Lohmann Information

Cuxhaven, April 2011

Prof. Dietmar Flock, Editor

Editorial

The recent tsunami in Japan with resulting damage of atomic reactors in Fukushima sent a shock wave around the world, forcing not only responsible people in politics, society and industry, but all of us to review priorities. Meanwhile the world population continues to grow, in many countries at higher rates than local agriculture can feed. This year, the world population will reach 7 billion, and the challenge to find better solutions to assure adequate nutrition for more people will intensify, especially if more energy is produced from feed grain to facilitate an early exit from atomic energy. Science offers many ideas and possible solutions, but most of us are confused by the mix of biased reports and opinions in the media. Perhaps it helps to be trained as geneticist and to live in a democratic environment where variation of preferences over a period of time is not unlike evolution: trial and error. Hopefully, the best arguments will win in the long run.

This issue of Lohmann Information offers the following papers as "food for thought":

1. Controversial issues should be easy to settle if opposite sides agree on a road map how to reach results. In his paper **"Ethics in the poultry industry", Prof. Peter Kunzmann**, Ethics Center of the Friedrich Schiller University Jena, looks at the special situation of animal agriculture. He proposes a 3-step model, based on "pathocentric" criteria, to evaluate which forms of animal husbandry and treatment of animals can be justified and accepted by society in a given cultural environment.

2. In the same context, **Dr. Ibrahim Youssef** and co-authors, University of Veterinary Medicine Hannover, conducted a series of experiments to determine causes of a wide-spread problem in broilers and turkeys: **"Impacts of diet composition and litter quality on foot pad dermatitis in turkeys"**. The results confirm unpublished results from Denmark, which suggest that FPD in broilers is a seasonal problem in winter months unless litter is kept dry with proper ventilation.

3. Animal welfare issues are not limited to poultry: the European society demands that the conventional castration of boars must be stopped. In their paper **"Breeding for reduced boar taint", Dipl. Ing. agr Luc Frieden** and co-authors review the current situation in Europe and examine possibilities to solve the problem by systematic selection.

4. The demand for poultry meat continues to grow at a faster rate than the global human population. **Prof. Hans-Wilhelm Windhorst**, ISPA, University of Vechta, presents detailed statistics for global and regional changes between 1990 and 2009 in his paper **"Patterns and dynamics of global and EU poultry meat production and trade"**.

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

5. Following the growing demand for poultry meat, a regional farmer may ask for advice before investing in production facilities. In his article **"Economic aspects of poultry meat production in Germany"**, the author **Dr. Klaus Damme**, Bavarian Research and Training Center Kitzingen, used German field results to compare the production cost and potential income from broiler, turkey and duck production.

6. Despite the fact that reproductive efficiency, a typical fitness trait, is difficult to improve by within-line selection, primary breeders have to include these traits in their continuing efforts to optimize selection strategies. In their article **"Improving hatchability in white egg layer strains through breeding"**, **Dr. Cavero** and co-authors present parameter estimates from commercial lines and discuss how further genetic progress can be achieved by taking correlations with egg quality traits into account.

7. Commercial hatcheries are often faced with variable timing and size of orders. In his article **"Recommendations for hatching egg handling and storage"**, the author **Robert Schulte-Drüggelte**, hatchery expert of Lohmann Tierzucht GmbH, briefly reviews general principles of hatching egg storage and shows how hatchability may be maintained over an extended storage period.

8. The global feed industry is under continuous pressure to formulate least cost rations, making best possible use of available ingredients while keeping in mind society's demand to minimize environmental pollution. In their paper **"Valine and Isoleucine: The next limiting amino acids in broiler diets"**, the authors **Etienne Corrent** and **Jörg Bartelt** focus on the requirements of fast growing broilers for two limiting amino acids.

With kind regards,

Dietmar Flock

Prof. Dietmar Flock,
Editor

Ethics in the poultry industry – answering moral questions of society

P. Kunzmann, Jena, Germany

Formulating the essential questions of animal ethics

When poultry welfare is discussed in our society, we usually confront a tangled bundle of pictures, intuitions and often personal judgment of ideals and principles. The lack of communicative clearness is enhanced by the fact that everybody considers himself or herself a competent expert in this field. In assessing the conditions under which animals or poultry are kept, we find: everybody knows how it should be done. People think they could do it. That may sound trivial, but I like to point out that the same is not true e.g. for orthopedic dentistry, an area of applied human knowledge that is hardly more complex than keeping animals with proper attention to all details. The fact that the definition and realization of "good" poultry husbandry involves substantial knowledge does not keep the general public from voicing their own strong judgment.

We are unlikely to find people who would admit that they do not know how to assess whether the management conditions for poultry are "good" or not. Possible reasons for the different reaction of people to issues of poultry husbandry and welfare than to orthopedic dentistry are an interesting subject for further research. You may start with pictures in books for pre-school children showing farm animals and poultry. The main point is that the professional expertise does not reach the general adult public when it comes to animal and poultry farming.

People not only have strong opinions how animals should be kept, but feel that their own judgment is non-debatable on moral grounds. Many may admit that they do not understand all necessary details to judge whether our tax laws are fair, they "know" what is right or wrong about keeping animals.

A similar self-assured attitude may be found regarding other moral questions: considerable disagreements in detail, while every engaged party is sure of their own moral superiority. Again, this may sound trivial, but we should keep this in mind as a fact when trying to resolve conflicts regarding farm animal management. For popular moral judgment on poultry husbandry we find specific intuitions which dominate and aggravate the issue:

1) Poultry is seen as typical „mass animal production"; the low economic value of each bird results in huge numbers of birds in commercial operations. Pictures from modern poultry farms reinforce the image of "mass animal" production. This has generally been conceived and judged as "unjust" in terms of an idyllic perception of humanity's relationship to farm animals, regardless of the birds' health and wellbeing.

2) The second point is cage management; a negative symbol frequently used in terms of poultry welfare. Like no other issue in animal farming, the fight against laying cages has become a symbolic battle. Apart from the factual issue, we should not overlook the communicative implications. Many questions regarding farm animal production are complicated and not easily answered with yes or no, but "the cage" forces us to come up with an answer, which may turn out much more rigorous than questions like optimal width of slats or minimum space per animal.

In other words, „the cage" is an ideal object to communicate: simple and easy to recognize by everybody and to be against. Pointing this out should not be misunderstood as an endorsement of cage management, but only to explain the focus of society and politics on banning cages.

Morals and ethics

With all this, we are first of all dealing with morals, i.e., action based on human judgment of good and evil. Morals means following what "one" ought to, living according to convictions, intuitions and actions about morality. The questions with which the poultry industry is confronted have a moral basis. Dealing with these moral questions requires ethical judgment.

Unlike morals, ethics requires reflexing, critical and self-critical thinking about moral dimensions and principles. Thoughtful evaluation of our moral standards regarding farm animals is an essential part of the reflective living of responsible people. This approach enables us to reflect about current practices in animal agriculture and to develop ethical judgment.

Thinking about our own moral standards also helps us to structure and promote a dialogue about moral questions in animal farming. Only a defined position can be discussed fruitfully. In the colorful concert of people who offer their opinions on poultry welfare, it is not sufficient to refer to personal experience and professional training. Since moral perspectives are always involved in the discussions, it is important and helpful to explain the principles of our own actions and to justify them rationally.

For these two points, ethics is required to reflect about morals. Although animal welfare issues get considerable attention in public, sometimes with heated discussions, most ethicists are more interested in areas of applied ethics other than the treatment or mistreatment of animals.

As Thurnherr (2000) stated ten years ago, "the search for reliable indicators suggesting the application of moral principles to animal farming is stuck in normative ethical reflections, and has not yet reached the normative applied level of reflection". There has been some progress, but it is still true to say that there is an abundance of general literature on the relationship between humans and animals, but very little on ethically relevant specific situations.

An exception is the classical topic of animal experimentation. Other specific relationships between humans and animals with quite different problems are hardly touched by ethics research. This includes the almost totally neglected area of domestically kept animals as hobby, but we also find little on farm animals. Practical aspects are addressed mainly by animal scientists with a background in veterinary medicine or agriculture who ask questions related to animal welfare, without engaging moral issues.

Questions of principles and the impact of Albert Schweitzer

Ethical reflection must be able to base its judgment on plausible principles of decency. To find these principles and to get them generally accepted is not an easy task in our culture. More and more people question or find inacceptable how animals are being kept. The current awareness of animal welfare issues still differs profoundly between countries of the Western World, but the changes are dynamic and strong. This may be seen as a revolution, because respect for animals does not have a strong tradition in our culture. On the contrary, Christian tradition cannot offer a single renowned philosopher to answer our question.

"Bio-centric" arguments play a dominant role when ethical (no legal) aspects of animal and poultry farming are discussed in Germany. Albert Schweitzer's (1875-1965) ideas still play a commanding role in this context. For Schweitzer, the principle to save lives was the "essence of all moral thinking". For "thinking and reflecting people", it follows that "it is good to save life, to support life and to develop it to its highest potential; it is evil to destroy life, to damage life and to keep life down" (Schweitzer, 1974). The fundamental intention of Schweitzer to save all lives is incompatible with the fact that the survival of some animals depends on killing other animals.

Our own species depends on other animals, and the same goes true for some of the animals we keep for various purposes. Saving all life indiscriminately is impossible. Schweitzer himself repeatedly dealt with the recurring problem that in certain situations it is not possible to save all lives.

The ethical maxim of Schweitzer „to respect all life equally“ creates considerable ethical problems. Radically thought and lived, the equivalence of all living things leads to contra-intuitive results or at least considerable difficulties when applied as daily practice in the real world. Schweitzer does not offer a solution for this dilemma for intentional and systematic reasons.

The seeming weakness in offering rules or even instructions on how to act in situations of ethical conflict turns out to be an advantage for its central demand. Schweitzer sees no need to offer "instructions" how to apply his ethics of respect for life. This is imminent in his ethics. In Schweitzer's (1974) eyes, ethics as a set of rules how to deal with recurring moral conflicts by resorting to accepted forms of decent behavior, involves a perfidious self-deception. "A ready-to-use balance between ethics and needs suggests a false security. A good conscience is an invention of the devil."

If there were an ethic dictating what is right and what is wrong, the individual would be released from having to reflect and judge. Such an ethic is not only utopic, but not even desirable for Schweitzer. If you have a functioning compass, you are not likely to get lost, even if you don't have a detailed road map which tells you where to turn. Similarly, ethics cannot and is not intended to guide us step by step in each and every imaginable situation.

Pathocentricity – our responsibility to minimize suffering of animals

The continuing challenge is to find the the least burdensome alternatives to limit killing and suffering of all animals to an essential minimum. Nobody can be released from this responsibility.

This special responsibility is involved whenever humans have contact with animals. Discussions are always about specific options for treating animals, because people control the situation. This is especially true for farm animals which are totally dependent on the husbandry provided by their owners or caretakers.

For farm animals, the pathocentric perspective can be used to measure and evaluate the degree of suffering for individual animals. In the case of farm animals, we are especially emotionally distressed if we see animals suffer and this can be argued on ethical grounds. Whether we have the right to "use" or "exploit" animals, cannot be answered unequivocally with philosophical arguments.

Enlightened philosophy no longer believes in „objective" natural causes: for each answer we assume a certain conception of the world, which always depends upon a subjective interpretation how we see the world and our position in it.

In contrast, we don't need any reference to metaphysics to agree that it is an evil to inflict pain or suffering upon an animal. Pathocentricity allows us to measure and evaluate the burden of suffering we impose on the animals. Veterinary medicine offers indicators for this evaluation. On this basis the discussion can become more factual and leave the realm of subjective judgment, although many details may still be disputed as to which treatments are acceptable.

Ethical problems start when the animal shows symptoms of stress, get sick or injured or exhibit abnormal behavior. According to the pathocentric principle, farm animals don't need to be kept "naturally", but under conditions which allow them to be as well off as possible. Therefore the management ideal is not "artgerecht" (appropriate for the species, with reference to the wild ancestor), but "tiergerecht" (animal-friendly for farm animals). The criterion is the apparent wellbeing of the individual – which is of course easiest to achieve if the environmental conditions are designed to take the inherent needs of the species into account.

With the pathocentric demand to minimize any suffering and stress for animals, current management practices that may compromise an animal's wellbeing are being challenged: Is it necessary, and if so, can the same goal be reached with less pain or stress for the animal? Is a more animal-friendly management system available? Is there an alternative to a given housing system, breed or line to reduce the chance of problems? Are there alternatives to specific treatments of animals? What can be avoided and how?

An animal may only be subjected to a painful or stressful treatment if no alternative is available and the treatment itself is not too extreme. Strict adherence to this principle is in agreement with existing animal welfare laws and a realization of the proverb from the Old Testament of the Bible (12,10) "The righteous care for the needs of their animals".

Advantages of the pathocentric approach

The pathocentric approach uses „suffering" (pathos in Greek) of animals as criterion, a term which goes beyond "pain" and "damage" as used in §1 of the German animal welfare law. In their interpretation of the German animal welfare law, Lorz and Metzger (1999) arrive at the concept of suffering by counting only those "factors which compromise wellbeing" which are neither pain nor damage, whereas the ethical term is understood as including all "factors which compromise wellbeing" regardless of their origin.

The pathocentric approach offers a number of advantages for ethical evaluation (KUNZMANN, 2005; 2010):

1) When alternative management practices are being discussed, „suffering“ can be quantified to assess the burden imposed on animals. The capacity to measure different degrees of suffering allows us to judge how much should be “acceptable”. Not all human handling of animals is equally critical and “levels” of stress can be measured and judged with the pathocentric approach.
   From an ethical point of view, we can then also say: as stress response to treatment increases, indicating more severe interference with the animal’s wellbeing, there must be strong arguments for such treatment (“treatment” in this context is not meant in the therapeutic sense, but any handling which may affect the wellbeing of animals).

2) With farm animals, the pathocentric approach immediately gets to the ethically relevant point. While Schweitzer used the metaphysical “will to live” as argument, pathocentricity uses only the assumption that suffering is an evil which has be avoided. This is evident and immediately obvious. Schweitzer’s approach, on the other hand, becomes only plausible in the context of ideological and religious convictions. The same goes for a number of other ethical theories. We may say that the pathocentric approach to bioethics is the “leanest” in terms of justification.
   As Busch and Kunzmann (2004) put it, „suffering“ has the function for animal ethics to provide a reason and a means: “The reason is that animals can suffer, which we have to respect; and the means is that we cannot escape the postulate to avoid suffering of animals as a fundamental basis of ethically legitimate activity”.

3) Direct verification is possible: Whereas the „will to live“ of Schweitzer depends largely on the personal intuition of the observer, there are several indicators which reflect the wellbeing of animals and disturbances. Adopting the pathocentric approach requires measurements of the animals. Despite possible pitfalls inherent in the methods used, it should be possible to measure and evaluate reductions in wellbeing.

Unshelm (in Methling & Unshelm, 2003) lists the following criteria which can be used to measure the reaction of animals to their housing system:

- Behavior
- Performance
- Physiological parameters
- Clinical symptoms
- Mortality and causes of death

There are many possibilities to test to what extent the wellbeing of an animal is affected: is it exhibiting unusual, atypical behaviors such as stereotypic repetitions or purposeless idle movements? Performance can be measured in terms of feed intake, daily gain or egg production. Physiological parameters can be measured, e.g., in terms of elevated hormone levels in blood samples. Are physical defects visible that are caused by the housing system? How many individuals are lost during one life cycle? All these criteria can provide information about compromised animal welfare. Ethical evaluation is based on the empirically determined condition of individual animals.

As an important afterthought, it should be noted that good results according to the indicator traits, especially performance, cannot be interpreted as proof of the animal’s wellbeing. Even if all parameters are OK, it is difficult to determine whether an animal feels well. Nevertheless, significant deviations from wellbeing are expressed in these parameters.In the context of pathocentric animal ethics, this is sufficient. Whenever the wellbeing of an animal is affected, the person in charge must be held responsible.

The „suffering“ of farm animals

How suffering of animals should be avoided has been uniquely formulated by the Farm Animal Welfare Council in terms of the five freedoms:

1) Freedom from hunger and thirst – access to fresh water and good nutrition.

2) Freedom from discomfort – suitable housing with protected areas to rest.

3) Freedom from pain, injuries and diseases – prevention, diagnostics and treatment.
4) Freedom to express normal behavior – sufficient space, adequate equipment, contact with pen mates.
5) Freedom from fear and suffering – husbandry conditions and treatment which do not cause psychic suffering.

The Farm Animal Welfare Council visualized the five freedoms as ideals that can never be completely realized in practice with farm animals. Animal production without any welfare compromise is not imaginable. But animals are adaptable within certain limits, and not every limitation automatically means that the animals will be suffering. We interfere with the wellbeing of the animals if their adaptability is exceeded or ignored. The definition of animal-friendly management in terms of limits to adaptability should not be misused to justify management practices "at the edge of a razor blade".

Ethical evaluation in steps

Our model of ethical evaluation (Busch & Kunzmann, 2006) starts from the five freedoms: every treatment which interferes with these five freedoms has to be justified with a specified reason or benefit, analogous to the German animal welfare law, which requires "reasonable justification". The model rests on three principles:

1) Every treatment that affects the wellbeing of animals has to be justified.
2) Animals should under no conditions be subjected to certain treatments.
3) Every morally allowed treatment has to be subjected to an evaluation of possible alternatives to minimize the burden.

In applying these evaluative principles, the model uses the following steps:

a) The first step determines how severe the treatment is. This step is especially important, because many controversies in animal ethics remain unresolved because critics and defendants of a certain practice cannot even agree as to how "severe" they consider the effect for the animal. This is not an ethical, but a factual question. How „severe" is, for example, dehorning calves from the calves' point of view?
A classical case is the controversy over battery cages for laying hens, where opposite parties have not been able to agree how "severely" the hens "suffer" if they cannot express their natural behavior. Only after agreeing on the intensity of the treatment can we think in a meaningful way about justification.
The severity of a treatment results from its depth and duration. The more intensive a treatment and the longer lasting its negative effect, the more serious is its implication for the animal's wellbeing. The model identifies not simply the obvious, massive or „brutal" treatments as problematic, but includes treatments which may only be "unpleasant" at the time of treatment but have a long-lasting effect. The German Supreme Court put conventional cages for laying hens into this category.

This decision is an example for the next step of evaluation:

b) The treatment is in itself too severe.
In this case, the treatment is excluded at this point of the evaluation, because it cannot be justified. This goes in Germany not only for conventional laying cages, but also for forced feeding of geese or ducks to produce fatty liver, and for raising calves tied down. We don't have to search for further arguments; the severity of the treatment precludes any attempt to balance animal suffering against economic or other benefits. This is also the point when animal welfare laws and regulations usually take action to prevent such practices.
At this point, it must be recognized that judgment is not and will never be completely clear. In specific cases, it will be difficult to find a consensus among all experts in defining a precise borderline for acceptable burdens. Controversies over "borderlines" for specific situations will continue, and this for several reasons:
First of all, the definition of a borderline relies on available knowledge. As new information becomes available from scientific research, judgment may change. More importantly, human judgment draws the line which we and other humans must not transgress to protect the wellbeing of animals. The

"suffering" can only be determined by measuring the response of animals, but the borderline has to be decided by humans. Such judgments are necessarily based on the social environment in a given society.

For example, the ban on forced feeding for fatty liver production in Germany rests on broad consensus of society, while delicatessen stores in Germany may still offer Pâté Foie Gras imported from France, where forced feeding is still tolerated. Despite this apparent gap between freedom to produce and freedom to choose as consumer, very severe treatments may be banned by law based on moral grounds if the society considers the treatment inacceptable in terms of animal welfare. Both the social environment and the growing body of knowledge regarding the needs of the animal contribute to shiftimg these borderlines over time. In Southern Europe, chained watch-dogs are common, as in Germany only a few decades ago. Nowadays, this practice would not be considered acceptable in Germany.

The important point is that our model identifies a number of treatments as inacceptable before proceeding to an evaluation of arguments justifying the practice. Certain practices that are not conflicting with existing law may be morally inacceptable. According to the model, treatments are only acceptable if the intended benefit cannot be achieved without this treatment. Benefits may be for the owner of the animal in terms of reduced work load, increased security or income, but also for the animal, e.g., if the claws of cows or sheep are treated or chickens "beak trimmed" to prevent feather pecking and cannibalism.

In contrast to the balancing of goods in the common meaning of the expression, it is seldom possible to perfectly weigh the benefits against the burdens, at least not without "off-hand" judgment as we weigh benefits for man against burdens for the animal. We don't have a "common currency", i.e., we are always comparing apples with pears.

c) The model therefore follows a different logic: the logic of necessity. If a treatment is not in itself too severe and if it serves a plausible benefit, it is required that the same benefit cannot be achieved by other means, i.e. that no alternative treatments are available.

