particular, their competitive strategies and advantages, processes of development of foreign markets, international supply and distribution channels, production design as well as cooperation established with foreign partners were analyzed. As criteria for the measurement of international establishment of the selected enterprises the following indicators were chosen: international market leadership in specific fields of business activity, distinctive and widely spread export and import activities and/or larger direct investments in the form of branches abroad and foreign subsidiaries.

Keeping in mind that concepts of success can not be directly copied from another enterprise, we intend to provide a framework of orientation for those enterprises that wish to expand their business in the international market. Each enterprise is characterized by a unique history, which is reflected in their corporate culture and staff selection and has to be taken into consideration when entering foreign markets. Each enterprise is determined through certain temporal paths (Schreyögg et al., 2003), which has to be ascertained when examining certain branches as well as the target countries. This makes it even more difficult to identify success factors which are relevant across countries and different industries. Nevertheless, the following results based on "best practice" cases may offer useful orientation for corporate-, industry- and country-specific internationalization of SMEs.

Quality leadership in narrow market niches

The competitive positioning of the mid-sized enterprises analyzed is characterized by specialization in clearly defined market segments, i.e. niches of the total market. In those niches they focus their business activities on specific (core) competences and market their service in Europe – and in some cases – globally. In their segment they focus on a wide range high quality service portfolio with special problem solutions primarily for narrow target groups. A transnational reputation for outstanding quality in a special area of expertise, developed over decades, is a fundamental competitive advantage in this context. The references are based on a high degree of customer satisfaction.

The positioning in narrow market niches generally takes place through services which are qualitative, functional, design-related, technological and/or high value service and top ranking. Apart from the quality of products, especially product associated services serve to distinguish them from competitors. In order to maintain the existing service advantages, the products and manufacturing processes are continuously refined.

2 In cooperation with eight Chambers of Commerce in Northern Germany, the proceedings of 65 internationally successful mid-size companies were examined. The research was conducted through interviews in internationally active companies identified as SMEs, organizationally and legally independent from multi-corporate enterprises and conducting their own business. As a rule, these were companies managed by their proprietor and/or family owned. The results of this study were first published by Dieckmann (2007).

For the preservation of this continuous innovative dynamic and pioneer role in their particular market segment, especially a high degree of customer proximity, creativity and flexibility are decisive. Sometimes they achieve an exceptional position, which is difficult to imitate, so that only few competitors with comparable profile of competence exist in market. Advantages in quality and image support customer loyalty and are effective in reducing the competition with imitators on the basis of price.

Specific know-how clusters

High market specialization requires the creation and the management of specific knowledge. The establishment of distinctive customer, market and expert knowledge is essential to remain competitive. This know-how is based on experience and thrives on a monitoring system for customer problems combined with state of the art knowhow in the special field. With distinct customer orientation potential problems are analyzed and corrected as soon as possible. Typical approaches are individual analysis of requirements, intensive communication with customers, mutual exchange of ideas, customer participation at an early stage of the solution finding process and in-house problem simulations. Process innovations and new demands often originate from the exchange of information between customer and supplier and are a driving force for innovations and new standards on the world market. Communication and close cooperation with specialists at universities and research institutions is essential to keep up with international developments and to identify problems which warrant new basic research.

Qualified personnel

The employment of qualified and experienced specialists represents a necessary prerequisite for mid-sized enterprises to be successful in the international market. The staff is emphasized as the most decisive pillar of professional competence and knowledge, their continuous education and training is rated as being of primary importance. In all sectors of the industry the shortage of qualified specialists is seen as a major factor limiting the international competitiveness.

Especially for employees directly involved in business abroad, adequate knowledge of foreign languages in addition to the subject specific qualifications is considered as a critical success factor, since a personal basis of communication and trust in foreign business partners can only develop through them. Apart from the knowledge of languages, especially passion for travel, flexibility, open-mindedness and a high degree of understanding of other cultures are seen as prerequisites for successful international business. The required intercultural competences are usually acquired through international experience by the employees concerned. Often the companies have recourse to immigrants from the respective target countries, which are acquainted with the cultures of the home as well as the host country.