A treatment is legitimate, because necessary, only if it is impossible

1) to achieve the same effect within the same system, e.g. by improved husbandry or with reduced density of housing. The focus in this case is on reducing the burden for the animal by improving the conditions with relatively little expenditure: more space per bird, enriched housing to allow species-specific behavior and choice of strains. At this point, poultry geneticists are especially challenged to contribute to acceptable solutions

2) If this approach does not lead to acceptable results and the undesirable treatment remains necessary, the second alternative is to change to another system, e.g. from cages to floor systems for laying hens. The basic idea is still to achieve a benefit for the owner with minimal expenditure, but with lower burden upon the animal. Many treatments are directly connected with the management system and – following the logic of the model – only legitimate if no alternative system exists. This again depends on whether the surrounding "structures" allow other management systems: supply and demand in a free market, legal restrictions and regional programs to support animal agriculture. Of course a farmer will only invest in alternative management systems if he or she can expect to be successful in the foreseeable future.

3) If, under present structures, the farmer is unable to change to another system, there is one last possible alternative to realize an acceptable profit with minimal burden for the animals, supported by changing consumer preferences and legal incentives.

A classic example is the Swiss banning of cage management for laying hens, made possible by a whole package of factors, including changed structures. A less dramatic structural change may be achieved with labeling products. The focus here is always on changing the structures for the benefit of the animals. Of the three possibilities, this approach will take the longest time and have the most profound effect, but it cannot be implemented by an individual producer.

Instead of appealing to "the consumer", the ethical model addresses first and foremost the owners of animals who must look for alternatives. Consumers and politicians have to contribute their part to the solutions if no acceptable solutions can be reached within existing structures.

A treatment can only be accepted as necessary if no alternative can be found which interferes less with one of the five freedoms of the animal. Application of the model works like a sieve which finally filters out only those treatments which are morally legitimate, justified by a benefit, causing no excessive burden on the animal's wellbeing, and for which no alternatives exist 1) to modify the current local practice, 2) to change to an alternative system or finally 3) to change the structure.

It is not the job of the ethicist to go through all details of current management practices and to play the role of a judge to decide what is necessary. The model can only offer a guideline to disentangle the current controversial discussions and to focus upon realizing possible improvements for the animals.

Summary

Keeping animals has become an issue of highly controversial debate. Ethical reflections on animal husbandry must address popular moral intuitions. The paper presents an ethical model based on human responsibility for animals capable of suffering. This pathocentric model differentiates types of action that can be justified with ethical standards.

Zusammenfassung

Ethische Antworten auf moralische Fragen an die Geflügelhaltung

Inmitten unübersichtlicher gesellschaftlicher Diskussionen über Tierhaltung allgemein ist es auch für die unmittelbaren Akteure sinnvoll, den bunten moralischen Intuitionen mit ethisch reflektierten Urteilen zu begegnen. Dazu dient das skizzierte Bewertungsmodell. Die Tierethik wird in der Verantwortung des Menschen und der Leidensfähigkeit des Tieres grundgelegt. Daraus folgt in Stufen, welche Handlungen sich auch ethisch begründet rechtfertigen lassen.

References

BUSCH, R., P. KUNZMANN (2006): Leben mit und von Tieren. Utz Verlag, München.

FARM ANIMAL WELFARE COUNCIL (2009): Five Freedoms. <http://www.fawc.org.uk/freedoms.htm>

KUNZMANN, P. (2005): Können Tiere leiden? Zur Begründung einer Tierethik. Stimmen der Zeit, 2/2005, 90–102.

KUNZMANN, P. (2010): Ethische Antworten auf moralische Anfragen an die Geflügelhaltung. Archiv für Geflügelkunde 74, 1-5.

LORZ, A., E. METZGER, 1999: Kommentar zum Tierschutzgesetz. Beck, München.

METHLING, W., J. UNSHELM, Hrsg. (2002): Umwelt- und tiergerechte Haltung von Nutz-, Heim- und Begleittieren. Parey, Berlin.

SCHWEITZER, A. (1974): Gesamtwerke in fünf Bänden. Hrsg. R. Grabs. Beck, München.

THURNHERR, U. (2000): Angewandte Ethik. Junius, Hamburg.

Aknowledgment

The author is indebted to Ulmer Publishing Company for granting copyright for this translation of an article which appeared first in the Archiv für Geflügelkunde and the help of Prof. Flock with the translation.

Author's address:

Prof. Dr. Peter Kunzmann
Ethikzentrum der Friedrich-Schiller-Universität Jena
Zwätzengasse 3
07743 Jena
Germany
E-mail: Peter.Kunzmann@uni-jena.de

Impacts of diet composition and litter quality on development and severity of foot pad dermatitis in growing turkeys

I.M.I. Youssef[1], A. Beineke[2], K. Rohn[3] and J. Kamphues[1]

[1]Institute of Animal Nutrition, [2]Institute of Pathology, [3]Institute of Biometry and Information Processing, University of Veterinary Medicine Hannover, Foundation, Germany

Introduction

Foot pad dermatitis (FPD) is a widespread problem in broiler and turkey production, affecting not only the welfare of the animals but also the quality of the product. FPD is a type of contact dermatitis where the lesions appear on the plantar surface of the bird's feet (Ekstrand *et al.*, 1997). It was observed that turkeys of almost all ages suffer from FPD and the disease can start at a very early age (Mayne *et al.*, 2006b). The prevalence of FPD in turkeys can be extremely high, e.g. only 2.8 % of the animals showed no lesions at slaughter in a study by Grosse Liesner (2007). Lesions caused by FPD range from discoloration and hyperkeratosis – often combined with erosion and necrosis of the epidermis - to deep ulcers in severe cases (Greene *et al.*, 1985). The lesions mainly affect the metatarsal pads but may also involve the digital pads of the feet in severe cases. The cause of this disease is complex and apparently "multifactorial" (Mayne, 2005). Many contributing risk factors have been associated with the prevalence such as genetic disposition, management and nutrition. FPD is thought to be caused by a combination of wet litter, high ammonia content and other chemical substances in the litter from excreta (Martland, 1985). The type of litter may have an effect on the incidence of FPD due to either the physical structure or the water binding capacity of the litter (Bilgili *et al.*, 2009; Youssef *et al.*, 2010). The contact of the turkeys' feet with the excreta may also induce FPD (Jensen, 1985; Tucker and Walker, 1992). High dietary protein is thought to increase the incidence of FPD (Nagaraj *et al.*, 2006; 2007b). High dietary levels of soybean meal (SBM) may contribute to a higher incidence of FPD in turkeys as a result of sticky/wet excreta and subsequent irritation of the pad (Jensen *et al.*, 1970). It is not clear from these findings whether the effect on FPD was related to certain carbohydrates or due to the potassium content of SBM, resulting in higher water intake and excretion (Youssef *et al.*, 2011c). There is obviously a great need to find out preventive measures against FPD. Specific dietary supplements (such as biotin, zinc, mannan oligosaccharides) are thought to reduce FPD due to their role in maintaining skin integrity and stimulating immunity.

Since diet composition affects excreta and litter quality, the effects of different nutrients were tested in this study in relation to litter moisture (standardized by experimental water application). The aim of the present study was to determine possible causes of FPD and to develop strategies which can help to prevent or minimise the incidence of FPD. Several factors were investigated mainly concerning litter quality and bedding materials, specific nutrients (protein, macro elements, biotin, zinc) and distinct dietary factors (soybean meal, soybean oligosaccharides, mannan oligosaccharides). Each litter/dietary factor was evaluated simultaneously under the influences of dry and wet litter, respectively.

Material and methods

Five consecutive experiments (Youssef *et al.*, 2010/2011a-d) were conducted on 2-week-old female turkeys (BUT, Big 6) for a period of 3 or 4 weeks. The animals in each experiment were divided into 4 groups, each with 20 or 29 birds. The turkeys in every experiment were exposed to wet litter for 8h / day to simulate the litter quality under field condition, where only specific areas are very wet, especially around drinkers. The wet litter was always maintained at about 27 % DM content by adding water as required. The foot pads of all birds were examined at the start and end of each experiment and at weekly intervals and assessed macroscopically and histologically according to external and histological scores of Mayne *et al.* (2007c; Fig. 1 - 2). External foot pad scores ranged from 0 (no evidence of FPD) to 7 (more than half of the foot pad covered in necrotic scales). Histopathological scores for foot pad lesions also ranged from 0 (normal) to 7 (ruptured epidermis and widespread inflammatory cells covering at least one-third of the foot pad). Moreover, the dry mater (DM) content of the litter was measured throughout the experiments.

Figure 1:
External FPD score 0: skin of the foot pad and digital pads appears normal.

Figure 2:
External FPD score 7: over half of the foot pad covered in necrotic scales.

Experiment 1: Effects of protein metabolites and litter quality

The main products of the protein metabolism in the excreta are uric acid and secondary ammonia. The effects of these protein metabolites as well as of the litter quality on the development of FPD were investigated. The turkeys were housed in floor pens on dry, clean wood shavings litter which was replaced daily with fresh material to maintain the litter clean and dry. The control animals were kept continuously on this litter throughout the experiment (3 weeks), whereas the experimental animals were exposed also to wet (27% DM) wood shavings for 8 h /d only in adjacent boxes. This wet litter contained water alone or water with NH_4Cl or uric acid. Ammonium chloride and uric acid were mixed with water and added to the litter to achieve the concentration of ammonia and uric acid in the litter as found in fresh excreta of turkeys (about 0.50g ammonia and 20g uric acid/kg). The wet litter was cleaned from excreta twice daily and changed twice a week. The foot pads of all birds were examined and assessed by an external scoring at the start and end of the experiment, and at weekly intervals. Three birds were selected from each group at the start, then weekly for histopathological examination of the foot pads. The remaining turkeys per group were sacrificed at the end of the experiment and the pads were assessed histopathologically. Additional details of the experiment are presented in Youssef *et al.* (2011a).

Experiment 2: Effect of macro elements oversupply in the diet

The excess of macro elements in the diet can lead to FPD by irritation of the foot pad when excreted in the droppings or by increasing the excreta/litter moisture. Groups 1 and 2 were fed a control diet that contained low levels (minimum requirements) of specific macro elements (6.65 Ca, 4.43 P, 1.40 Mg, 1.12 Na, 3.16 Cl g/kg diet) while groups 3 and 4 were fed an experimental diet containing high levels of these elements, about twice the minimum requirements (17.1 Ca, 7.73 P, 2.79 Mg, 2.32 Na, 4.58 Cl g/kg diet). One half of the birds were housed in floor pens on dry wood shavings, the other half (groups 2 and 4) were exposed to wet litter (with excreta) for 8 h/d throughout the experiment (3 weeks). The wet litter was maintained at about 27% DM by adding water as required. The foot pads were examined externally and histopathologically. Further information on material and methods are presented in Youssef *et al.* (2011b).

Experiment 3: Effects of high dietary level of soybean meal and its constituents

Soybean meal (SBM) is the most common protein source for use in turkey diets. The “indigestible” carbohydrate part of the soybean meal is thought to be responsible for contact foot pad dermatitis. Stachyose and raffinose are the main components in soy oligosaccharides that cannot be digested by the intestinal enzymes in turkeys (but fermented by intestinal bacteria). It is also suspected that higher levels of potassium in such diets of high SBM lead to a higher moisture content in litter and might be predisposing for FPD. We wanted to elucidate which constituents in SBM, i.e. soybean oligosaccharides (especially stachyose and raffinose) and/or the potassium content, are associated with the higher incidence and severity of FPD.

The birds were randomly allotted to four groups that were fed a control, high SBM, high potassium (K) or high oligosaccharides (OS) diet for 3 weeks. During the experiment, half of the birds were kept on dry wood shavings, the other half exposed to wet litter for 8 h/d in adjacent pens. The wet litter was maintained at a dry matter content of about 27% by adding water as required. All diets were formulated to have identical nutrient contents (except K, stachyose and raffinose). The high SBM diet was formulated to contain about 44% SBM and the high K and OS diets were designed to have the same content of K or oligosaccharides as the high SBM diet. Potassium bicarbonate was added to the high K diet to increase its content of K to be nearly identical to the SBM diet (about 12g K/kg). Also, a commercial soybean oligosaccharides product was used to increase the stachyose and raffinose content of the OS diet to be the same as in the high SBM diet (15g stachyose + raffinose /kg). The foot pads of birds were examined externally and histopathologically at the start and end of the experiment, as well at weekly intervals. Details of the material and methods are documented in Youssef *et al.* (2011c).

Experiment 4: Effect of litter type

Different bedding materials that can be used for turkeys were tested in this trial in order to evaluate the effect of these litter types on the development of foot pad dermatitis. The birds were housed on: wood shaving, lignocellulose (SoftCell®), chopped straw (Strohfix®) or dried maize silage. Half of the turkeys in each treatment were additionally exposed to wet (27% DM) litter for 8 h/d throughout the experiment (4 weeks). The foot pads were examined externally and histopathologically. The material and methods of this experiment are described in detail in Youssef *et al.* (2010).

Experiment 5: Effect of dietary supplementation of biotin, zinc and mannan oligosaccharides

Two week-old female turkeys were randomly allotted to 4 groups, with 29 each, and housed on wood shavings for a period of 4 weeks. Four diets were fed: control, high biotin, high Zn or mannan oligosaccharide (MOS) diet. The control diet contained required amounts of biotin (300 µg/kg) and Zn (50 mg/kg), while the high biotin or Zn diet comprised 2000 µg biotin or 150mg Zn/kg. The MOS diet was formulated by adding mannan oligosaccharide (Bio-Mos®) at a level of 1% (higher than commonly used [0.05-0.20%] to provoke its effect on FPD) but with amounts of biotin and Zn like the control diet. Half of the turkeys in each group were exposed to wet litter (27% DM) for 8 h/d. Foot pads of all birds were assessed macroscopically on day 0, 7, 14, 21 and 28. Three birds per litter treatment were selected from each group on day 0, 7, 14 & 28 and 4 birds on d 21 for histopathology of foot pads. The DM content of litter as well as plasma biotin and Zn levels were measured at the start, once a week and at the end of the experiment. Details of the material and methods are published in Youssef *et al.* (2011d).

Results:

- Experiment 1:

The severity of FPD was markedly higher on wet than on dry litter (Fig. 3), and no differences in foot pad scores were found between various treatments within wet litter. Similar results were also obtained by histopathology of foot pad lesions. These findings indicate that the high litter moisture solely can cause FPD in turkeys and the high protein content in the diet does not play a dominant role in the development of FPD.

- Experiment 2:

There was no difference between birds housed on dry litter and fed low vs. high levels of macro elements (Fig. 4). The severity of FPD was higher on wet than on dry litter, and birds fed the high macro elements diet and exposed to wet litter had slightly higher FPD scores, especially at the end of experiment. Nevertheless, the effect of macro elements was slight in comparison to that of high litter moisture. The results of histological foot scores were consistent with the external FPD scores.

Figure 3: Effect of litter treatment on external FPD scores at the end of the experiment.

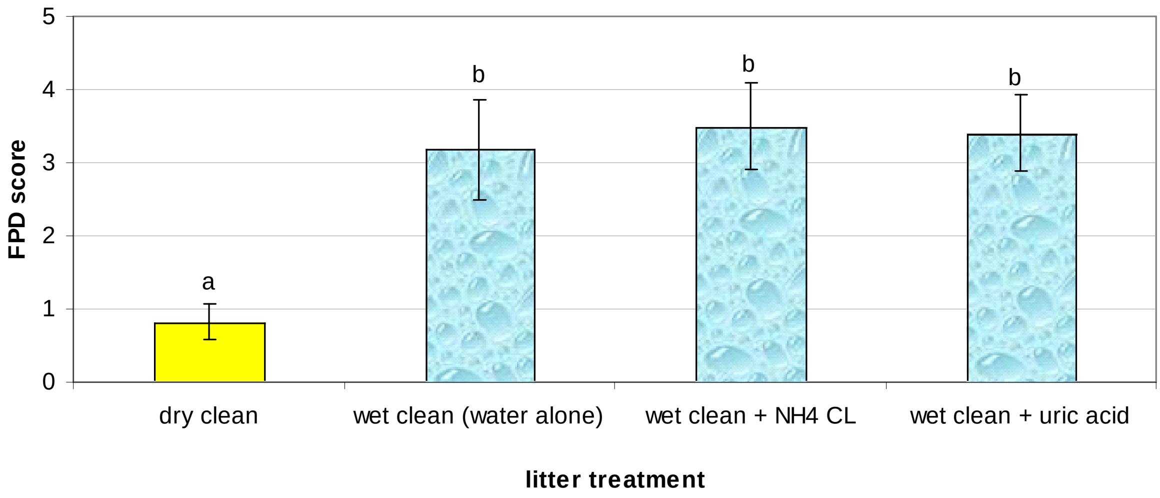
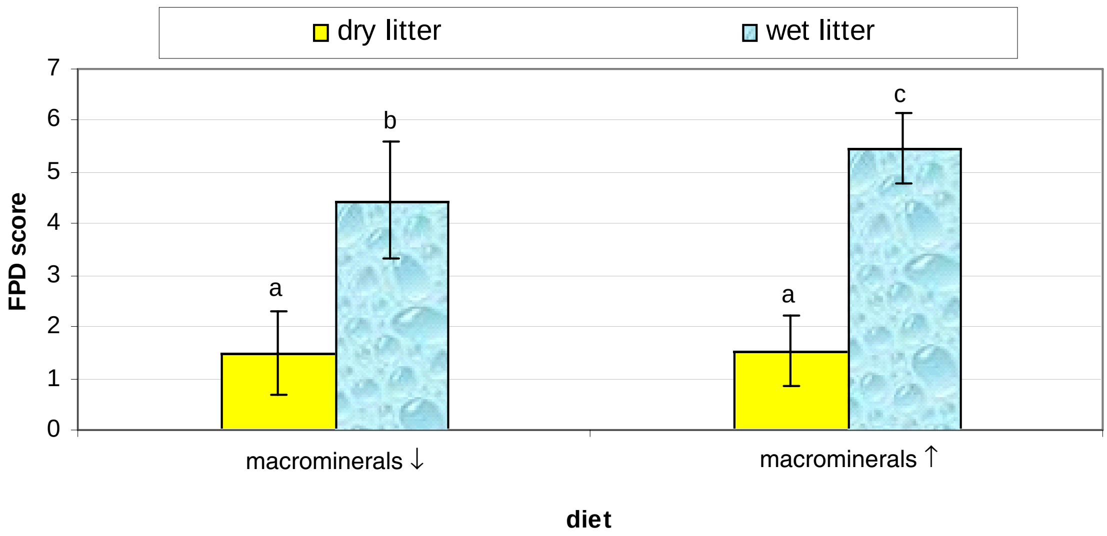


Figure 4: Effect of macromineral diet on external FPD scores at the end of the experiment (Youssef *et al.*, 2011b).



- Experiment 3:

There was no difference in the severity of FPD between the birds housed on dry litter, but the severity was higher in turkeys fed high SBM, K or OS diet and exposed to wet litter when compared to the control diet (Fig. 5). The severity was generally higher on wet litter than on dry litter. However, there were no histopathological differences between the animals housed on dry litter or between those exposed to wet litter. The birds fed the high SBM diet had a markedly higher water intake than the other groups (SBM > K > OS > control), and their excreta appeared wet or sticky by visual inspection (Fig. 6).

Figure 5: Effect of high dietary SBM, potassium and oligosaccharides on external FPD scores at the end of the experiment.

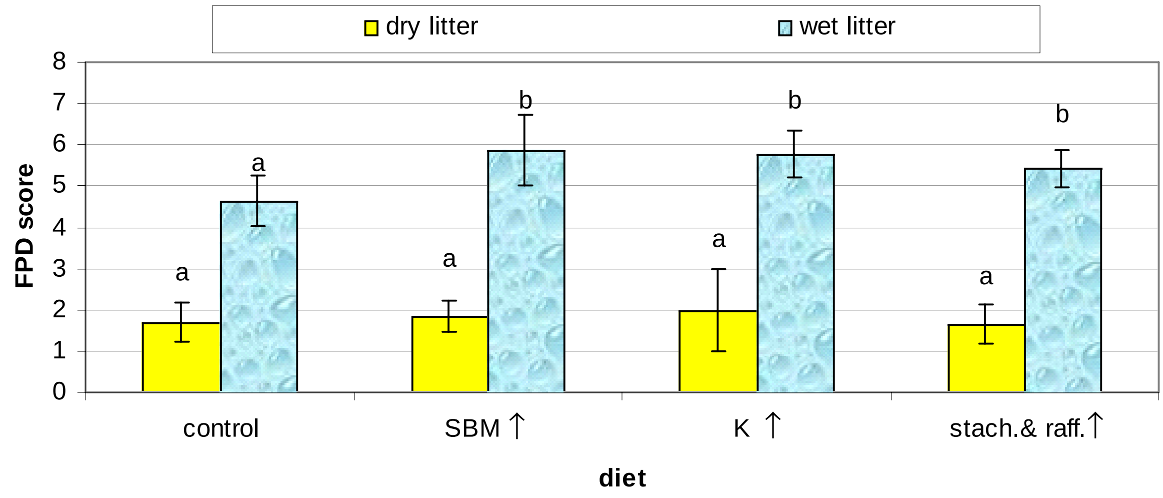
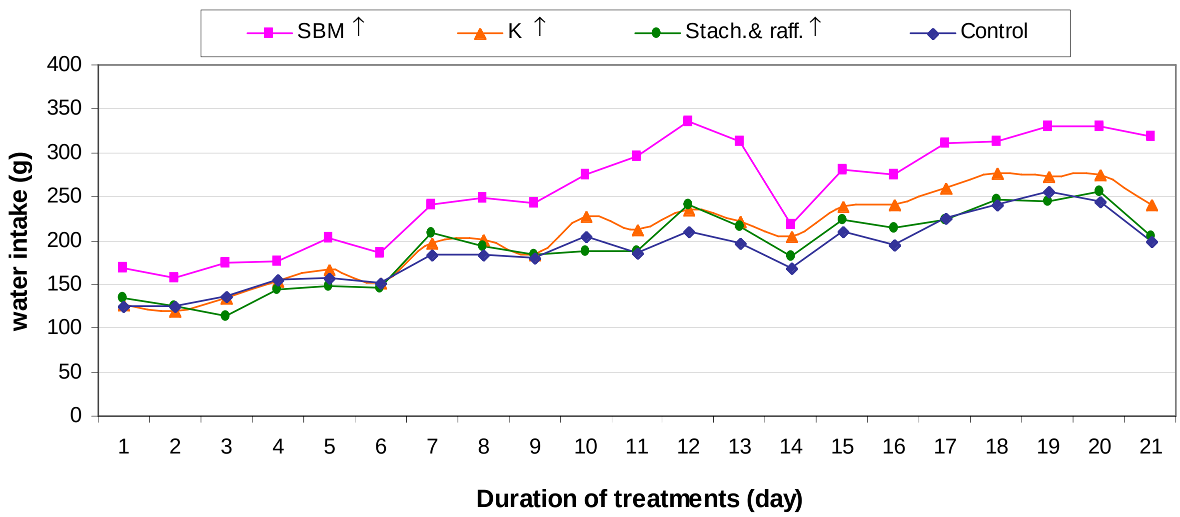


Figure 6: Water intake (g) of turkeys fed different experimental diets throughout the experiment (Youssef *et al.*, 2011c).



<u>- Experiment 4:</u>

Lignocellulose litter showed the lowest severity of foot pad lesions on dry and wet litter (Fig. 7). However, chopped straw (dry treatment) was associated with higher foot pad scores. Moreover, the severity of FPD was higher on wet than on dry litter in each litter type. The histology of foot pads showed similar results to the external FPD scores, with significantly higher scores on chopped straw. With identical diets and stocking density, the DM content in the pens with dry litter treatment was 76.7, 83.2, 68.8 and 75.0% for wood shavings, lignocellulose, chopped straw and dried maize silage, respectively (Fig. 8). Foot pad scores and the moisture content of litter materials were highly correlated (R^2 = 0.96).

Figure 7: Effect of different litter material on external FPD scores at the end of the experiment.

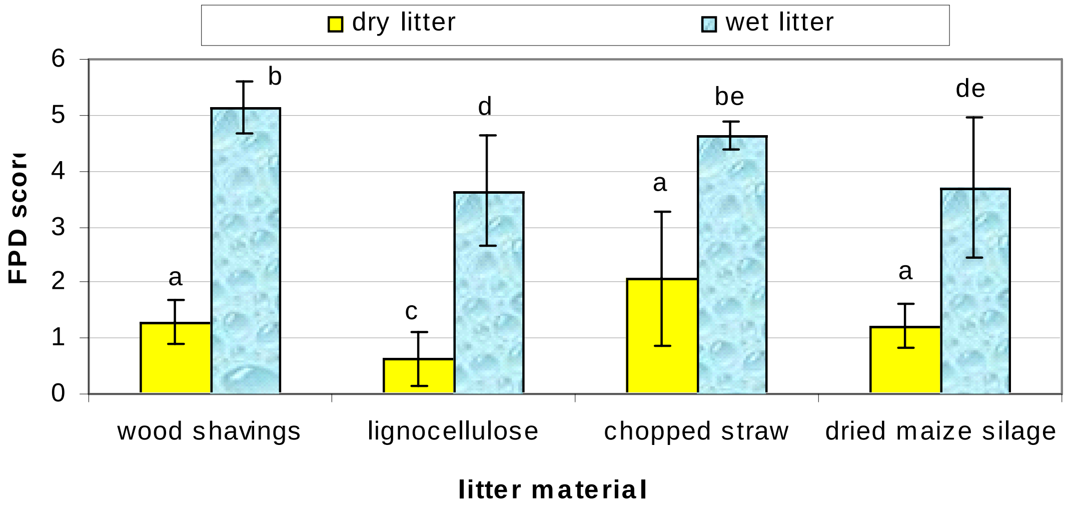
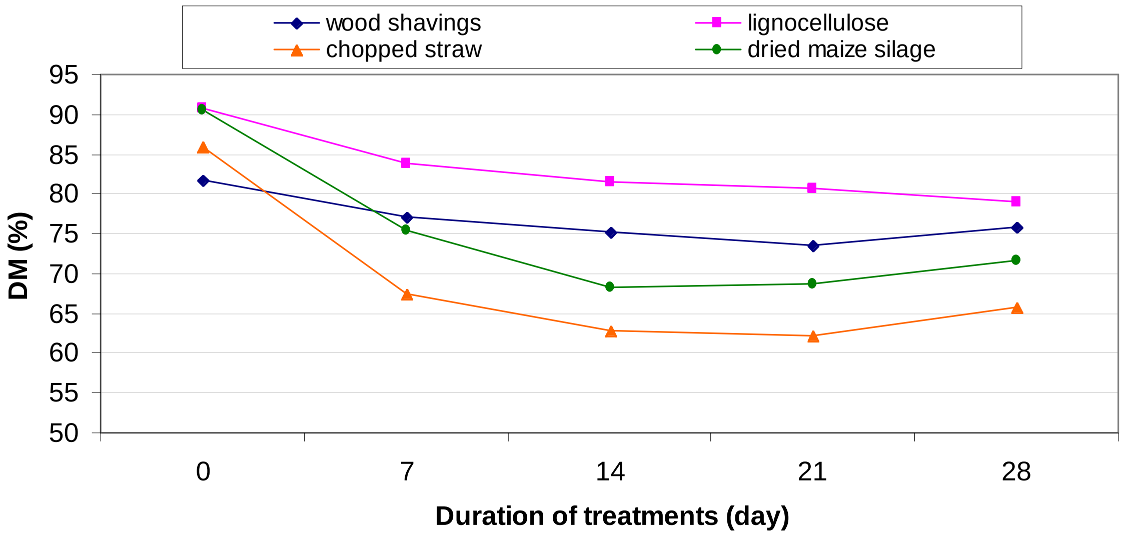


Figure 8: DM content (%) of bedding materials for dry treatments (Youssef *et al.*, 2010).



<u>- Experiment 5:</u>

The severity of FPD was much higher in all pens with wet litter (Fig. 9). High dietary levels of biotin or Zn significantly reduced the severity on dry litter (75% DM), but had no preventive effects on wet litter (27% DM). The histological FPD scores showed similar results to external scores. Plasma biotin and Zn levels increased in turkeys fed a high biotin or Zn diet (Fig. 10).

Figure 9: Effect of dietary supplementation of biotin, Zn and MOS on external FPD scores at the end of the experiment.

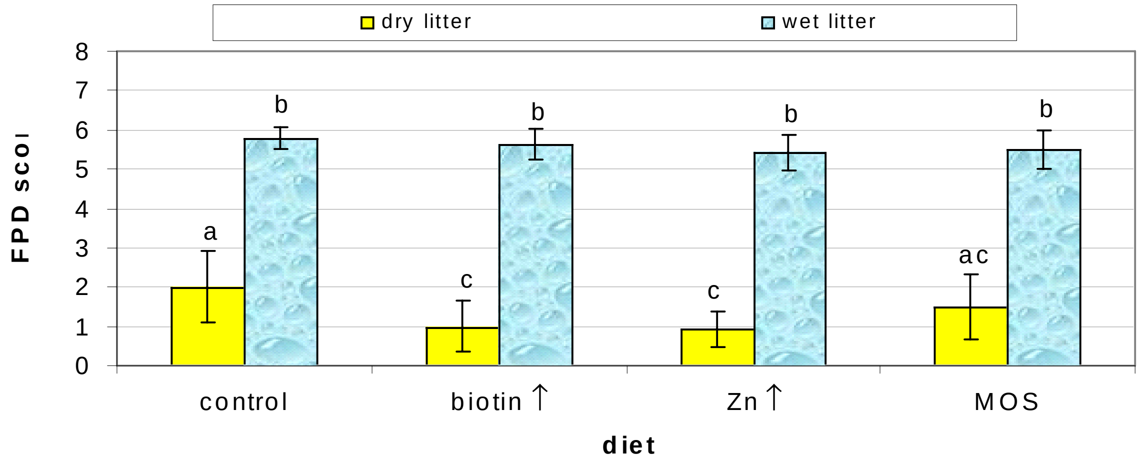


Figure 10: Plasma biotin (ng/l) and Zn (ug/dl) levels at the end of the experiment (Youssef *et al*., 2011d).

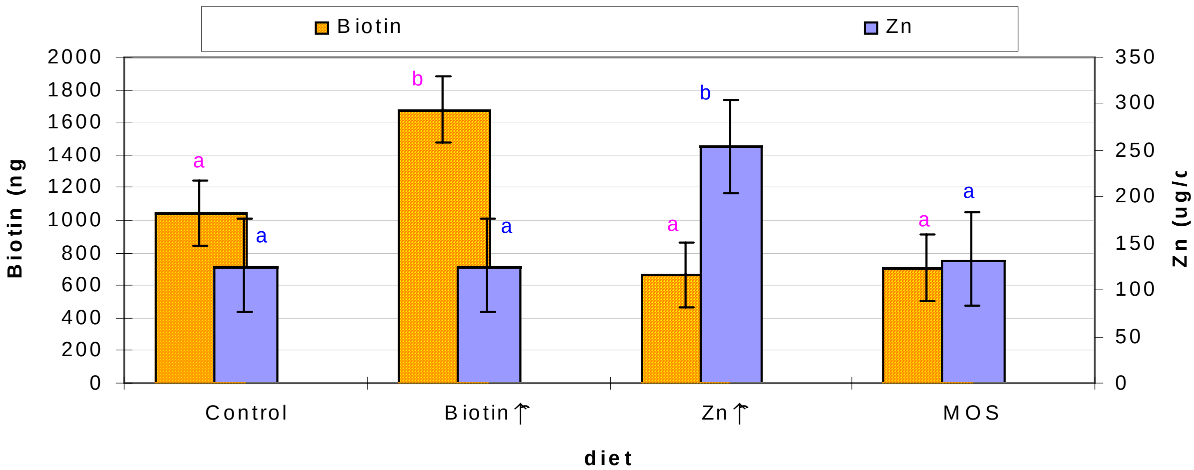


Table 1 Averages of external/histopathological scores on dry and wet litter (8 h/d) at the end of the experiments, independent of litter type/constituents and dietary contents

FPD score	Litter	Exp. 1 (water, NH_3, uric acid in litter)	Exp. 2 (macrominerals)	Exp. 3 (SBM/K/OS)	Exp. 4 (litter material)	Exp. 5 (biotin/Zn/MOS)
	excreta	-	+	+	+	+
external	dry	0.82 ^{aA}	1.53 ^{bcdA}	1.80 ^{bA}	1.30 ^{cA}	1.36 ^{cdA}
	wet	3.36 ^{aB}	4.95 ^{bB}	5.43 ^{bdB}	4.28 ^{cB}	5.59 ^{dB}
histologic	dry	1.41 ^{aA}	2.37 ^{abA}	1.88 ^{abA}	1.91 ^{abA}	2.16 ^{bA}
	wet	3.75 ^{aB}	5.39 ^{bB}	5.89 ^{cB}	5.25 ^{bB}	5.81 ^{cB}

Means with different small letters indicate significant differences between the experiments, whilst those with capital letters indicate differences between dry and wet litter within external or histological scores ($P < 0.05$).

Exposure of turkeys to wet litter for only 8 h per day was sufficient to induce foot pad lesions. Mayne *et al.* (2007c) found that fully developed lesions were induced within 2 to 4 days after continuous housing of the birds on wet litter. The foot pad scores were always much higher on wet than on dry litter in all trials, regardless of the effects of litter type/constituents and of dietary factors (Table 1). Comparing the results of foot pad scores across all experiments, especially at the end, the scores were slightly higher on wet dirty litter than on wet clean litter. This indicates that the contact with excreta can aggravate the effect of wet litter.

Discussion

High dietary protein level has been found to increase the incidence and severity of FPD in broilers (Nagaraj *et al.*, 2006 and 2007b), which may be due to increased nitrogen excretion and NH_3 formation in the litter. In our study, the water content in the litter was the major causative agent of FPD, whereas the main protein metabolites (uric acid, NH_3) in wet litter had no significant negative effects. This suggests that the focus on high protein content of the diet as a possible cause of FPD is probably unjustified. The higher ammonia content of the litter may be a causative agent of FPD, but volatile ammonia in the litter was not confirmed as a cause of FPD in several studies. Nagaraj *et al.* (2007c) found that a high dietary protein level did not affect the prevalence of FPD in broilers, despite the increased excretion of nitrogen in the litter and higher release of NH_3.

The results of the present experiments showed that high amounts of macro-minerals, SBM, K or oligosaccharides in the diets slightly increased the severity of FPD on wet litter only, but had no negative effects as long as the litter was dry. The effects of these dietary factors were very slight in comparison to the effect of wet litter per se. Wet litter probably softens the epidermis which makes the skin more susceptible to contact dermatitis (Mayne *et al.*, 2007c). Prolonged contact with excreta and high litter moisture contributes to a higher prevalence of FPD, which is thought to be caused by a combination of wet litter and chemical substances in the litter or unidentified irritants in excreta. The findings of our study agree with the results of Steenfeldt *et al.* (2005), who found no effect of different levels of calcium and phosphorus on the incidence and severity of FPD in broilers. The impact of high SBM levels could be related to its content of both K (increasing excreta moisture) and oligosaccharides (producing viscous/sticky excreta).

High litter moisture (for only 8 h/d) potentiated the prevalence and severity of FPD in all experiments. This clearly shows that litter moisture is the major factor causing FPD. Similar results were observed in previous experiments after continuous exposure to wet litter. In our study, the exposure to wet litter for only 8 h/d was sufficient to provoke FPD. This implies that all factors which affect the litter moisture either directly or indirectly are of interest. The prevalence of FPD paralleled high litter moisture as also reported by Bilgili *et al.* (2009). The severity of foot pad dermatitis began to increase when the litter contained more than 30% moisture.

Of all tested bedding materials, lignocellulose showed the lowest severity of FPD. This could be due to higher water binding capacity and to faster release of water from lignocellulose. These findings are consistent with the results of Berk (2007). In dry litter treatments, chopped straw was associated with higher FPD scores, probably due to lower water evaporation and caking (Bilgili *et al.*, 2009), resulting in a higher moisture content in this litter. Several other studies reported that chopped straw was associated with the highest FPD severity scores in broilers and in turkeys. The ability of litter to bind and/or quickly release water is aparently a very important factor in the etiology of FPD. The physical structure of the litter either soft (lignocellulose) or sharp edges (chopped straw) may also contribute to lower or increase the prevalence of FPD. The FPD scores on wood shavings and dried maize silage were similar on dry treatments. On wet litter treatments, there was no difference in FPD scores between wood shavings, straw or wet maize silage (histologically only). The FPD scores on wet maize silage were decreased, probably due to change of this litter each week (as a result of mould growth) or due to low pH and lactic acid content (formed during ensiling) which might have bactericide effects (Bosse and Meyer, 2007; Wilms-Schulze Kump, 2007).

Mayne *et al.* (2006b, 2007a) found that FPD is associated with massive increases in heterophils and macrophages and the loss of surface keratin. These cellular changes are an inflammatory response and not an allergic reaction. The correlation between external and histopathological scores was very high (about 0.90), while the relationship between external and histological FPD scores was much lower (r = 0.56).

Depending on severity, foot pad lesions are probably painful. Mayne *et al.* (2007c) found that turkeys (23 days old) had an extreme inflammatory response and were reluctant to move after only 2 days continuous exposure to wet litter. The external FPD scores of these birds varied around 6.70, indicating signs of inflammation. In this study, the external FPD scores on dry litter ranged from 0 to 4, while those on wet litter varied from 1 to 7. Regardless of the experimental treatments, the incidence of severe external scores (6.0, 6.5 and 7.0) at the end of the experiments was 13.7%, 3.59% and 1.43%, respectively. However, no signs of discomfort or pain during movement were observed in this study. Platt *et al.* (2001) found that the incidence of superficial lesions decreased in turkeys after 14 weeks, while more severe ulceration increased, indicating that the lesions become more severe in older birds and consequently may be become painful.

High levels of dietary biotin or Zn could help to reduce the incidence of FPD. However, the effects of these nutrients appear to depend largely on DM content of the litter. As observed in this study, inclusion of high levels of biotin or Zn reduced the severity of FPD on dry litter, but not on wet litter. It was reported that supplementation of biotin decreased the severity of FPD in turkey poults raised on dry litter, but not in poults maintained on wet litter (Harms and Simpson, 1977; Mayne, 2005). Several studies reported that biotin supplementation reduced the prevalence of FPD, while others could not confirm that high dietary biotin levels prevent FPD. Some studies reported that dietary Zn reduced the incidence and severity of foot pad lesions (Hess *et al.*, 2001; Bilgili, 2009), but found no effect of Zn on the severity of FPD when birds were reared in cool weather (4 – 15 ºC), indicating that the effect of Zn varies with environmental conditions (which may affect the litter moisture). High concentrations of biotin or Zn failed to reduce the severity of FPD on wet litter. Perhaps the potentially positive effects of these additives on healing of the lesions were suppressed by the stronger negative effect of high litter moisture. The foot pad lesions on wet litter may also be complicated by secondary bacterial contamination which inhibits the healing process induced by biotin or Zn. The lesions on wet litter were more severe (necrosis or ulcer) and accompanied with inflammatory reaction as indicated histologically by infiltration of inflammatory cells. This inflammatory response is probably related to bacterial infection. Foot pad lesions on dry litter, on the other hand, were mild and not associated with bacterial invasion, so that the lesions could respond to biotin or Zn supplementation.

Conclusions

The results indicate that high dietary protein is not a major cause of FPD and may only have an indirect effect by increasing litter moisture. High amounts of macro-minerals in the diet had only slight effects on foot pads when the animals were exposed to wet litter. High dietary levels of SBM, K and OS slightly increased the FPD severity, but only on wet litter. Presumably, water softens the epidermis which makes the skin more susceptible to contact dermatitis. Lignocellulose as litter material reduced the incidence of FPD, whereas chopped straw increased it compared to wood shavings. High dietary levels of biotin or Zn may help to lower the severity of FPD, but only on dry litter and not on wet litter. Moreover, the severity of FPD was always much higher on wet than on dry litter, indicating that high litter moisture is the dominant factor causing FPD. Exposure of animals to wet litter for 8 h/d was sufficient to cause FPD. All dietary factors which increase water intake and excreta or litter moisture may contribute to FPD. Therefore, control of litter moisture (optimum diet composition and ventilation) is likely to be highly effective in diminishing the prevalence and severity of FPD in commercial turkey flocks. The present results suggest that litter moisture should not exceed 30% to minimize the incidence of foot pad lesions.

Summary

Foot pad dermatitis (FPD) is a common problem in growing turkeys. FPD is an animal welfare issue and accompanied with reduced growth rate (due to lower feed intake) and lameness in severe cases. Nutrition affects directly and indirectly the development of FPD. The litter quality plays also an important role in the incidence of FPD, which in turn is influenced by the diet composition. This study was conducted on young turkeys to determine the most relevant causes and possible preventive measures. Effects of wet litter and/or protein metabolites (uric acid, NH_3) in the litter and of excessive dietary macro-minerals on FPD were investigated as well as influences of high dietary soybean meal (SBM) and its contents from potassium and certain oligosaccharides. Also, the impact of litter type (wood shavings, lignocellulose, chopped straw, dried maize silage) and litter quality (especially moisture content) was assessed. Effects of specific dietary supplements [biotin, Zn, mannan oligosaccharide (MOS)] as preventive measures were also tested. Each factor investigated was evaluated under dry and wet litter conditions (73% moisture; achieved by adding water). High litter moisture was found to be the dominant factor contributing to the development of FPD. Presence of ammonia or uric acid in the litter did not aggravate the effect of wet litter. All dietary factors which increase excreta or litter moisture may contribute to FPD. Lignocellulose litter reduced the severity of FPD, whereas chopped straw showed higher foot pad scores. High dietary levels of biotin or Zn might be able to lower the severity of foot pad lesions, but only on dry litter and not on wet litter. To minimise the development and severity of FPD in commercial turkey flocks, the litter should be kept dry.