Direct cultivation of foreign markets

The potential of foreign markets is sounded out primarily through an attentive media analysis, thorough research in professional magazines, the visit to trade fairs and/or personal on-site investigation. International and national trade fairs are the most prominent platform to establish contacts with potential foreign business partners and customers. Contacts in the form of personal visits in the target country foster the development of business transactions. Existing contacts prove to be the best multipliers to attract new customers or distribution partners. In this context, people who are acquainted with culture and language serve as valuable communicators.

The distribution of products and services of the SMEs abroad mainly takes place through their own representative offices or locally established on site sales staff. Yet, direct selling from the home location is generally preferred for services which tend to be of low frequency, such as e.g. special facilities. Representative offices abroad are either opened by themselves or are managed in cooperation with existing partners on site. Contractual partnerships with locally established sales people (such as e.g. specialized wholesale merchants, contractual sellers or agencies), who serve as sales, distribution and service centers for the respective market are typical forms of cooperation. These partners may also serve as market observers and establish first contacts to potential customers. The establishment of direct personal contacts with potential distribution partners is often realized at trade fairs or direct addressing on the basis of branch information. The decisions in favor of selected distribution ways are often made in a situation-related context.

Often sales partners are selected by chance, depending on which contacts emerged at trade fairs, through already existing business relationships or on personal trips. The most important criteria for the selection of potential sales partners are their expertise as well as already existing contacts in the branch, existing knowledge of the language and mentality, an existing customer base and their reputation and credit rating. A personal basis of trust and the motivation of the potential partner to promote the business for mutual benefit are of essential importance.

The cooperation often consists of exclusive sales with exclusive distribution character so that the partners are not allowed to offer competitive products. The enforcement of exclusive contracts depends on the market power of the partners involved. The offered services are either performed by the local partner on their own account or on external account based on commission payment.

Apart from the cooperation with the foreign partners, proprietary branch offices or the foundation of subsidiaries with sales and service function are the most important forms of presence in the target market. Variants exist in strategically important markets or markets with a high turnover or countries with restrictive legal frameworks or local peculiarities, which do not permit any alternative form of market cultivation.

Evidently the approaches described in the literature to date, i.e. the sequential development of foreign markets, starting with export passing on to cooperation and further to the foundation of subsidiaries, do not appear to be typical for SMEs. Rather the conditions found in the target country influence which form of internationalization is regarded as appropriate, which has led SMEs to “leapfrog” i.e. to skip some forms of internationalization and enter more resource intensive forms such as joint venture and subsidiary companies (Enßlinger, 2003).

Favorable international conditions of supply and production

Simple parts, which can be standardized, are needed in large quantities and/or can be kept in stock, may be imported to benefit from low-priced components. The imported primary products are then integrated into the end product to improve margins and to remain competitive in terms of price.

The supply of imported primary products is usually organized in the form of contracts with independent suppliers or partner enterprises, which are bound by contract. As a rule, the production of finished parts, components or modules which are outsourced abroad, takes place with production standards specified by the importing SME and often includes supporting technical service.

In some cases proprietary investments abroad are preferred to transfer sensitive and labor-intensive production steps to subsidiaries abroad, in which case used machines and facilities from domestic production plants may be transferred to the production facilities abroad. Proprietary production capacities for market development may be needed in countries with specific limitations, e.g. in countries with high import barriers or to minimize transport cost to remote markets.

The purchase of external and internal primary services from abroad and outsourcing of production steps abroad are limited for specific primary products, which:

- are required in small quantities, i.e. the purchase from abroad does not offer significant savings,
- are required in different versions, depending on specifications of individual orders requiring immediate in-house reaction to ensure fast delivery,
- require a very high degree of know-how to assure the quality needed and/or
- are prone to imitation if sensitive technology has to be transferred.

This kind of primary product is either produced at the home base or purchased from specialized suppliers located close to the home base. This enables a more flexible reaction to fluctuating order inflow. In-house production is preferred to ensure special quality requirements, which leads to a higher vertical range of manufacture.

Functioning co-operations

Technology intensive SMEs are especially aware of the fact that international co-operations can increase their competitiveness and are often the key success factor. A significant transfer of know-how is taking place in this area (Gerum, 1999).