Zusammenfassung

Beeinflussbarkeit von Fußballenentzündungen bei Mastputen durch Futterzusammensetzung und Einstreuqualität

Die Fußballenentzündung (foot pad dermatitis, FPD) ist eine in der Putenhaltung weit verbreitete Erkrankung, die in schweren Fällen mit eingeschränkter Bewegungsaktivität (Schmerzen) und Leistungseinbußen (reduzierte Futteraufnahme) einhergeht. Insbesondere aus Tierschutzgründen sind Lösungen erforderlich, die zu einer Entschärfung des Problems führen. Ursächlich spielt die Einstreuqualität eine wesentliche Rolle. Diese wiederum wird auf vielfältige Weise durch die Fütterung beeinflusst. Vor diesem Hintergrund wurden mit jungen Mastputen die Auswirkungen von Endprodukten des Proteinstoffwechsels (Harnsäure und Ammoniak in der Einstreu), die Effekte bedarfsüberschreitender Mengenelementgehalte und die Bedeutung von Sojaextraktionsschrot für die Entwicklung der FPD näher untersucht, wobei jeweils parallel die Feuchtigkeit in der Einstreu mit variiert wurde. Des Weiteren wurde auch der Einfluss des Einstreumaterials (Hobelspäne, Lignozellulose, Stroh, getrocknete Maissilage) untersucht. Schließlich interessierten mögliche Auswirkungen verschiedener Futterzusätze [Biotin, Zink, Mannan-Oligosaccharide (MOS)] zur Prävention dieses Bestandsproblems. Es zeigte sich, dass der Feuchtegehalt der Einstreu ganz entscheidend das Vorkommen und die Ausprägung der FPD bestimmt. Metaboliten des Proteinstoffwechsels (Harnsäure/Ammoniak) und eine bedarfsüberschreitende Mengenelementaufnahme (außer Kalium), bleiben ohne wesentlichen Einfluss. Hohe Sojaschrotanteile wirkten eindeutig nachteilig, und zwar durch ihren hohen K-Gehalt, aber auch wegen ihres Oligosaccharidgehaltes (Effekte auf die FPD waren Folgen einer forcierten Wasseraufnahme und -abgabe über die Exkremente); unter den geprüften Einstreumaterialien war die Lignozellulose sowohl unter den Bedingungen einer trockenen Einstreu als auch bei (experimentell) nasser Einstreu besonders vorteilhaft (jeweils signifikant günstigere FPD-Scores). Schließlich verdient Erwährung, dass unter den Bedingungen einer trockenen Einstreu (und nur hier) eine Zulage von Zink oder Biotin eindeutig günstig wirkte. Insgesamt basieren die Zusammenhänge zwischen der Fütterung und Futterzusammensetzung einerseits und dem FPD-Geschehen andererseits ganz wesentlich auf den Veränderungen in der Wasseraufnahme und der Exkremente- bzw. Einstreuqualität.

This paper is summarized from five original papers published in international journals:

Youssef, I.M.I., A. Beineke, K. Rohn, and J. Kamphues (2010): Experimental study on effects of litter material and its quality on foot pad dermatitis in growing turkeys. International Journal of Poultry Science 9 (12), 1125-1135.

Youssef, I.M.I., A. Beineke, K. Rohn, and J. Kamphues (2011a): Effects of litter quality (moisture, ammonia, uric acid) on development and severity of foot pad dermatitis in growing turkeys. Journal of Avian Diseases, **55**, 51-58.

Youssef, I.M.I., A. Beineke, K. Rohn, and J. Kamphues (2011b): Effects of macrominerals - surplus in the diet and high litter moisture on development and severity of foot pad dermatitis in growing turkeys. Journal of European Poultry Science, (In Press).

Youssef, I.M.I., A. Beineke, K. Rohn, and J. Kamphues (2011c): Effects of high dietary levels of soybean meal and its constituents (potassium, oligosaccharides) on foot pad dermatitis in growing turkeys housed on dry and wet litter. Archives of Animal Nutrition, **65**, 148-162

Youssef, I.M.I., A. Beineke, K. Rohn, and J. Kamphues (2011d): Influences of increased levels of biotin, zinc or mannan-oligosaccharides in the diet on foot pad dermatitis in growing turkeys housed on dry and wet litter. Journal of Animal Physiology and Animal Nutrition, Article first published online: 4 January 2011.

A complete list of references may be obtained from the corresponding author:

I.M.I. Youssef
Institute of Animal Nutrition,
University of Veterinary Medicine Hannover, Foundation
Hannover, Germany
E-mail: Ibrahim.Youssef@tiho-hannover.de

Breeding for reduced boar taint

L. FRIEDEN, C. LOOFT and E. THOLEN, University of Bonn, Germany

Introduction

Intact boars are rarely used for fattening, because consumers would object to the boar taint, which tends to develop with sexual maturity and renders pork inedible. To eliminate this problem, boars are usually castrated at a young age, a practice which is painful and has been criticized repeatedly as not in line with animal welfare. In 2008, representatives of the German pig farming community, the processing industry and the trade drafted a resolution („Düsseldorfer Erklärung“) to stop castration of piglets without anesthezation. European pig farmers and their union (COPA-COGECA) agreed in December 2010 to terminate surgical castration by 2018. This means that castration of piglets with anesthesia will only be accepted as a transitional step until castration will be completely banned in Europe. However, if intact boars are fattened, negative consumer response to boar taint in pork has to be prevented: by testing carcasses routinely with sufficient speed and accuracy and by reducing the incidence of boar taint at slaughter age. This may be approached in different ways: by genetic selection, nutrition and/or management.

Development of boar taint

Boar taint develops under the influence of genetic and non-genetic factors as has been summarized by Bracher-Jakob, 2000. Several studies have shown that the level of skatole and androstenone, the two main components responsible for boar taint, is moderately to highly heritable; the deposition in fat increases with sexual maturity. Non-genetic contributing factors which have been identified are group vs. single pen management and light for androstenone level and nutrition, housing system and hygiene for skatole.

Breed differences in boar taint

In order to assess the chances to reduce and eventually eliminate the boar taint by genetic selection, we need to know the relevant population parameters. In table 1 we have summarized results from the literature to show the existing variation between breeds or populations. This may be of special interest for breeding programs which focus on quick response. However, these estimates should not be taken at face value without taking all essential factors into account: age and live weight at the time of testing, management conditions, laboratory techniques applied, and sample size. As pointed out by Haugen (2009), neither are official reference methods available to determine and compare *androstenone* and *skatole* levels, nor are all results have been published.

The relevance of laboratory techniques has been demonstrated by Harlizius *et al.* (2008), whose results from different laboratory methods differed by a factor of 2 to 4 for identical samples of backfat. This should be kept in mind; for genetic evaluation, genotypes must always be compared under the same conditions.

The critical level of 0.5 µg androstenone per gram fat, above which most people would notice the boar taint, was exceeded in all but one small sample in table 1.

Typically, more than 40% of boar carcasses would be “off-odor“ according to the androstenone level. Comparing different breeds, Durocs and the early maturing Piétrains tend to have the least desirable taint scores. In the ongoing project called Electronic nose, breeding, entire boar fattening (EN-Z-EMA), funded by the German Federal Ministry of Food, Agriculture and Consumer Protection, about 1,000 progeny of Piétrain sires are currently being tested for meat taint in addition to conventional performance criteria.

Currently 800 boars with measurements of this study are available. 38% of the boars exceeded the critical levels of 250 ng skatole and 1,000 ng andostenone per gram backfat; skatol and andostenone

Table 1: Breed differences in androstenone level

Breed	Country	N	Age days	Weight kg	Androstenone µg / g fat		Number animals >0.5 µg	Ref.
					$\bar{x}$	s		
Piétrain (Pi)	F			100	1.75			1[a]
Belgian Landrace				100	0.61			
Large White (LW)	F	120	170	101	0.60	0.60		2[a]
		183	182	112	0.60	0.50		
[Ha×Pi] × [LW×LR]		148	171	105	2.40	170		
Landrace (LR)	D		170		0.28	0.22		3[a]
			190		0.44	0.67		
			210		0.54	0.76		
LR	DK			90	0.71			4[a]
Yorkshire (Y)	S	143	201	110	1.26	0.94		5[a]
BHZP-Cross	D	32		95	0.54	0.39	50.0	6[a]
		30		115	0.67	0.47	40.6	
LW×LR		32		95	0.73	1.64	34.5	
		29		115	0.73	0.58	28.1	
Pi×LR		28		95	0.63	0.50	46.7	
		30		115	1.13	2.09	46.4	
LR	N	1728	143	100	1.19	1.10		7
Duroc (Du)		1202	156	100	3.27	252		
Topigs commercial boar	NL	1539			1.71	1.42		8
Pi×F1 *1) group pen *2) single pen	D	61		105[*1)]	0.69	0.79	40.6	9
		64		120[*1)]	0.94	0.91	57.8	
		27		105[*2)]	1.50	1.12	87.5	
		27		120[*2)]	1.89	0.89	92.6	

[a] cited by Bracher-Jakob (2000); [1] Bonneau *et al.*, 1979; [2] Bonneau and Russeil, 1985; [3] Willeke *et al.*, 1987; [4] Jonsson and Joergensen, 1989; [5] Lundström *et al.*, 1987; [6] Weiler *et al.*, 1995; Xue [7] Tajet *et al.*, 2006; [8] Bergsma *et al.*, 2007; [9] Adam *et al.*, 2009.

contributing similarly to this percentage. The skatole levels are more likely to be influenced by non-genetic factors than andostenone levels. Nutrition, management, hygiene and the point of sampling (backfat vs. bacon) can influence the skatole level measured and limit the accuracy of genetic evaluation.

Reduction of boar taint by conventional selection

The breeding goals and selection indexes in commercial pig breeding programs include a number of traits defining the efficiency of live weight gain, carcass value and reproductive performance. To predict and achieve the desired genetic progress in specific traits, we need to know the relevant population parameters. As shown in table 2, the androstenone level apparently has a high heritability, and the somewhat lower heritability estimates for skatole and indole levels are also encouraging.

Table 2: Heritability estimates for androstenone, skatole and indole level

Source	Androstenone	Skatole	Indole
Sellier *et al.*, 2000	0.55	0.23-0.55	
Tajet, 2006	0.50-0.60	0.23-0.56	
Bergsma *et al.*, 2007	0.75	0.44	0.32

Assuming that the skatole level can be significantly reduced by management and nutrition, genetic approaches may focus on controlling androstenone.

Androstenone is produced in the gonads along with other sexual steroids, androgens and estrogens. Therefore we should be aware of possible antagonistic correlations between androstenone and reproductive performance (Claus, 1993). Published estimates of genetic correlations between andostenone and paternal or maternal reproductive traits are, however, rare.

Bergsma *et al.* (2007) reported antagonistic correlations between androstenone and paternal fertility in terms of sperm motility (0.32), ejaculate volume (0.18) and livability of sperm (0.11), whereas the correlation with sperm concentration pointed in the desired direction (-0.22). In the same study, antagonistic correlations were found between androstenone levels in backfat probes and maternal reproductive performance in terms of sexual maturity and age at first insemination (-0.24), interval between weaning and subsequent conception (-0.44) and number of stillborn piglets (-0.59).

Willeke (1987) concluded from his analysis that selection for reduced androstenone level would have the undesirable effect of increasing the age at sexual maturity of boars as well as sows. Sellier *et al.* (2000) tried index selection for lower androstenone level while keeping the size of the bulbourethal gland constant, but failed.

Own study

To answer the question of an assumed commercial breeder who has to determine which selection approach is most promising, we modeled several different scenarios, applying index theory (proportional index) to predict the possible reduction of androstenone levels (Tholen and Frieden 2010).

Table 3 shows the traits to be measured. It is assumed that the androstenone level can be measured in live boars from backfat probes obtained by microbiopsy.

Table 3: Traits to be measured for performance testing boars

Trait	Information from
Androstenone	Boar being tested
Live born piglets	Dam of boar, first 2 litters
Age at first mating	Dam of boar
Daily gain, feed conversion ratio, carcass composition and valuable parts	2 × 3 fullsibs and halfsibs of boar

Table 4 shows the relative importance and expected economic progress in the traits included in the index as breeding goal, separately for dam and sire lines. The parameter estimates are based on own analysis of German herdbook data and literature (Sellier *et al.*, 2000). For androstenone we assumed a heritability of 0.50.

Table 4: Breeding goals and predicted relative economic progress (in %)

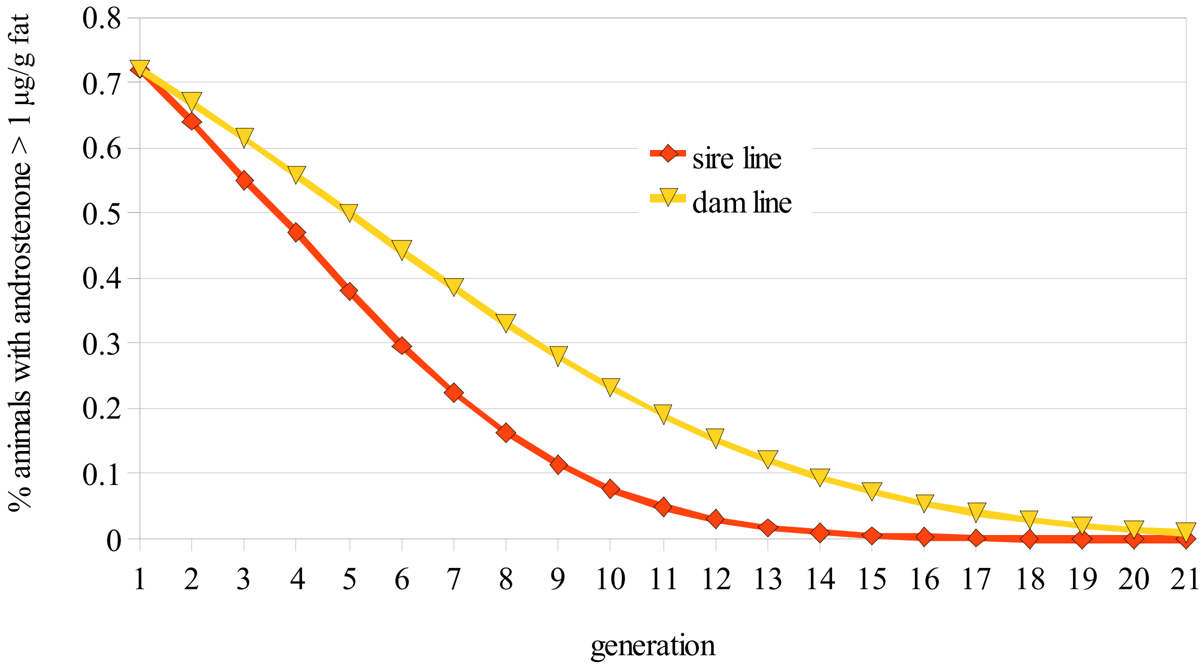
Selection trait	Dam line		Sire line	
	Breeding goal with vs. without androstenone			
	without	with	without	with
Androstenone	-	22.3	-	17.8
Live born piglets	59.8	34.4	1.1	1.0
Age at first mating	0.0	0.0	0.0	0.0
Daily gain	25.3	24.6	21.4	18.4
Feed conversion rate	13.0	14.0	33.7	29.0
Meatiness of carcass	1.9	4.8	43.8	33.9

The economic weights (w) differ considerably between the sire and dam lines: the dam lines are mainly selected for number of piglets weaned per year, the sire lines for carcass composition. Change in age at first service was set to zero for all lines. Antagonistic correlations between androstenone level and reproductive performance were assumed to be $r_g = |0.2|$.

The economic weight for androstenone level was determined with the condition that 80% of the progress in conventional traits should be retained. In each generation the best 10% males and 50% females are selected in both lines.

Inclusion of the androstenone level in the index results in significantly less progress in reproductive performance, but slightly more progress in carcass value in the dam line, whereas considerable progress in meatiness is sacrificed in the male line to achieve a reduction in androstenone levels.

Figure 1: Predicted frequency of boars with >1 µg/g androstenone in backfat probes if this trait is included in a proportional selection index



The model calculations suggest that at least 4 to 6 generations, i.e. 8 to 12 years would be required to reduce the frequency of boars with >1 µg/g fat from 20% to 5%, even with optimistic assumptions regarding the antagonistic correlation between fertility and boar taint (fig. 1).

Our estimate of time required for a genetic solution may be compared with the result of Ducro-Steverink (2006) who calculated less than 5 years to reduce the incidence of boar taint from 30% to 10%, assuming a heritability of 0.40 for the androstenone level and ignoring negative changes in reproductive traits.

Reduction of boar taint with molecular genetic methods

Another breeding strategy to reduce boar taint in pork would be to identify the relevant genes with DNA chips. The pig genome has been almost completely sequenced, which offers the possibility to search for DNA markers associated with boar taint.

Using genome analysis, the genome of individuals is described in terms of SNP (**S**ingle **N**ucleotide **P**olymorphism) markers and compared with the phenotypic expression of the relevant trait. Several recent studies in Europe have identified markers for boar taint. In a Dutch project reported by Duijvesteijn *et al.*, (2010), 13.7% of the additive genetic variation in androstenone level could be explained by the five most important SNPs.

As a second step, genomic selection would be applied to identify and select individuals with the desired genotype of low androstenone level without the need for trait recording.

On first sight, genomic selection may seem to offer a quick and easy solution. Before drawing premature conclusions, the results of Grindflek *et al.* (2010) should be noted who found markers for fertility traits on the same locations of the chromosome as for androstenone level, which is not surprising in view of the described antagonistic effects. Moreover associations between markers and traits are known to be breed specific. In any case, genetic markers have to be identified in each population, with relevant correlations to other traits, before genomic selection is applied in practice.

Discussion and outlook

The intensity of boar taint in carcasses of intact boars can be reduced by selection. This can help the pork industry in gradually reducing the number of carcasses discarded because of boar taint and eventually eliminate the need for castration. To achieve optimal response to selection, standardized procedures for measuring the two main components of boar taint, androstenone and skatole, should be developed. Two current research projects (Anon, 2009a,b) are focused on the development of automated measurement of boar taint for use in slaughter lines of commercial abattoirs as well as on live animals for selection purposes. The eventual goal is to develop techniques for screening live boars for taint score, based on microbiopsy of backfat, saliva or blood samples, which would speed up genetic progress.

The rate at which genetic progress can be reached will depend on antagonistic correlations between boar taint and reproductive traits. These genetic correlations have to be determined in relevant commercial male and female lines.

When identified QTLs for boar taint are being used in genomic selection, special attention should be on gene locations which are not known to be negatively correlated with reproductive performance.

Under current economic conditions in Germany it would make sense to screen terminal sires for boar taint before they are widely used for AI. This approach is currently being field tested with the German Piétrain population in the EN-Z-EMA project (Anon, 2009a). In case this approach does not lead to desirable results, testing of boars will be extended to all male and female lines.

Including the reduction of boar taint in the breeding goal will in any case decrease the rate of progress in other traits, which can mean a loss of competitiveness. A breeding organization may expect benefits from a significantly reduced rate of boar taint:

1) if commercial slaughter houses introduce incentives by paying a premium based on the rate of discarding carcasses due to boar taint; and/or
2) if growing intact boars is significantly more economical than growing castrated males in terms of feed conversion ratio and carcass value (Adam, 2009).

With increasing production of pork from intact boars, the processing industry has to expect substantial losses, because pork with boar taint has no market value. Any potential benefit of growing intact boars can only be realized if the frequency of rejected carcasses is substantially reduced below a critical level of 10% or even less. It will take a considerable number of years to find out whether the European pork industry will be successful in eliminating the need for castrating boars as postulated by animal welfare.

Zusammenfassung

Züchterische Möglichkeiten zur Verminderung der Ebergeruchsproblematik bei Schlachtschweinen

Die Ferkelkastration in seiner bisherigen Form wird keine Zukunft in der EU haben. Es gibt einige Alternativen, wie z.B. die Ebermast. Hierbei stellt der Ebergeruch, welcher hauptsächlich durch die zwei Komponenten Androstenon und Skatol bestimmt wird, ein Problem dar. Allerdings kann Skatol durch Fütterung, Haltungsform und Hygiene reduziert werden, dagegen wird Androstenon hauptsächlich durch genetische Komponenten beeinflusst. Deshalb ist die züchterische Bearbeitung des Ebergeruchs vielversprechend aufgrund der hohen Erblichkeit. Ein Problem stellt dabei die unerwünschte Beziehung des Ebergeruchs zur maternalen und paternalen Fruchtbarkeit dar, die im Züchtungsprogramm berücksichtigt werden muss. Bei dem derzeitigen Stand wird es zwischen 8 und 12 Jahren dauern, um den Anteil Eber mit über 1000 ng Androstenon je g Fett von 20 auf 5 % zu reduzieren. Eine Verkürzung dieser Zeitspanne könnte die Genomische Selektion bieten. Jedoch wird die Selektion gegen Ebergeruch nur dann erfolgreich sein, wenn eine zuverlässige Technologie zur Verfügung steht, wie z.B. die „elektronische Nase“, die einen mit Ebergeruch behafteten Schlachtkörper am Schlachtband eindeutig identifiziert.

References

Anon., 2009a: Forschungsprojekt “Vermeidung von Ebergeruch durch züchterische Maßnahmen und neuartige messtechnische Erfassung (EN-Z-EMA)” bewilligt. http://www.zds-bonn.de/vermeidung_von_ebergeruch_durch_ zuechterische_mass.html.

Anon., 2009b: Verzicht auf Ferkelkastration - QS bringt Forschungsprojekte voran. http://www.q-s.de/ fileamin/QS _Fileadmin/tt_news/091126_PM_ Foerderung_Forschungsprojekte.pdf

Adam, F., C. Schulze-Langenhorst und L. Büttfering, 2009: Düsser Ergebnisse zur Ebermast. Landwirtschaftliches Wochenblatt, 43.

Bergsma, R., E. Knol and H. Feitsma, 2007: Parameters of AI boars and predicted correlated responses of selection against boar taint. Proc. EAAP Meeting, Dublin.

Bracher-Jakob, A., 2000: Jungebermast in Forschung und Praxis. Arbeit im Auftrag der Eidgenössischen Forschungsanstalt für Nutztiere, Posieux.

Bonneau M. *et al.*, 1992: Contributions of fat androstenone and skatole to boar taint: I. Sensory attributes of fat and pork meat. Livestock Prod. Science 32, 63–80.

Claus, R., 1993: Die unendliche Geschichte der Ebermast – Eine historisch-physiologische Analyse. Fleischwirtschaft 73, 449 – 453.

Duijvesteijn, N. *et al.*, 2010: A genome-wide association study on androstenone levels in pigs reveals a cluster of candidate genes on chromosome 6. BMC Genet. 2010 May 20, 11:42.

Grindflek, E, 2010: Revealing genetic relationships between compounds affecting boar taint and reproduction in pigs. J Anim Sci. 2011 Mar;89, 680-92.

Harlizius, B. *et al.*, 2008: Breeding against boar taint. An integrated approach. EAAP meeting, 26-27. March, Girona.

Haugen, J.E., 2009: Detection of Boar Taint. Need for harmonised methods and rapid methods. 55. Intern. Meat Science and Technology Congress, Copenhagen. http://www.icomst2009.dk.kappa.headline.dk

Moe, M. *et al.*, 2009: Association between SNPs within candidate genes and compounds related to boar taint and reproduction. BMC Genet. 2009; 10: 32.

Sellier, P., Le Roy, P., Foilloux, M.N., Gruand. J., Bonneau, M., 2000: Responses to restricted index selection and genetic parameters for fat androstenone level and sexual maturity status of young boars. Livestock Prod. Science 63, 265-274.

Tajet H., Andresen O., Meuwissen T., 2006: Estimation of genetic parameters of boar taint; skatole and androstenone and their correlations with sexual maturation. Prevention of Boar Taint in Pig Production. 19th Symp. Nordic Committee for Veterinary Scientific Cooperation, Gardermoen, Norway, 21-22 November 2005.

Tholen, E. and L. Frieden, 2010: Züchterische Möglichkeiten zur Vermeidung von Ebergeruch. 8. Schweine-Workshop "Neue Herausforderungen für die Schweinezucht", 23./24.2.2010, Uelzen.

Weiler, U., M. Dehnhard, E. Herbert and R. Claus, 1995: Einfluss von Geschlecht, Genotyp und Mastendgewicht auf die Androstenon- und Skatolkonzentration im Fett von Mastschweinen, 14-32. In: Die Ebermast, Angewandte Wissenschaft Heft 449, Schriftenreihe des Bundesministeriums für Ernährung, Landwirtschaft und Forsten, Landwirtschaftsverlag Münster.

Willeke, H., R. Claus, E. Müller, F. Pirchner and H. Karg, 1987: Selection for high and low level of 5 α- androst-16-en-3-one in boars. I. Direct and correlated response of endocrinological traits. Journal Animal Breeding and Genetics 104, 64-73.

Xue, J. *et al.*, 1996: Breed differences in boar taint: relationship between tissue levels boar taint compounds and sensory analysis of taint. J. Anim. Sci. 74:2170-2177.

Address of corresponding author:

Dr. Ernst Tholen
Rheinische Friedrich-Wilhelms-Universität Bonn
Institut für Tierwissenschaften
E-Mail: etho@itw.uni-bonn.de

Patterns and dynamics of global and EU poultry meat production and trade

Hans-Wilhelm Windhorst, Vechta, Germany

Introduction

Between 1990 and 2009, global poultry meat production increased by over 50 mill. t or 123 %. No other agricultural product reached such a remarkable relative growth rate. The growth was not homogeneous, however, the highest absolute increase can be found in Asia with 21 mill. t , followed by South and Central America with 12.3 mill. t and North America with 10.5 mill t. In Europe, the absolute increase was much smaller with only 4 mill. t. In the same time period poultry meat production in the EU (27) grew by 4 mill. t or 50.9 %. The contribution of European countries to the global production volume decreased from 28.7 % in 1990 to only 17.2 % in 2009.

In 2008, the traded volume of poultry meat was more than five times higher than in 1990 and reached almost 14 mill. t. The share of North American, South and Central American as well as European countries in poultry meat exports was almost equal, with North America in a leading position. In poultry meat imports, European and Asian countries shared almost the same volume. Together, countries in these two continents imported almost 81 % of all poultry meat that reached the world market. EU (27) member countries exported 2.9 mill. t of poultry meat in 2008 and imported 2.3 mill. t. When canned meat and preparations are included, the export volume even reached 3.8 mill. t.

The main goals of this paper are:

- to give an overview about the development of global and EU poultry meat production between 1990 and 2009 by meat type,
- to identify the leading countries in production,
- to characterize changing patterns of poultry meat trade between 1990 and 2008 by regions and meat type,
- to identify the leading countries in poultry meat exports and imports by meat type.

Development of global poultry meat production between 1990 and 2009

Global poultry meat production increased from almost 41 mill. t in 1990 to 91.3 mill. t in 2009 or by 123 %. As can be seen from the data in table 1, the production volume of chicken meat grew by over 44 mill. t. Chicken meat contributed 87.8 % to the absolute growth, turkey meat 3.2 %, duck meat 5.2 %, goose and guinea fowl meat 3.7 % and other poultry meat 0.1 %. Chicken meat contributed 87.2 % to the overall poultry meat production in 2009, followed by turkey meat (5.8 %) and duck meat (4.2 %).

Table 1: The development of global poultry meat production by meat type between 1990 and 2009; data in 1,000 t (Source: FAO database)

Meat type	1990	2000	2009	Increase (%)
Chicken	35,350	58,307	79,596	125.2
Turkey	3,717	5,071	5,320	43.1
Duck	1,232	2,868	3,845	212.1
Goose*	621	1,911	2,476	298.7
Other	17	41	71	317.6
Total	40,937	68,198	91,308	123.0

* includes guinea fowl

Table 2: Development of global poultry meat production between 1990 and 2009 by continents; data in 1,000 t (Source: FAO database)

Continent	1990		2000		2009	
	1,000 t	%	1,000 t	%	1,000 t	%
Africa	1,979	4.8	2,982	4.4	3,821	4.2
Asia	9,965	24.3	22,480	33.0	31,120	34.1
N America*	12,285	30.0	19,349	28.4	22,798	25.0
SC America	4,465	10.9	10,735	15.7	16,808	18.4
Europe	11,759	28.7	11,885	17.4	15,721	17.2
Oceania	483	1.2	767	1.1	1,039	1.1
World	40,937	100.0	68,198	100.0	91,308	100.0

*Canada, Mexico, USA

Table 2 reveals the remarkable regional shift that occurred parallel to the absolute and relative growth rates. Whereas European countries lost 11.5 % of their former contribution to global poultry meat production in the analysed time period, the share of Asian countries grew by 9.1 % and that of South and Central American countries by 7.5 %. North America, which was in leading position in 1990 with a share of 30 %, lost 5 % and only ranked second behind Asia.

A closer look at the development of the two leading meat types shows (tables 3 and 4) that in chicken meat production Asian countries ranked only on third place behind North American and European countries in 1990. Because of the dynamic development in Asia and South and Central America, Europe only ranked as number four in 2009 with 16.8 %. In turkey meat production, the regional shift was less dramatic. North American countries are still in an absolutely leading position with a share of 51.7 %, followed by European countries with 32.3 %. The highest relative growth rate could be observed in South and Central America with 496 %. In contrast to chicken meat turkey meat production is still only of minor importance in Asia. Consumption of this meat type has no tradition in South and Eastern Asia.

Table 3: Development of global chicken meat production between 1990 and 2009; data in 1,000 t (Source: FAO database)

Continent	1990		2000		2009	
	1,000 t	%	1,000 t	%	1,000 t	%
Africa	1,849	5.2	2,780	4.8	3.571	4.5
Asia	8,524	24.1	18,241	31.3	25.443	32.0
N America*	10,015	28.3	16,673	28.6	19.972	25.1
SC America	4,347	12.3	10,482	18.0	16.210	20.4
Europe	10,162	28.7	9,400	16.1	13.410	16.8
Oceania	454	1.3	732	1.3	989	1.2
World	35,350	100.0	58,307	100.0	79.596	100.0

*Canada, Mexico, USA

Table 4: Development of global turkey meat production between 1990 and 2009; data in 1,000 t (Source: FAO database)

Continent	1990		2000		2009	
	1,000 t	%	1,000 t	%	1,000 t	%
Africa	39	1.0	76	1.5	120	2.3
Asia	79	2.1	167	3.3	121	2.3
N America*	2,201	59.2	2,595	51.2	2,748	51.7
SC America	97	2.6	236	4.7	578	10.0
Europe	1,277	34.4	1,970	38.8	1,716	32.3
Oceania	25	0.7	26	0.5	38	0.7
World	3,717	100.0	5,071	100.0	5,320	100.0

*Canada, Mexico, USA

Over 50 % of global poultry meat production were contributed by the three leading countries in 2009 (table 5). The USA was still in a leading position with a share of 20.8 % but it may have already been surpassed by China in 2010 according to a FAO-OECD Outlook.

Of the ten leading countries, listed in table 5, four were located in Asia, three in the Americas and three in Europe.

Table 5: The ten leading countries in global poultry meat production in 2009; data in 1,000 t (Source: FAO database)

Country	1,000 t	%
USA	18,953	20.8
China	16,438	18.0
Brazil	10,385	11.4
Mexico	2,633	2.9
Russia	2,360	2.6
France	1,720	1.9
Iran	1,682	1.8
United Kingdom	1,652	1.8
Indonesia	1,435	1.6
Japan	1,394	1.5
10 countries	58,652	64.2
World	91,398	100.0

The dynamics of poultry meat production in the EU between 1990 and 2009

In 2009, poultry meat production reached a volume of 11.9 mill. t, 4 mill. t more than in 1990 (table 6). Chicken meat contributed 81.2 % to the overall production volume, followed by turkey meat with 14.3 %. The highest relative growth rate could, however, be observed in duck meat production, mainly a result of the dynamic development in Germany and Hungary.

In 2009, six EU member countries produced more than 1 mill. t of poultry meat (table 7). France was in a leading position with a contribution of 14.4 % to the overall production volume of EU countries, followed by the United Kingdom with 13.9 % and Germany with 11.0 %. The regional concentration of poultry meat production in the EU was quite high for the ten leading countries contributed 86.2 %.

Table 6: Development of poultry meat production in the EU (27) by meat type between 1990 and 2009; data in 1,000 t (Source: FAO database)

Meat type	1990	2000	2009	Change (%)
Chicken	6,355	8,192	9,670	+ 52.2
Turkey	1,229	1,950	1,699	+ 38.2
Duck	223	401	467	+ 109.4
Goose*	86	79	75	- 12.8
Other	3	3	3	+/- 0
Total	7,896	10,625	11,914	+ 50.9

* includes guinea fowl

Table 7: The ten leading EU member countries in poultry meat production in 2009; data in 1,000 t (Source: FAO database)

Country	1,000 t	%
France	1,720	14.4
United Kingdom	1,652	13.9
Germany	1,316	11.0
Spain	1,205	10.1
Poland	1,155	9.7
Italy	1,154	9.7
Netherlands	834	7.0
Belgium	475	4.0
Hungary	387	3.2
Romania	371	3.1
10 countries	10,269	86.2
EU (27)	11,914	100.0

The data published by MEG (2010) differentiate between broiler meat and turkey meat production, whereas the FAO only shows data for chicken meat and turkey meat.

The data in table 8 shows that the ranking in broiler meat production differed considerably from that in poultry meat. The United Kingdom ranked on first place in 2009 with a production volume of 1.27 mill. t or 14.4 % of the overall broiler meat production in the EU. Spain (12.1 %), France (11.2 %), Germany (10.6 %) and Poland ranked on places two to four. It can be expected that because of the remarkable dynamics in Germany and the structural problems in France, Germany may have even surpassed France in 2010.

The regional concentration in EU turkey meat production was quite high in 2009. The ten leading countries contributed 86.3 % to the overall production volume. Five countries produced more than 100,000 t of this meat type with Germany and France in a leading position. These two countries alone shared 48.3 % of turkey meat production in the EU. The dynamics in these two countries differed considerably, however. Whereas in France the production volume decreased from 624,400 t in 2004 to 430,000 t in 2009 or by 31 %, turkey meat production in Germany grew from 391,000 t to 442,000. France lost large amounts of its former market shares whereas Germany could expand its export volume.

Table 8: The ten leading EU member countries in broiler meat production in 2009; data in 1,000 t (Source: MEG 2010)

Country	1,000 t	%
United Kingdom	1,269	14.4
Spain	1,063	12.1
France	990	11.2
Germany	930	10.6
Poland	890	10.1
Italy	729	8.3
Netherlands	640	7.3
Romania	320	3.6
Portugal	259	2.9
Belgium	255	2.9
10 countries	7,345	83.4
EU (27)	8,802	100.0

Table 9: The ten leading EU member countries in turkey meat production in 2009; data in 1,000 t (Source: FAO database)

Country	1,000 t	%
Germany	442	24.3
France	430	23.8
Poland	285	15.7
United Kingdom	157	8.6
Hungary	110	6.1
Portugal	38	2.1
Ireland	28	1.5
Spain	28	1.5
Netherlands	26	1.4
Austria	25	1.4
10 countries	1,569	86.3
EU (27)	1,818	100.0

Dynamics and pattern of global poultry meat trade

A complete data set for poultry meat exports and imports on the global level is only available for 2008. Table 10 shows the development of poultry meat exports and imports by meat type between 1990 and 2008. One can easily see that chicken meat shared about 75 % of the traded volume in 2008, followed by turkey meat with 7 %. It is also worth mentioning that the amount of canned meat and preparations increased considerably in the analysed time period. Exports and imports of duck and goose meat were of minor importance.

A closer look at the share of the contribution of the continents to poultry meat exports and imports in 2008 reveals considerable differences. In exports, the share of North America as well as South and Central America was very similar, followed by Europe. In Imports, Europe was in a leading position, followed by Asia. North America ranked as number three, a result of the high imports of Mexico.

Table 10: The development of global poultry meat exports and imports by meat type between 1990 and 2008; data in 1,000 t (Source: FAO database)

Exports				
Meat type	1990	2000	2008	Increase (%)
Chicken	2,201	6,888	10,404	372.7
Turkey	243	903	939	286.4
Duck	48	107	124	158.3
Goose*	3	48	46	1,433.3
Other**	182	835	2.416	1,227.5
Total	2,677	8,781	13,929	420.3
Imports				
Meat type	1990	2000	2008	Increase (%)
Chicken	2,163	5,932	9,601	343.9
Turkey	199	774	912	358.3
Duck	63	165	156	147.6
Goose*	22	50	31	40.9
Other**	206	823	2,159	948.1
Total	2,653	7,744	12,859	384.7

* includes guinea fowl
** canned meat and preparations

Table 11: Global poultry meat trade by continents in 2008; data in 1,000 t (Source: FAO database)

Continent	Exports 1,000 t	Share (%)	Continent	Imports 1,000 t	Share (%)
Africa	12	0.1	Africa	847	6.6
Asia	1,650	11.8	Asia	5,082	39.5
N America*	4,281	30.7	N America*	940	7.3
SC America	4,084	29.3	SC America	648	5.0
Europe	3,862	27.7	Europe	5,289	41.2
Oceania	39	0.3	Oceania	45	0.3
World	13,928	100.0	World	12,958	100.0

* Canada, Mexico, USA

At the country level (tables 12 and 13) it becomes obvious that in 2008 the regional concentration in exports was much higher than in imports. The ten leading exporting countries shared 88.1 % of the total export volume with the USA and Brazil in a leading position. These two countries contributed 56.5 % to global exports.

The ten leading poultry meat importing countries only shared 59.9 % of the import volume. China ranked as number one, followed by Russia and Japan. These three countries contributed 30.4 % to global poultry meat imports. The lower regional concentration in imports reflects on the one hand the fact that poultry meat is consumed also in countries which prohibit the consumption of pig meat because of religious taboos and on the other hand that in several developed, threshold and less developed countries the demand grew much faster than domestic production.

Table 12: The ten leading poultry meat exporting countries in 2008; data in 1,000 t (Source: FAO database)

Country	Exports	Share (%)
USA	4,089	29.4
Brazil	3,772	27.1
Netherlands	999	7.2
China (incl. Hong Kong)	819	5.9
Thailand	610	4.4
France	537	3.9
Germany	464	3.3
Belgium	378	2.7
United Kingdom	325	2.3
Poland	280	2.0
10 countries	12,273	88.1
World	13,928	100.0

Table 13: The ten leading poultry meat importing countries in 2008; data in 1,000 t (Source: FAO database)

Country	Exports	Share (%)
China (incl. Hong Kong)	1,782	13.9
Russia	1,229	9.6
Japan	889	6.9
Netherlands	718	5.6
United Kingdom	677	5.3
Mexico	638	5.0
Germany	636	4.9
Saudi Arabia	519	4.0
France	319	2.5
United Arab Emirates	298	2.3
10 countries	7,705	59.9
World	12,859	100.0

Dynamics and patterns of EU poultry meat trade

In the EU (27), poultry meat trade developed less dynamically than on the global level (table 14). Nevertheless, the export volume increased by almost 1.7 mill. t or 134.3 % between 1990 and 2008, the import volume by 1.5 mill. t or 188.7 %. Chicken meat contributed about 80 % to EU poultry meat export and imports in 2008, turkey meat 17 %. The trade of duck and goose meat was of minor importance.

Table 14: Development of poultry meat* trade by meat type in the EU (27) between 1990 and 2009; data in 1,000 t (Source: FAO database)

Exports				
Meat type	1990	2000	2008	Change (%)
Chicken	1,022	1,794	2,325	+ 127.5
Turkey	195	610	496	+ 154.4
Duck	27	65	68	+ 151.9
Goose**	1	23	28	+ 2,700.0
Total	1,245	2,492	2,917	+ 134.3
Imports				
Meat type	1990	2000	2008	Change (%)
Chicken	575	1,116	1,859	+ 223.3
Turkey	156	315	386	+ 147.4
Duck	42	52	51	+ 21.4
Goose**	32	35	28	- 12.5
Total	805	1,518	2,324	+ 188.7

* without canned meat and preparation
** includes guinea fowl

A closer look at the situation on the country level shows that the regional concentration in chicken meat exports (table 15) was considerably higher than in imports (table 16).

Table 15: The ten leading EU member countries in chicken meat exports in 2008; data in 1,000 t (Source: FAO database)

Country	Exports	Share (%)
Netherlands	684	29.4
France	343	14.8
Belgium	317	13.6
United Kingdom	218	9.4
Germany	206	8.9
Poland	153	6.6
Denmark	77	3.3
Spain	72	3.1
Italy	54	2.3
Hungary	35	1.5
10 countries	2,159	92.9
EU (27)	2,324	100.0

The Netherlands dominated chicken meat exports with a share of 29.4 %, followed by France and Belgium. Germany ranked as number 5 in 2008, but the fast increase of broiler meat production since 2005 has led to a self sufficiency rate of 107 % and growing exports. It can be expected that the export volume will have surpassed that of the United Kingdom in 2009 and may have come close to that of France. Poland could strengthen its position as one of the leading exporting countries, a result of foreign investments in the Polish poultry industry.

At first glance it seems surprising that The Netherlands also ranked as number one in chicken meat imports in 2008 with a share of 21.9 %. This is due to the fact that the FAO data include imports of live birds. A considerable share of the broilers slaughtered and further processed in The Netherlands are grown just across the border in Germany. The four leading chicken meat importing countries shared 61.9 % of all chicken meat imports. Besides the intra-EU trade large amounts of chicken meat were also imported into the EU from Brazil and Thailand, mainly chicken breasts.