The co-operation of internationally operating SMEs with partners abroad is generally set up for a long term and is understood as a strategic partnership. To ensure quality and safety standards the partners are supported with training and extensive technical support. Mutual trust and common interests are the basis for the establishment and long term maintenance of business co-operations and essential for success. To assure smooth business, problems must be openly discussed with due respect for each other's position, and enough time must be allowed for extensive consultations. Concerted visits to or presentations at trade fairs are the preferred forum for this.

Success as cluster of existing potential for internationalization

The case-specific examples analyzed indicate that successful internationalization is not so much based on individual factors, which have previously been treated in an isolated way in the literature, but are generally based on a sensible combination of success components, as listed above.

Especially the clusters of a tight market niche positioning, specific know-how, a network of long term business relations, advantages in market experience, individual and unique product/service combinations, a high degree of customer orientation, an intelligent design of transnational activities to generate added value, efficient organizational and decision-making structures, and, last but not least, highly qualified personnel enable the medium sized enterprises to generate continuous innovations, to expand market penetration, to seize new market opportunities and not only to hold their ground in a competitive world market.

The characteristics of successful SMEs outlined have revealed that they deploy integrated forms of internationalization and opt for a calculated mix of alternatives instead of following isolated motives of sales and economization. Especially the wide range of simultaneous exports, imports, formal and informal co-operations, as well as direct investments enables them to benefit from network synergy, which could not be offered by individual forms of internationalization (DIHK 2005).

The internationalization of SMEs frequently consists of a bundle of activities which complement each other rather than being built up sequentially. Instead of "either-or" and "first-then" decisions, "as-well-as" approaches are typical in successful SMEs. A well balanced mix of different forms of internationalization enhances the probability that transnational activities of SMEs are successful.

Conclusion

The identified success factors of internationally active SMEs indicate that they are not threatened by the ongoing globalization. Instead, through internationalization they achieve increased sales and lower cost, which enables them to compensate existing disadvantages due to their company size. Successful internationalization results from competitive advantages which are independent of size, such as specific know-how, experience from their domestic market, a high degree of specialization, individual product/service combinations and close customer relationships. Based on these factors they can establish themselves successfully against large scale enterprises and even achieve global market leadership with their niche products and corresponding service.

Zusammenfassung

Kleine und mittelständische Unternehmen (KMU) – Gewinner der Globalisierung?

Die Globalisierung von Märkten stellt nicht nur eine Herausforderung für Großunternehmen dar, sondern betrifft in zunehmendem Maße auch mittelständische Firmen. Vor allem aufgrund ihrer Innovationsdynamik werden KMU heute zu einem immer größer werdenden Bestimmungsfaktor der internationalen Wettbewerbs-fähigkeit der nationalen Volkswirtschaft.

Von grundlegender wissenschaftlicher Bedeutung ist in diesem Zusammenhang die Frage nach der konkreten Ausrichtung der Internationalisierung von KMU. Ein Grundproblem hierbei besteht darin, dass es weder eine umfassende Internationalisierungstheorie von KMU gibt noch hinreichende empirische Untersuchungen über dieses Themengebiet existieren und man sich bei der wissenschaftlichen Erklärung der Internationalisierung von KMU vorliegender Erkenntnisse und Erfahrungen von Großunternehmen bedient und diese auch für KMU als allgemeingültig hingestellt werden.

Ziel dieses Beitrags soll es sein, auf Basis vorhandener Einzelfallstudien sowie einer eigens im Rahmen eines Verbundforschungsvorhabens durchgeführten Studie strategische Erfolgsfaktoren für die Internationalisierung von KMU abzuleiten und somit einen Beitrag für die Entwicklung einer KMU-spezifischen Internationali-sierungstheorie zu leisten.

Die herausgestellten Erfolgskonzepte von international erfolgreichen KMU zeigen, dass KMU nicht zwingend von der Globalisierung benachteiligt sind. Vielmehr ermöglicht ihnen die Internationalisierung, entgegen gängiger Lehrbuchmeinungen, mit der Erreichung erfolgskritischer Absatz- und Kostengrößen erst vorhandene Unternehmensgrößennachteile auszugleichen. Ihre Internationalisierungserfolge resultieren nämlich meist aus größenunabhängigen Wettbewerbsvorteilen, wie spezifischem Know-how, heimatmarktbezogenen Erfahrungsvorsprüngen, hohem Spezialisierungsgrad, individueller Produkt-/Servicekoppelungen sowie engen Kundenbeziehungen.

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