Table 16: The ten leading EU member countries in chicken meat imports in 2008; data in 1,000 t (Source: FAO database)

Country	Exports	Share (%)
Netherlands	408	21.9
United Kingdom	297	16.0
France	230	12.4
Germany	216	11.6
Belgium	98	5.3
Romania	86	4.6
Spain	80	4.3
Ireland	46	2.5
Czech Republic	43	2.3
Greece	41	2.2
10 countries	1,545	83.1
EU (27)	1,859	100.0

In the EU, France dominated turkey meat exports for several decades. Because of the drastic reduction of the production volume, exports decreased from 230,000 t in 2004 to only 110,000 t in 2008. Whereas France contributed 40 % to the EU exports in 1990, its share was as low as 22 % in 2008. Parallel to this decrease, German turkey meat export grew from 57,000 t to almost 80,000 t in the same time period. Poland could also strengthen its position among the top turkey meat exporting countries. In 2008, it ranked second behind France with an export volume of slightly over 80,000 t.

In spite of the considerable increase in production, Germany was the leading EU member country in turkey meat imports with a share of 24.4 %, followed by The Netherlands with 10.1 %. In The Netherlands, the last turkey slaughterhouse was closed in 2009 so that this country now has to import all turkey meat for domestic consumption. There are still several growers but it will be only a matter of time until they switch to broiler production.

The different dynamics in broiler and turkey meat production in France and Germany has several reasons. On the one hand, German broiler growers and processors are operating in a growing domestic and export market which enabled investments in primary production, slaughtering and further processing. Many of the facilities were built during the last decade and installed the latest available technologies. The average size of recently built growing houses is 40,000 to 80,000 places. In contrast, producers in France had to operate in a rapidly shrinking market with low margins. Many of the growing houses are old and small and the slaughterhouses as well as the further processing plants were not able to finance the most recent technological equipment. So it can be expected that France will lose further market shares.

The main results of the preceding analysis can be summarized as follows:

- Global poultry meat production increased from 41 mill. t in 1990 to over 91 mill. t in 2009.
- Parallel to this dynamics, a remarkable spatial shift occurred. Asia as well as South and Central America gained market shares, Europe and North America lost in importance.

- The USA, China and Brazil contributed over 50 % to the volume of global poultry meat production.
- In the EU (27) poultry meat production grew from 7.9 mill. t in 1990 to 11.9 Mill. t in 2009 or by 54 %.
- France, the UK, Germany and Spain shared almost 50 % of the overall production volume.
- On the global level, poultry meat exports and imports showed a remarkable dynamics in the analyzed time period. The export volume reached almost 14 mill. t in 2008.
- North, South and Central American countries are leading in poultry exports, while European and Asian countries shared over 80 % of the import volume.
- The USA and Brazil dominated poultry meat exports. Imports were more widely distributed over many countries reflecting the worldwide increase of poultry meat consumption.
- The dynamics of poultry meat trade in the EU (27) was much slower than on the global level.
- The Netherlands, France and Belgium were the leading chicken meat exporting countries in 2008. In chicken meat imports, The Netherlands, United Kingdom, France and Germany ranked on places one to four with a combined share of almost 62 %.
- In turkey meat exports France still ranked as number one in spite of drastic losses of market shares, followed by Poland and Germany. In turkey meat imports, Germany ranked as number one, followed by The Netherlands.

Zusammenfassung

Muster und Dynamik der globalen Geflügelfleischproduktion und des Handels mit Geflügelfleisch

Zwischen 1990 und 2009 ist die weltweite Erzeugung von Geflügelfleisch von 41 mill. t auf 91 mill. t oder um 123 % angestiegen. Kein anderer Zweig der tierischen Produktion wies vergleichbare Steigerungsraten auf. Allerdings erfolgte die Zunahme in den einzelnen Kontinenten sehr unterschiedlich, was zu einschneidenden räumlichen Verlagerungsprozessen und zur Ausbildung neuer Zentren führte. Die höchste absolute Zunahme des Produktionsvolumens erfolgte in Asien mit 21 mill. t, gefolgt von Süd- und Mittelamerika mit 12,3 mill. t und Nordamerika mit 10,5 mill. t. Der relative Anteil Europas und Nordamerikas an der globalen Produktion hat deutlich abgenommen. Asien wurde, vor allem bedingt durch die schnelle Produktionsausweitung in China, zum neuen Zentrum. In der EU stieg das Produktionsvolumen im betrachteten Zeitraum um 4 mill. t oder nahezu 51 % an.

Im Jahr 2008 wurden weltweit etwa 14 mill. t Geflügelfleisch gehandelt, fünf mal mehr als 1990. Die Exportvolumina sind recht gleichmäßig auf die Kontinente Nordamerika, Süd- und Mittelamerika sowie Europa verteilt, wobei die USA und Brasilien eine führende Position einnehmen. Bei den Einfuhren dominieren europäische und asiatische Länder. Mitgliedsländer der EU (27) exportierten im Jahr 2008 etwa 2,9 mill. t Geflügelfleisch und importierten 2,3 mill. t. Auch hier sind es wenige Länder (Niederlande, Frankreich, Spanien, das Vereinigte Königreich und Deutschland), die den Handel bestimmen.

References

FAO database: http://faostat.fao.org

MEG-Marktbilanz: Eier und Geflügel 2010. Stuttgart 2010.

Author´s address

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

Economic aspects of poultry meat production in Germany

Klaus Damme, Kitzingen, Germany

Introduction

The production of poultry meat continues to expand in Germany as in most other countries. Apart from aquaculture, it is the only sector of the farm animal industry with significant growth rates. Per capita consumption of poultry meat was 18.6 kg in 2009, compared to 23.1 kg of the 27 EU countries and 48.8 kg in the USA. While the total demand for poultry meat is predicted to increase in the foreseeable future, producers need to study local limitations and opportunities to benefit from this market. In this context, it is of interest to compare the production cost and margins for different poultry species. The expansion during the past decade has been essentially due to increased broiler production, whereas turkey meat and duck meat consumption appear to have reached limits near 6.0 and 1.0 kg respectively.

The increased broiler meat consumption has been supported by simultaneous expansion of processing facilities, resulting in self-sufficiency, whereas turkeys and Pekin ducks could satisfy only 76 and 86.5% of the domestic demand (Beck, 2010). Farmers interested in poultry meat production now have to decide whether to invest in broiler production for export or other poultry for the domestic market.

In this study, we will use statistical data from the German Extension Service (Damme, 2010) to address the following questions:

- How much area, capital and labor are required for growing broilers, turkeys and Pekin ducks to market weight?
- Which margins can be expected from growing different species of poultry?
- How do the profitability and income per working hour compare between species?
- Which bird capacity and capital investment is required to generate an acceptable family income?

Assumptions for comparative study

In order to develop comparable results, it was assumed that a family farm would produce 600 t live poultry annually. For broilers, this would be an all-in, all-out growing capacity for 40,000 unsexed chicks, grown to 2 kg final weight; placements every 7 weeks i.e. 7.5 time per year. To produce 600 t live turkeys, 14,300 poults would be placed 2.8 times per year in a rearing unit for the first 5 weeks, at which time the sexes would be separated and the males moved to the second unit with sufficient space for an extended growing period. To produce 600 t of live ducks, 14,800 Pekin ducklings would be placed in a warm rearing unit for the first 18 days, then moved to a finishing unit to reach 3 kg at 40 days of age; day-old placements about every 4 weeks or 13.5 times annually. Details are shown in table 1.

Table 1: Parameters of production (output of 600 t live weight)

Species	Method	Places per 1,000 animals	Turnover per year	Target weight kg	Space m²
Broiler	all in-all out	40	7,5	2,0	2050
Turkey	Rearing/fattening	7.15/7.15	2.8	15	3760
Pekin Duck	Rearing/fattening	14.8/14.8	13.5	3	3086

Capital, land and labor requirements

The EU and German regulations limiting the output of nitrate to 170 kg/ha arable land have to be observed. These legal figures are based on 0.38 kg, 2.02 kg and 0.83 kg average N output per bird place for broilers, turkeys and ducks, respectively. The figures shown in table 2 are based on the assumption that 40% of the total N output is lost in the atmosphere during the growing period and while spreading the manure in the field. The substantial differences in land requirements reflect the differences in feed conversion ratio: 1.75 for broilers, 2.15 for Pekin ducks and 2.65 for turkeys to the final weights assumed in this study.

Table 2: Capital, area and work requirements (output of 600 t LG)

Species	Area*) ha	Capital €	Labor h
Broiler	41	500,000	1250
Turkey	88	750,000	2002
Pekin Duck	68	620,000	3163

*): EU-Nitrates Regulation: max. 170 kg N/ha

Capital requirement for annual production of 600 t live weight is lowest for broilers, 50% higher for turkeys and in between for fattening ducks. These differences are mainly due to the different live weights produced annually per square meter house capacity: 293 kg broilers, 194 kg ducks and 154 kg turkeys. In other words, the same live mass of broilers can be grown on 34% and 45% less housing area than Pekin ducks or turkeys.

Differences in labor requirement for housing, daily care, moving to another unit, depopulation and cleaning between flocks are also significant: 25 min/100 broilers (Joos *et al.*, 1999), 300 min/100 turkeys (Janning, 1996) and 95 min/100 Pekin ducks. Turkeys and especially Peking ducks require regular attention to check litter quality and add dry litter as necessary. For ducks, two persons will be needed for this job. Peak labor requirements and need for hired help also should be considered. Labor peaks depend on the frequency of housing. In this respect, turkeys have an advantage over broilers and especially ducks with their frequent placements (Tischler *et al.*, 2008).

Margins and contributions to farm income for different meat type poultry

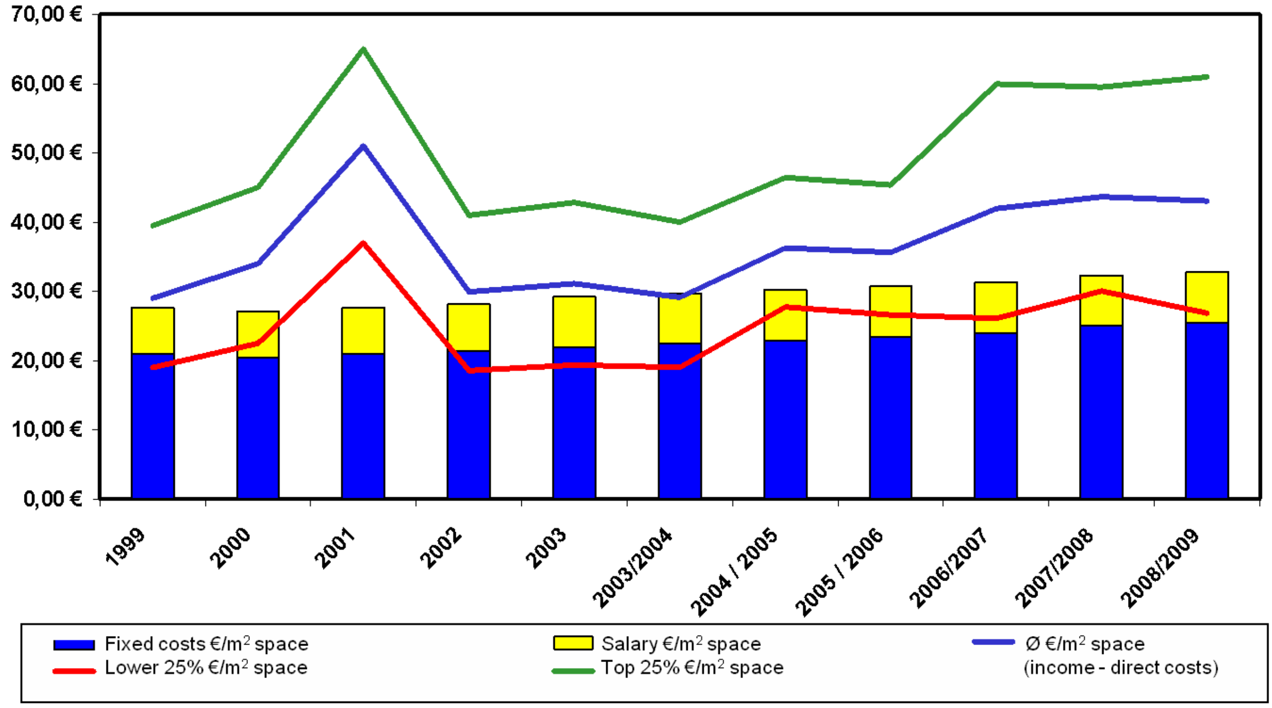
The figures used to calculate margins (DB) and income per farm are taken from published reports of the Working Group Broilers of the Agriculture Department Hannover, the Working Group Turkeys in North Rhine-Westphalia, and the Working Group Pekin Ducks in Lower Saxony and Southern Germany (Damme, 2010).

The figures are based on a large and thus representative volume of field data: 10 years, each year with 400 to 450 batches on 55 to 60 farms for broilers; 8 years with 50 to 60 batches on 27 to 30 farms for turkeys; and 4 years with about 120 batches from 12 farms for Pekin ducks.

Figure 1 shows the average annual margins and the upper and lower quartile of all broiler batches for the years 1999 to 2009. The fixed capital cost for interest and depreciation of housing and equipment increased from 20 to 25 EUR per square meter during this 10-year period; labor cost was assumed constant at 8 EUR per square meter and year. With the exception of 2003/04, the average margin for all broiler farms was always positive, with a modest average annual return of 6.75 EUR per square meter.

The difference between the upper and lower quartile is obvious, and it appears that the spread between the 25% most successful and the 25% least successful batches even increased in recent years. These differences include a range of possible effects, including chick quality, management skill, house temperature and humidity during different seasons, feed quality, and disease control.

Figure 1: Average farm income and cost per m2 space for broiler growers during the years 1999 - 2009



As shown in figure 2, the economic results were less favorable for turkey growers. Fixed costs and labor costs increased from 30 to 33 EUR per square meter for new houses, and average margins were positive in only three out of eight years. Between 2002 and 2006, the income per working hour was less than 15 EUR, and many farmers could barely earn the depreciation. Only the top 25% of all batches produced 5 to 34 EUR income over capital and labor cost during the years 2002 to 2009.

Figure 2: Average farm income and production cost per m² for turkey growers during the years 2002 – 2009

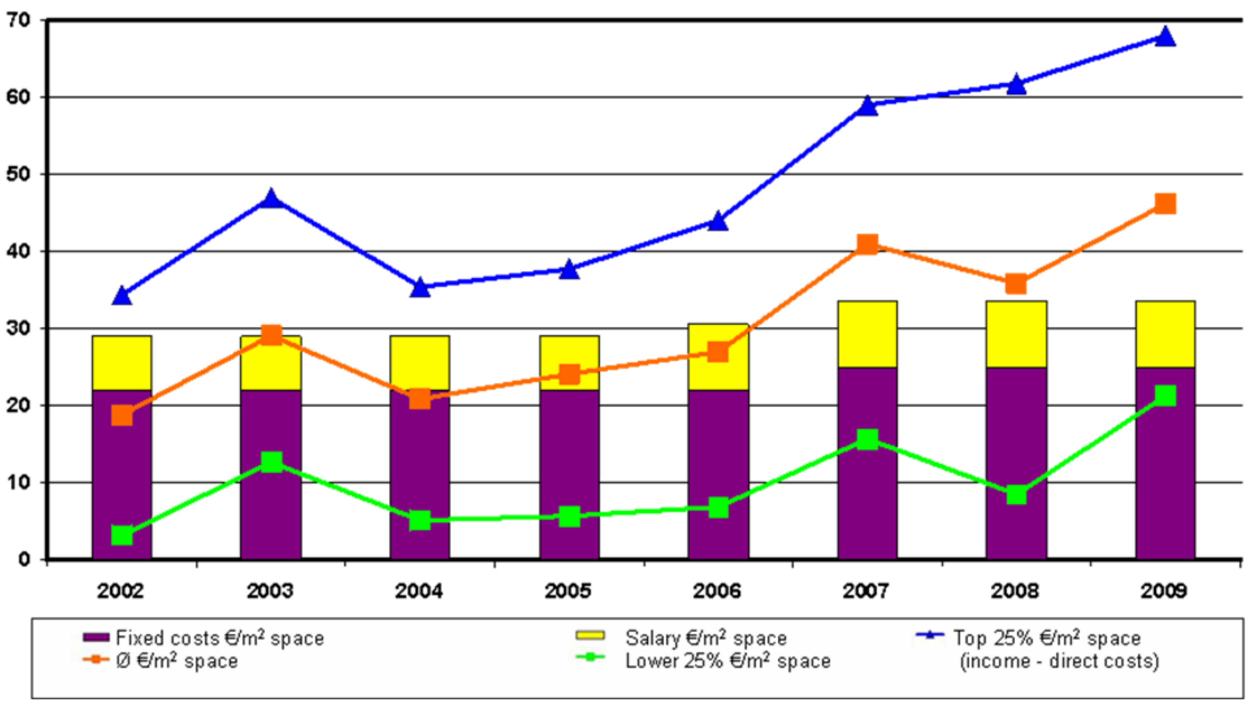


Table 3 shows details of the income and cost calculation for Pekin ducks, based on data from the producers' cooperative in Southern Germany. During the 4-year period from 2006 to 2009, the income minus fixed and variable cost was 0.22 EUR per duck, which would not cover the assumed labor cost of 15 EUR, i.e. actual income per working hour was 13.75 EUR.

Table 3: Cost and margin analysis Pekin duck (Süddeutsche EG 2006/2009)

Income (EUR/duck)	**3.48**
Chick	0.77
Feed	1.69
Water	0.02
Straw	0.07
Energy	0.15
Vet. Service, disinfection	0.05
Other [1]	0.11
Direct costs (EUR/duck)	**2.86**
Income – direct cost	**0.62**
Building	0.20
Equipment	0.06
Interest cost	0.13
Other fixe costs	0.01
Fixed costs (EUR/duck)	**0.40**
Income - (fixed + direct cost)	**0.22**
Labor	0.24
Profit (EUR/duck)	**-0.02**

[1] Insurance etc.

Necessary size of operation to generate a family income of 50,000 EUR

To generate a similar income as people with comparable education working in the industry, a young farmer may ask: what size of operation would I need to earn 50,000 EUR annually as broiler, turkey or duck grower? Based on the production cost and margins shown in figures 1 and 2 and the figures summarized in tables 4 and 5, the capacities shown in table 6 would be required: 74,000 broilers or 30,000 turkeys or 34,000 Pekin ducks. In other words, a family farm would need to grow more than half a million broilers, 227,000 Pekin ducks, or at least 86,000 heavy turkeys per year to earn an income of 50,000 EUR. Assuming that new facilities are built, bank credits close to 1 million EUR would be needed for broiler or Pekin duck growing, 1.8 million EUR for growing heavy turkeys.

Table 4: Production costs per animal and per kg live weight in ct. (Geflügeljahrbuch 2010)

Species *)	Fixed cost per animal	kg	Direct cost per animal	kg	Labor cost per animal	kg	Total cost per animal	kg
Broiler	16	8	164	78	4	2	184	88
Turkey	205	13	1557	95	69	4	1831	112
Pekin ducks	40	13	286	92	24	8	350	113

*) target live weights: Broiler: 2.1 kg; Turkey: 16.3 kg; Pekin Duck: 3.1 kg

Table 5: Actual economic results of poultry meat production with different poultry species; statistics from extension service

Species	Income-direct cost per m²	Margin per animal	Margin per kg live wt	Labor cost per animal	Salary per hour
	EUR	ct.	ct.	ct.	EUR
Broiler 1999-2009	36.4	9	4.5	6	21.60
Turkey 2002-2009	29.4	58	3.9	70	11.60
Pekin ducks 2006-2009	53.2	22	7.3	24	13.75

Table 6: Animal places and capital requirements to realize a farmer income of 50,000 EUR per year

Species	No. animals per year	Animal places	House size m²	Investment EUR
Broiler	555,556	74,074	4,004	925,925
Turkey	86,207	29,726	7,807	1,824,095
Pekin ducks	227,272	33,670	3,502	840,480

Summary and Conclusions

The comparison of poultry meat production from broilers, turkeys and Pekin ducks under economic conditions in Germany suggests significant advantages for broilers compared to the other species in terms of required arable land, total margin and earning per working hour. Further investment in broiler growing capacity appears justified if domestic consumption continues to grow and/or the production cost remains competitive with other EU countries. To support 1 kg higher per capita domestic consumption would require e.g. 190 new units with a capacity of 40,000 birds.

The economic situation for turkey growers recovered during the last three years, after a very difficult period of adjustment to overcapacity and losses due to blackhead disease breaks. In view of the higher capital cost it is unlikely that many farms will want to start with this business, but successful farms may decide to expand existing facilities, change to a shorter cycle to reduce the fixed cost or venture into the niche market for organic turkey meat, possibly in connection with the production of bio-energy, as long as politics provides such incentives.

Peking ducks offer the chance to maximize the return per square meter growing space, but many working hours are required. The robustness of Pekin ducks and lower disease risk make duck growing attractive for farms starting with poultry meat production. However, the market potential is still subject to seasonal demand, and unless consumption becomes more uniform throughout the year, the assumptions underlying the present study will not fully materialize in practice.

To be successful in any one of the three alternative types of poultry meat production, it will be necessary to study the market potential before the investment, to learn the basics from other successful farms and to plan on a long-term learning process to find an attractive position in the upper quartile of all farms.

Acknowledgement

The author thanks the Editor Prof. D.K. Flock for the translation of the manuscript, which was submitted in German, based on a paper presented at the annual meeting of the German WPSA Branch in 2010.

References

Beck, M.M. (2010): Versorgungsbilanz Geflügelfleisch. In: Marktinfo Eier und Geflügel. Eugen Ulmer KG Stuttgart, ISBN 978-3-8001-7534-5.

Damme, K. (2010): Faustzahlen zur Betriebswirtschaft. In: Geflügeljahrbuch 2011, Eugen Ulmer KG, Stuttgart; ISBN 978-3-8001-6988-7

Janning, T. (1996): Arbeitswirtschaftliche Beurteilung der Mastputen, KTBL Schrift 374, Landwirtschaftsverlag Münster, Hiltrup.

Joos, B., J. Beck., T. Jungbluth (1999): Geringer Arbeitszeitbedarf in der Junggeflügelmast. DGS Magazin 48, 18-24.

Tischler A., K. Damme, S. Graser (2008): Perspektiven der integrierten Hähnchen-, Puten – und Pekingentenproduktion in Bayern. Heft Nr. 13 der Schriftenreihe der LfL ISSN 1611-4159.

Author's address:

Dr. Klaus Damme
Leiter des Lehr-, Versuchs- und Fachzentrums für Geflügel
der Bayerischen Landesanstalt für Landwirtschaft
Mainbernheimer Str. 101
97318 Kitzingen
eMail: klaus.damme@lfl.bayern.de

Improving hatchability in white egg layer strains through breeding

D. Cavero, M. Schmutz, W. Icken and R. Preisinger
Lohmann Tierzucht GmbH, Cuxhaven, Germany

Abstract

Hatchability is of considerable economic importance for all hatcheries and therefore must be given appropriate attention in breeding programs for commercial layers. The variability between and within strains will tell us whether reproductive performance can be improved by selection within specific lines. The aim of this study was to analyse the genetic variation of hatchability and correlations with production traits. Data collected from two pure-bred female lines (LSL) at 45-46 weeks of age were used. Estimated heritabilities were low (h^2 = 0.13 and 0.15) for fertility, but moderately high (h^2 = 0.27 and 0.30) for hatch of 'fertile' eggs (eggs transferred at 18 days). Hatchability was negatively correlated with egg weight (r_g = -0.43 to -0.52) and albumen height (r_g = -0.25 to -0.42). Favourable correlations were found with egg production (rg = -0.01 to +0.28), percentage yolk (r_g= +0.08 to +0.39) and some shell quality traits like shape index and breaking strength (r_g = +0.14 to +0.32), but not with dynamic stiffness (r_g = -0.08 to -0.17).

Hatch of fertile eggs has sufficient genetic variation in these White Leghorn lines to expect improvement by within-line selection, especially if supported by a reduction in total egg weight and selection for higher egg production, yolk percentage and shell breaking strength.

Introduction

The avian egg is a biological system intended to ensure the well-being of the embryo and its successful hatching into a fully developed chick (Narushin and Romanov, 2002). Predictable reproductive performance of parent stock is essential for every commercial hatchery to produce as many saleable chicks at the lowest possible cost, and uniform chicks set the basis for a successful rearing and subsequent production. If the conditions in the setters and hatchers are not optimized, the uniformity of chicks will suffer and the hatching time will spread out. Many factors can affect hatchability, especially egg size and age of breeders, season of the year and nutrition, egg handling and storage, temperature and humidity throughout the incubation and hatching period (Wilson 1997).

Reproductive traits usually reach a peak close to peak production and decline with increasing age toward the end of the laying cycle. The decrease of hatchability in older flocks is well-known and may be explained as a result of lower fertility of males and females, but probably more important is the reduction in eggshell quality with increasing egg weight. Bamelis (2003) suggested that low hatchability of fertile eggs at the beginning of the breeding season and the decline in hatchability with increasing age is also due to improper egg water loss, which should be avoided by adjusting incubation conditions in accordance with water vapour eggshell conductance. In management guides for commercial parents, 52 to 68 g may be specified as optimal weight range for hatching eggs. The critical question is how many small eggs from young flocks and how many large eggs from old flocks are discarded to guarantee the best possible chick quality and satisfied customers.

Breeds and lines of the same breed differ in reproductive traits, but relatively little within-line selection has been practiced for hatchability in commercial breeding programs focused on efficient egg production of the final cross (Flock, 1995). Reproductive traits usually benefit from heterosis in cross-line parents. Natural selection should always favour families with above average reproductive rates, because they contribute with more progeny to the next generation. Hatchability is a typical fitness trait with low heritability, which suggests that optimization of breeder farm and hatchery management is the most promising route for improvement (Förster *et al.*, 1992). However, low heritability does not exclude improvement by selection; it only takes a long time to see measurable results. Estimates of heritability for hatch of fertile eggs in the literature ranges from 0.02 to 0.24 (i.e. Förster, 1993; Beaumont *et al.*, 1997; Szwaczkowski *et al.*, 2000; Sapp *et al.*, 2004; Bennewitz *et al.*, 2007; Rozempolska-Rucinska *et al.*, 2009; Sharifi *et al.*, 2010; Wolc *et al.*, 2010).

There is a positive correlation between egg weight and incubation time, but the incubation time is affected much more by pre-incubation storage time than by initial egg weight (Wilson, 1991). As a rule of thumb, the lengthening of the incubation time with increasing storage time is estimated to be 0.5 to 1 h of incubation for each additional storage day (Förster, 1994). Moreover, the moisture loss of the eggs during storage should be kept at a minimum; this can be reached with a high relative humidity in the air, 75-85%. Furthermore a positive effect in the hatch results after long storage is reported when the eggs are stored upside down, with the pointed end up (Mayes and Takeballi, 1984; Förster, 1994). Regularly turning of eggs during incubation is important to ensure the nutrition and fluid balance of the embryo and improves hatchability. In commercial hatcheries, eggs are turned in a 45° angle each hour thorough the setter period, although it seems to be no need for further turning after twelve days of incubation. Wilson (1991) concluded that maximum hatchability was achieved with a turning frequency of 96 times per day, but 24 times per day was a practical frequency.

Hatching time from the first to last chick on a tray often spreads over a period of 24-48 hours, and all chicks are kept in the hatcher until most chicks have hatched. Chick processing in the hatchery and transport to the destination farm may involve up to 72 hours without water and feed for some chicks, which will have negative effects on survival and later performance. The spread in individual hatch causes variability in biological age and chick quality (Tona *et al.*, 2003; Willemsen *et al.*, 2008). As Decuypere and Bruggeman (2007) pointed out, the spread of hatch varies due to pre-incubation factors (e.g. age of parent flock and duration and temperature during egg storage, egg turning, the gaseous environment), only some of which can be controlled with optimal management. If hatching eggs from different parent flocks are used to supply large orders, these effects should be known and taken into account.

Hatchability declines with storage duration of hatching eggs over an extended period even under optimum storage conditions (Mayes and Takeballi, 1984). Although commercial hatcheries avoid prolonged storage of hatching eggs, sometimes there is no other option to fill large orders. Tona *et al.* (2003) concluded that long egg storage time increases incubation duration, which affects negatively the quality of the chicks. One of the methods to reduce the negative effect of long-term storage has been to pre-incubate eggs for short periods before storage (Meijerhof, 1992).

Different lines may also respond differently to longer storage periods, i.e. some lines maintain acceptable hatchability longer than others (Förster, 1994). A good management practise to optimize hatchability is to pre-heat the eggs before they are introduced in the setters, thus reducing the temperature difference between storage and setters. With comparable humidity in the setter, large eggs lose relatively less water than small eggs, which should be taken into account by lowering humidity in the setter so that the desired weight loss is achieved.

Egg characteristics greatly influence the process of incubation and are responsible for its success (Narushin and Romanov, 2002). The egg shell has an important role during embryonic development, isolating the embryo from the external environment while allowing the proper gas exchange through the shell. Barnett *et al.* (2004) reported that eggs with hair-cracks showed increased bacterial exposure and weight loss, with significantly lower hatchability (56.4% vs. 80.9%) compared with intact shells. Bennet (1992) compared thin and thick shells based on specific gravity measurements and reported a reduction in hatchability of 3 to 9%, which he attributed to increased cracks, moisture loss and bacterial contamination of eggs with thin shells.

To support hatchery management in producing high quality chicks within a reduced hatch window, even from older flocks and/or prolonged egg storage, primary breeders select families with persistent hatchability under these conditions (Förster, 1994). The aim of the present study is to estimate genetic parameters for reproductive traits and to evaluate genetic relationships with egg quality and production traits so that genetic improvement of total performance including hatchability can be optimized.

Material and methods

Data of 6,226 and 6,516 fully pedigreed hens of two pure-bred female lines C and D of a commercial White Leghorn breeding program (LSL) were analyzed. The average number of daughters per sire and per dam was 48.3 and 6.4 and 50.5, and 6.6 for the lines C and D respectively. Each hen was tested twice at the age of 45 and 46 weeks. Hatching eggs were collected for a period of 7 days each time. Double-yolk eggs, misshaped eggs, dirty eggs, eggs without shell or with abnormal shell were excluded.

Prior to setting, the hatching eggs were subjected to long storage challenging conditions, which explains the low average hatchability (Table 1). Prolonged storage was expected to increase the apparent variation between families, thus improving the basis for selection. All eggs were stored in the hatchery for 7 days after the last collection day at 16°C and 60-70% HR, i.e. the eggs were between 8 and 15 days old when set. Furthermore, the time of incubation was limited to exactly 508 hours (21 days + 4 h), 8 hours less than commercial hatcheries would plan for these lines. Pooled semen was used from several males to eliminate the influence of male fertility.

Trays for 150 eggs were used, allowing 2 hens per row (max. 7 eggs per hen and a gap in the middle), i.e. eggs of 20 hens per tray. The trays were randomly distributed in the incubators, and possible environmental differences within the machines were treated as part of the error variance.

Table 1: Phenotypic statistics for the reproductive traits analysed (data from two years)

Trait	Mean	s	Minimum	Maximum
Line C (N = 6,226 hens)				
Number of eggs set per hen (7d)	6.60	0.73	3	7
Fertility rate (F)	83.4	16.7	0	100
Hatch of eggs set (HoS)	48.7	24.5	0	100
Hatch of ‘fertile’ eggs (HoF)	57.6	25.5	0	100
Line D (N = 6,516 hens)				
Number of eggs set per hen (7d)	6.54	0.75	3	7
Fertility rate (F)	83.3	16.5	0	100
Hatch of eggs set (HoS)	53.0	24.0	0	100
Hatch of ‘fertile’ eggs (HoF)	62.3	24.9	0	100

The eggs were candled on the 18th day of incubation and transferred to the hatchers after elimination of ‘clear’ eggs (infertile eggs and early embryonic mortality). True fertility was probably around 95%, based on data reported by Sharifi *et al.* (2010), who found fertility ranging between 94% and 97% in a similar test of data from these lines. Families with less than 3 fertile eggs were completely removed. At hatch, only first-quality chicks were taken into account, which means, that chicks which had physical abnormalities, unhealed navels or were too wet or too weak were not counted and not considered to calculate hatchability.

Data of two generations were used for this study. In each generation, three different houses were tested with two hatches. The traits recorded in this test are: fertility rate (F), hatch of eggs set (HoS) and hatch of fertile eggs (HoF). Information about egg production and egg quality of these pedigree birds was available as well. Egg quality was measured on other eggs of the same hens before and after the hatching test.

Statistical Analysis

In breeding practice there are often situations in which individual performance can be measured repeatedly, and the average of individual records can be used as selection criterion. The collection of repeated measurements and subsequent use of average performance as selection criterion can be especially advantageous in traits with low heritability but good repeatability. For the estimation of the heritability of hatchability and fertility, the mean value of the two hatches was calculated for each hen. A multicode was created combining generations (2 generations), houses (3 houses), and tier-batteries where the hens were allocated (4 batteries with 3 tiers per house). The genetic parameters for the average F, HoS and HoF were estimated based on the following linear multi-trait animal model:

$$y = Xb + Za + e$$

Where: y = vector of observations on t traits; b = vector of fixed effects of the multicode (year, house and battery/tier); a = vector of random additive genetic effects; e = vector of random errors; X and Z = known design matrix of fixed effects and random additive effects, respectively.

Variance and covariance components were estimated using the REML-method of the software VCE4 (Neumeier and Groeneveld, 1998). Although the distribution of reproductive traits is not normal, the percentage data of hatchability and fertility were not converted to arcsine, because the benefit of transformation is relatively small (Förster *et al.*, 1993). Moreover, the breeding values on a transformed scale have no biological meaning and are difficult to interpret (Savas *et al.*, 1999).

Breeding values were calculated by adding the line mean to the BLUP values estimated with the software PEST (Groeneveld *et al.*, 1990).

Results and discussion

Heritabilities and genetic correlations using model 1 are shown in Table 2. As expected, the estimated heritabilities in this study were higher for hatchability compared to fertility, which is in accordance with other studies (Förster, 1993; Szwaczkowski *et al.*, 2000; Bennewitz *et al.*, 2007). On the contrary, other authors have found lower heritabilities for hatchability compared to fertility (Beaumont *et al.*, 1997; Hartmann *et al.*, 2002; Sharifi *et al.*, 2010; Wolc *et al.*, 2010). High genetic correlations were found between the reproductive traits (F, HoS and HoF), as has been consistently reported in the literature. That means that hens laying a high proportion of fertile eggs also tend to have a high hatchability. Since the genetic correlation between HoF and HoS is very close to one, it would be sufficient to use one of these traits or total number of chicks during the hatching egg saving period as basis for selection.

Table 2: Heritabilities (diagonal) and genetic correlations for fertility rate (F), hatch of eggs set (HoS) and hatch of fertile eggs (HoF)

Trait	F	HoS	HoF
Line C			
F	**0.15**	+ 0.63	+ 0.47
HoS		**0.30**	+ 0.98
HoF			**0.30**
Line D			
F	**0.13**	+ 0.71	+ 0.53
HoS		**0.28**	+ 0.98
HoF			**0.27**

The estimated heritabilities were similar for both lines and in the case of hatchability slightly higher than values reported in the literature, where the heritability ranged from 0.02 to 0.24 by applying different statistical methods (Förster, 1993; Beaumont *et al.*, 1997; Szwaczkowski *et al.*, 2000; Sapp *et al.*, 2004; Bennewitz *et al.* 2007, Rozempolska *et al.*, 2009, Sharifi *et al.*, 2010; Wolc *et al.*, 2010). Estimates from different studies in the literature are difficult to compare, due to different definition of traits, data collection and structure of the data and statistical models used in the analysis. Using a cumulative model may overestimate the heritability (Sapp *et al.*, 2004; Swalve, 1995). Higher heritability and accuracy of selection can be obtained by averaging fertility over several weeks, either by pooling all weeks or by calculating average fertility (Wolc *et al.*, 2009).

Genetic correlations were estimated between reproductive traits and other economically important traits, including:

- Egg Production: at the start of the laying cycle (**P1**), around peak production (**P2**) and at the end of the laying cycle (**P3**).
- Egg Quality: Egg Weight (**EW**), Shell Strength (**SS**), Dynamic Stiffness (**DS**), Egg Shape (**ES**, length/width), Albumen Height (**AH**), Yolk Proportion (**YP**).
- Body weight at 30 weeks of age (**BW**).

Since the genetic correlations between fertility and different egg quality and production traits are generally low (Table 3), and no distinction could be made between true infertility and early embryonic mortality, we will focus on the genetic correlations involving hatch of fertile eggs (HoF).

Table 3: Estimated genetic correlations between reproductive traits and production and egg quality traits

Trait	P1	P2	P3	EW	SS	DS	AH	ES	YP	BW
Line C										
F	- 0.01	+ 0.04	+ 0.13	- 0.08	+ 0.06	- 0.08	- 0.08	- 0.11	- 0.08	- 0.09
HoS	- 0.01	+ 0.01	+ 0.19	- 0.43	+ 0.19	- 0.10	- 0.25	+ 0.14	+ 0.08	- 0.08
HoF	+ 0.01	- 0.01	+ 0.17	- 0.46	+ 0.22	- 0.09	- 0.26	+ 0.19	+ 0.10	- 0.08
Line D										
F	- 0.07	+ 0.35	+ 0.33	- 0.18	+ 0.10	- 0.11	- 0.20	+ 0.15	- 0.05	- 0.17
HoS	+ 0.04	+ 0.28	+ 0.24	- 0.48	+ 0.27	- 0.17	- 0.40	+ 0.29	+ 0.32	- 0.05
HoF	+ 0.05	+ 0.23	+ 0.20	- 0.52	+ 0.29	- 0.17	- 0.42	+ 0.32	+ 0.39	- 0.00

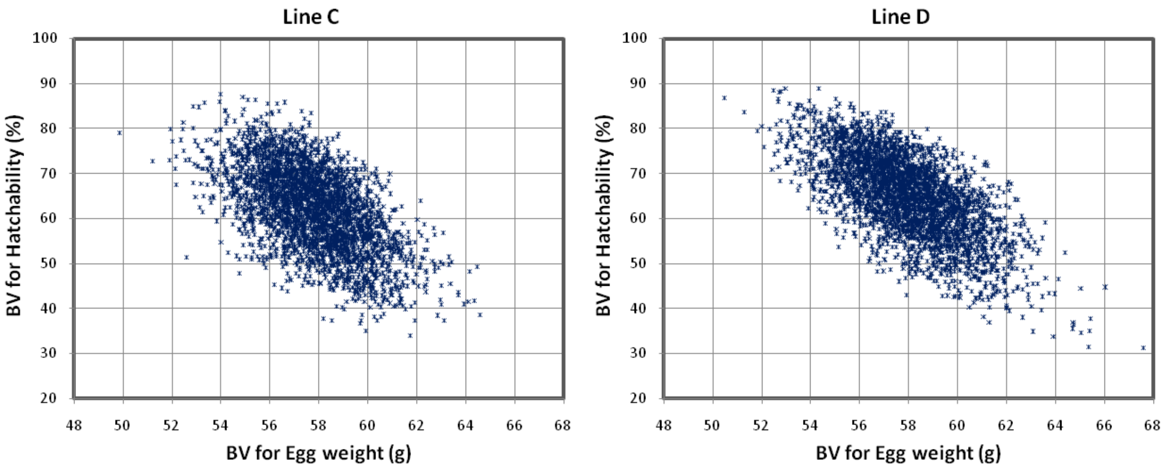
The negative correlation between egg weight and hatchability (r_g = -0.46 and -0.52) in both lines (Table 3) confirms earlier results of Förster *et al.* (1992), who found correlations ranging from r_g = -0.50 to -0.54 in two brown-egg pure lines. In a breeding program for layers the male lines can be selected for higher egg weight if the female lines lose egg weight as a result of more emphasis on reproductive traits. In this way, it is possible to overcome the negative correlations and maintain a balanced performance profile in the commercial layers. Heterosis effects are also utilized for fitness traits (Förster *et al.*, 1992).

Consumers in Europe prefer eggs of size M or L, i.e. between 53 and 73 g, but the average egg size would be under this economical optimum if this trait were not selected for, due to negative correlations with fitness traits (Stöve-Schimmelpfening and Flock, 1982). Large eggs tend to have relatively less shell surface, and that can be an obstacle for normal gas exchange for the embryo (Narushin and Romanov, 2002).

The higher negative correlation between egg weight and hatchability of fertile eggs (HoF) compared to hatchability of eggs set (HoS) and Fertility (FER) suggests that higher egg weight might mainly affect late embryonic mortality and may prolong incubation time, which is in accordance with practical experience. Egg weight at start of incubation seems to have an effect on the time of hatch within the hatch window, thus, early hatchers had a significant lower starting egg weight as compared to late hatchers (Careghi *et al.*, 2005). Therefore in this study, where the incubation time was shorted, eggs with a high egg weight might be additionally penalised in hatchability results.

It has been suggested that it may be a nonlinear relationship between egg weight and hatchability (Wolc *et al.*, 2010). As shown in Figure 1, that is not the case in this study, thus a clear linear negative effect of egg weight can be distinguished.

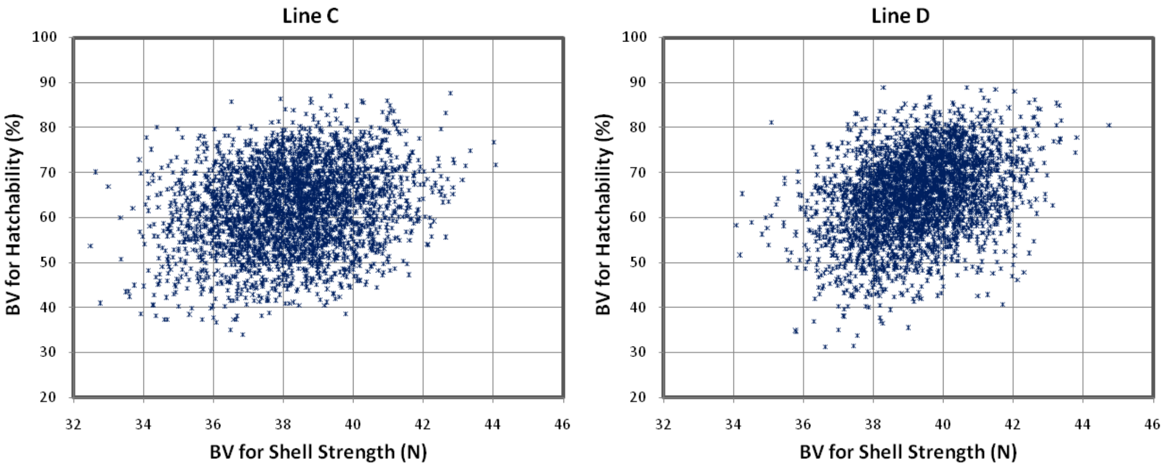
Figure 1: Breeding values for hatch of fertile eggs (HoF) plotted against breeding values for egg weight



A positive correlation was found between egg production at the end of the laying period and hatchability and fertility, especially in line D, which was also shown during peak production. The values are according to the values indicated by Förster *et al.* (1993), who gave a possible explanation based on the negative correlation existing between egg production and egg weight. This author further argued that the first egg in a sequence shows a lower hatchability, and that hens with lower productivity have a higher number of first eggs. Förster *et al.* (1992) reported a decrease in hatchability ranging from 4 to 9% comparing first egg and middle egg in a sequence, this drop was even bigger for single egg sequences (12-14%). Robinson *et al.* (1991) found that the eggs in the first position of the laying series had lower fertility compared to the following eggs. However, other authors did not find significant differences in hatchability relative to time of oviposition (Zakaria *et al.*, 2005), where early laid eggs were associated to first-in-sequence eggs.

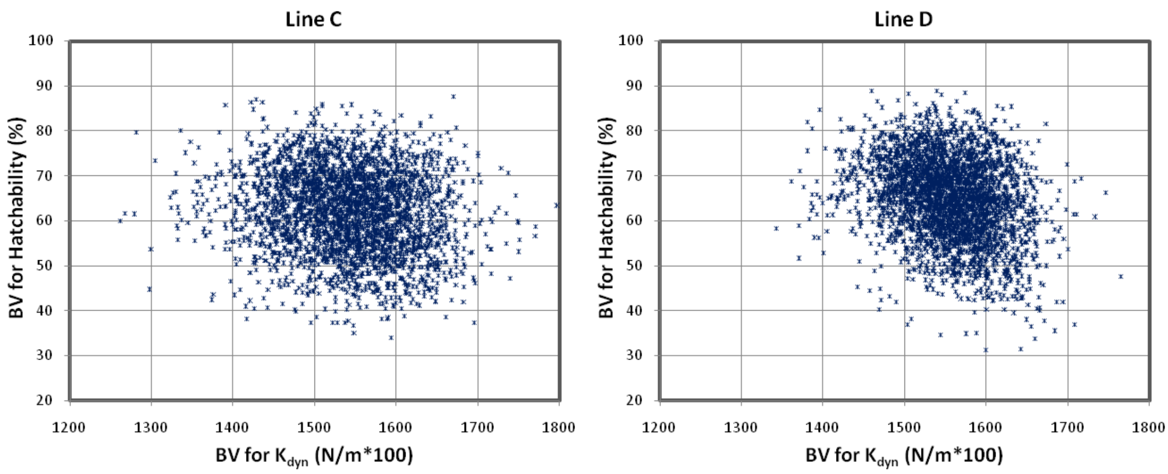
The eggshell performs a double function during embryo development. It has to be strong enough to protect the embryo from external influences and penetration of pathogens, but at the same time it should have enough porosity to allow gas exchange for embryonic development (Narushin and Romanov, 2002). These authors also indicated that hatchability tends to increase with increasing shell thickness and length-to-width ratio. The positive effect of egg shell quality on hatchability has been confirmed in several studies (i.e. Bennet, 1992; Barnett *et al.*, 2004). The correlations estimated in our study range from $r_g = +0.19$ to $+0.29$ (Table 3), which is in agreement with the positive genetic correlation reported by Wolc *et al.* (2010) between specific gravity and hatchability ($r_g = +\,0.53$). The relationship between shell strength and hatchability is plotted in Figure 2.

Figure 2: Breeding values for hatch of fertile eggs (HoF) plotted against breeding values for shell strength



Coucke *et al.* (1999) proposed that acoustic resonance frequency analysis could measure the mechanical stiffness of intact eggs and defined a novel eggshell parameter, dynamic stiffness (K_{dyn}). De Ketelaere *et al.* (2003) propose that K_{dyn} might provide a better indicator of an egg's ability to withstand insult because most forces leading to breakage are dynamic and not static. Dunn *et al.* (2005) and Icken *et al.* (2006) found that K_{dyn} has a higher heritability than breaking strength, while the correlation between these traits was significantly below 1 (r_g = +0.49 and +0.40). This suggests that K_{dyn} measures different aspects of the mechanical properties of the egg, in particular structural strength (Dunn *et al.*, 2005). Although the negative genetic correlations with hatchability are low (r_g = -0.09 and -0.17) strong selection on K_{dyn} may not help to improve hatchability, especially in line D, as shown in Figure 3.

Figure 3: Breeding values for hatch of fertile eggs (HoF) plotted against breeding values for dynamic stiffness (K_{dyn})

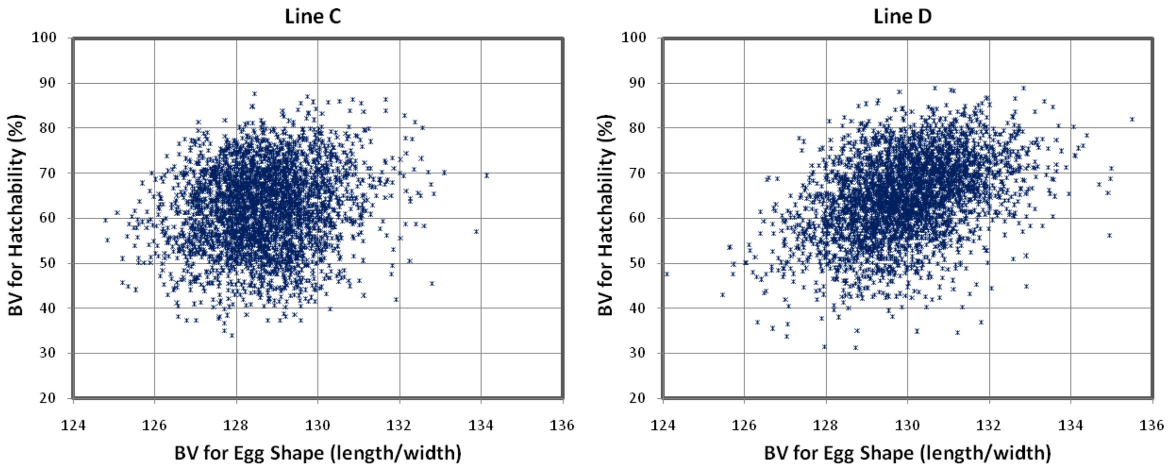


A possible explanation is that K_{dyn} has a lower negative correlation with egg weight than breaking strength (Dunn *et al.*, 2005; Icken *et al.*, 2006). A negative effect of increased dynamic stiffness may also be the result of reduced shell porosity, which is essential for gas exchange and for embryo development. The number and size of pores influences the rate of moisture loss and heat conductance across the eggshell (Hulet *et al.*, 2007). Further research is desirable to substantiate this tentative explanation.

The genetic correlation between albumen height and hatchability (r_g = -0.26 and -0.42) would perhaps have been less highly negative, if albumen height had been transformed to Haugh Units to remove the effect of the egg weight. Nevertheless, the negative correlation between albumen quality and hatchability is real (Flock *et al.*, 2007) and may be due to limited nutrient availability in eggs with higher albumen and lower yolk percentage. Wolc *et al.* (2010) reported also a negative correlation between Haugh Units and hatchability (r_g = -0.25). Practical experience has also shown that the hatchability of very fresh eggs, which have high Haugh Units, is lower than after a few days of storage (Förster *et al.*, 1992), but that is not relevant here. Albumen consistency is mainly an issue in connection with storage conditions for shell eggs in retail stores rather than for hatcheries.

Round eggs often have lower hatchability. The positive correlations between egg shape (length/with) and hatchability (r_g = +0.19 and +0.32) confirm that "longer" eggs tend to hatch better. Most eggs used in this study had shapes within the normal range, and eggs with abnormal shapes were already sorted out before setting.

Figure 4: Breeding values for hatchability of fertile eggs (HoF) plotted against the breeding values for egg shape



A high proportion of yolk, i.e. a high dry matter content of the egg, is appreciated by the egg-processing industry. The breeding goal is therefore at least 30% yolk in these white egg lines (Flock *et al.*, 2007), not only for the egg-processing industry, but also for optimal hatchability and chick quality. We confirmed positive correlations with hatchability (r_g = +0.32 and +0.39 for HoS and HoF, respectively). Similar results in a White Leghorn line were also reported by Hartmann *et al.* (2002), who found positive correlations between hatch of fertile eggs and yolk weight, yolk proportion and albumen dry matter of r_g = +0.28, +0.52 and +0.26, respectively. Narushin and Romanov (2002) concluded from the values obtained in the literature that hatchability decreased when the liquid content of the egg increased. Milisits *et al.* (2010) used electrical conductivity measurements to demonstrate that the hatchability of eggs benefits from a high egg yolk ratio.

In our study, this relation can be partly explained by the negative correlation between yolk proportion and egg weight (r_g = -0.60 and -0.65). The composition of the egg changes with egg size: yolk proportion decreases with increasing egg weight. This decrease in yolk proportion may have a negative effect on the nutrient supply of the embryo and consequently on the hatchability of larger eggs (Förster *et al.*, 1992). Wilson (1997) emphasized the crucial role of maternal nutrients for the developing avian embryo and concluded that inadequate, excessive or imbalanced levels of nutrients could even have lethal effects.

In contrast to Förster *et al.* (1993), who reported negative correlations in two brown layer lines ranging from r_g = -0.12 to -0.25, no significant correlation was found between body weight and hatchability in these White Leghorn lines.

Conclusions

Predictable hatchability of first quality chicks within a narrow time window is a common objective for commercial hatcheries. To improve reproductive traits by genetic selection, they must be included in the selection index, with proper attention to all genetic correlations to other traits. In view of the negative correlation with egg weight, focus on hatchability should be limited to female lines, while selection for desirable egg weight is practiced in male lines. With this strategy, egg weight could decline in the female lines toward a level determined by chick quality standards. A possibly negative relationship between dynamic stiffness of egg shells and hatchability can also be taken care of with appropriate choice of shell quality criteria in male and female lines. Persistent egg production and high yolk percentage are positively related to hatchability, and only the negative correlation with albumen height indicates a conflict with traditional breeding goals in White Leghorns.

Zusammenfassung

Züchterische Verbesserung der Schlupfrate bei Weißen Leghorn (LSL)

Pedigree-Daten von zwei LSL Reinzuchtlinien wurden ausgewertet, um genetische Parameter für Fruchtbarkeit und Schlupfrate und Korrelationen zu Eiqualitätskriterien zu bestimmen. Die Schlupfrate befruchteter Eier hatte mit 0,27-0,30 eine deutlich höhere Heritabilität als die Fruchtbarkeit mit 0,13-0,15 und ist deshalb als Selektionsmerkmal geeigneter. Genetische Korrelationen zum Eigewicht und zum Eiklaranteil waren deutlich negativ, während positive Beziehungen zum Dotteranteil und zur Schalenstabilität bestehen. Daraus ergibt sich die Empfehlung, bei Hennenlinien auf höheren Dotteranteil zu selektieren und eine Reduzierung des Eigewichts durch natürliche Selektion in Kauf zu nehmen. Ein marktgerechtes Eigewicht kann durch entsprechende Selektion auf Eigewicht in den Hahnenlinien abgesichert werden.

References

BAMELIS, F. (2003): Non invasive assessment of eggshell conductance and different developmental stages during incubation of eggs. Ph.D. Thesis, KU Leuven, Belgium.

BARNETT, D.M., B.L. KUMPULA, R.L. PETRYK, N.A. ROBINSON, R.A. RENEMA and F.E. ROBINSON (2004): Hatchability and early chick growth potential of broiler breeder eggs with hairline cracks. Journal of Applied Poultry Research, 13: 65-70.

BEAUMONT, C., N. MILLET, E. LE BIHAN-DUVAL, A. KIPI and V. DUPUY (1997): Genetic parameters of survival to the different stages of embryonic death in laying hens. Poultry Science, 76: 1193-1196.

BENNET, C. D. (1992): The influence of shell thickness on hatchability in commercial broiler breeder flocks. Journal of Applied Poultry Research, 1: 61-65.

BENNEWITZ, J., O. MORGADES, R. PREISINGER, G. THALLER and E. KALM (2007): Variance component and breeding value estimation for reproductive traits in laying hens using a Bayesian threshold model. Poultry Science, 86: 823-828.

CAREGHI, C., K. TONA, O. ONAGBESAN, J. BUYSE, E. DECUYPERE and V. BRUGGEMAN (2005): The effects of spread of hatch and interaction with delayed feed access after hatch on broiler performance until seven days of storage. Poultry Science, 84: 1314-1320.

COUCKE, P., E. DEWIL, E. DECUYPERE and J. BAERDEMAEKER (1999): Measuring the mechanical stiffness of an eggshell using resonant frequency analysis. British Poultry Science, 40: 227-232.

DE KETELAERE, B., H. VANHOUTTE and J. DE BAERDEMAEKER (2003): Parameter estimation and multivariable model building for the non-destructive, on-line determination of the eggshell strength. Journal of Sound and Vibration, 266: 699-709.

DECUYPERE E. and V. BRUGGEMAN (2007): The endocrine interface of environmental and egg factors affecting chick quality. Poultry Science, 86: 1037-1042.

DUNN, I.C., M. BAIN, A. EDMOND, P.W. WILSON, N. JOSEPH, S. SOLOMON, B. DE KETELAERE, J. DE BAERDEMAEKER, M. SCHMUTZ, R. PREISINGER and D. WADDINGTON (2005): Heritability and genetic correlation of measurements derived from acoustic resonance frequency analysis; a novel method of determining eggshell quality in domestic hens. British Poultry Science, 46: 280-286.

FLOCK, D.K. (1995) Changing emphasis in genetic development of egg-type chickens. Archiv für Tierzucht 47: 479-488.

FLOCK, D.K., M. SCHMUTZ and R. PREISINGER (2007): Optimierung der Eiqualität aus züchterischer Sicht. Züchtungskunde, 79: 309-319.

FÖRSTER, A., E. KALM and D.K. FLOCK (1992): Schlupffähigkeit aus züchterischer Sicht. Lohmann Information (Sept./Okt.): 13-16.

FÖRSTER, A. (1993): Züchterische Möglichkeiten einer Verbesserung der Schlupfrate in Reinzuchtlinien eines Zuchtprogrammes für braune Legehybriden. PhD Thesis. Schriftenr. Inst. Tierzucht und Tierhaltung, Christian-Albrechts-Univ., Kiel, Germany.

FÖRSTER, A. (1994): Optimierung der Schlupfrate und Kükenqualität - biologische Zusammenhänge und Bruttechnik. Lohmann Information (Mai/August): 11-16.

GROENEVELD, E., KOVAC, M., WANG, T. (1990): PEST, a general purpose BLUP package for multivariate prediction and estimation. Proceedings of the 4th World Congress on Genetics Applied to Livestock Production, Edinburgh, UK. Pages: 488-491.

HARTMANN, C., E. STRANDBERG, L. RYDHMER and K. JOHANSSON (2002): Genetic relations between reproduction, chick weight and maternal egg composition in a white leghorn line. Acta Agriculturae Scandinavica, Sect. A, Animal Science 52: 91-101.

HULET, R., G. GLADVS, D. HILL, R. MEIJERHOF and T. EL-SHIEKH (2007): Influence of egg shell embryonic incubation temperature and broiler breeder flock age on posthatch growth performance and carcass characteristics. Poultry Science, 86: 408-412.

ICKEN, W., M. SCHMUTZ and R. PREISINGER (2006): Dynamic stiffness measurements with the “crack detector”: a new method to improve egg shell strength. Lohmann Information, 41 (1): 13-19.

MAYES, F.J and M.A. TAKEBALLI (1984): Storage of the eggs of the fowl (Gallus domesticus) before incubation: a review. World’s Poultry Science Journal, 40: 131-140.

MEIJERHOF, R. (1992): Pre-incubation holding of hatching eggs. World’s Poultry Science Journal, 48: 58-67.

MILISITS G., E. KOVÁCS, O. POCZE, J. UJVÁRI, Z.S. TARASZENKÓ, G. JEKKEL, L. LOCSMÁNDI, GY. BÁZÁR, A. SZABÓ, R. ROMVÁRI, and Z SÜTO (2010): Effects of egg composition on hatchability and on growth and slaughter characteristics of meat-type chicks. British Poultry Science 51: 289-295.

NARUSHIN, U.G. and M.N. ROMANOV (2002): Egg physical characteristics and hatchability. World’s Poultry Science Journal, 58: 297-303.

NEUMAIER, A. and E. GROENEVELD (1998): Restricted maximum likelihood estimation of covariances in sparse linears model. Genetics Selection Evolution, 30: 3-26.

ROBINSON, F.E., R.T. HARDIN, N.A. ROBINSON and B.J. WILLIAMS (1991): The influence of egg sequence position on fertility, embryo viability, and embryo weight in broiler breeders. Poultry Science, 70: 760-765.

ROZEMPOLSKA-RUCINSKA I., G. ZIEBA and M. LUKASZEWICZ (2009): Hatchability traits as selection criteria in breeding of laying hens. Archiv für Geflügelkunde, 73: 263-267.

SAVAS, T., R. PREISINGER, R. RÖHE and E. KALM (1999): Einfluss der Box-Cox Transformation auf die Schätzung genetischer Parameter für Legerate bei Legehennen. Züchtungskunde, 71: 380-391.

SAPP, R.L., R. REKAYA, I. MISZTAL and T. WING (2004): Male and Female Fertility and Hatchability in Chickens: A Longitudinal Mixed Model Approach. Poultry Science, 83: 1253-1259.

SHARIFI, A.R., R. PREISINGER, F. VAHIDI, K. JAWASREH and H. SIMIANER (2010): Statistical and genetic analysis of reproductive traits in laying hens. Proceedings of the 9th World Congress on Genetics Applied to Livestock Production, Leipzig, Germany.

STOVE-SCHIMMELPFENNIG, K. and D.K. FLOCK (1982): Eigewicht und relative Fitness in der Legehennenzüchtung. Archiv für Geflügelkunde, 46: 270 - 275.

SWALVE, H.H. (1995): The effect of test day models on the estimation of genetic parameters and breeding values for dairy yield traits. Journal of Dairy Science, 78: 929-938.

SZWACZKOWSKI, T., S. WEZYK, P. PIOTROWSKI and K. CYWA-BENKO (2000): Direct and maternal genetic and environmental effects for fertility and hatchability in laying hens. Archiv für Geflügelkunde, 64: 115-120.

TONA, K., F. BAMELIS, B. DE KETELAERE, V. BRUGGEMAN, V. M. B. MORAES, J. BUYSE, O. ONAGBESAN AND E. DECUYPERE (2003): Effects of egg storage time on spread of hatch, chick quality, and chick juvenile growth. Poultry Science, 82: 736-741.

WILLEMSEN, H., N. EVERAERT, A. WITTERS, L. DE SMIT, M. DEBONNE, F. VERSCHUERE, P. GARAIN, D. BERCKMANS, E. DECUYPERE AND V. BRUGGEMAN (2008): Critical Assessment of Chick Quality Measurements as an indicator of posthatch Performance. Poultry Science, 87: 2358-2366.

WILSON, H.R. (1991): Interrelationships of egg size, chick size, posthatching growth and hatchability. World's Poultry Science Journal 47: 5-20.

WILSON, H.R. (1997): Effects of maternal nutrition on hatchability. Poultry Science, 76:134-143.

WOLC, A., I.M.S. WHITE, V.E. OLORI and W.G. HILL (2009): Inheritance of fertility in broiler chickens. Genetic Selection Evolution, 41:47.

WOLC, A., I.M.S. WHITE, W.G. HILL and V.E. OLORI (2010): Inheritance of hatchability in broiler chickens and its relationship to egg quality traits. Poultry Science, 89: 2334-2340.

ZAKARIA A.H., P.W. PLUMSTEAD, H. ROMERO-SANCHEZ, N. LEKSRISOMPONG, J. OSBORNE AND J. BRAKE (2005). Oviposition pattern, egg weight, fertility and hatchability of young and old broiler breeders. Poultry Science, 84: 1505-1509.

Corresponding author:

Dr. David Cavero Pintado
Lohmann Tierzucht GmbH
Am Seedeich 9-11
27474 Cuxhaven, Germany
e-mail: cavero@ltz.de

Recommendations for hatching egg handling and storage

R. Schulte-Drüggelte, Cuxhaven, Germany

Introduction

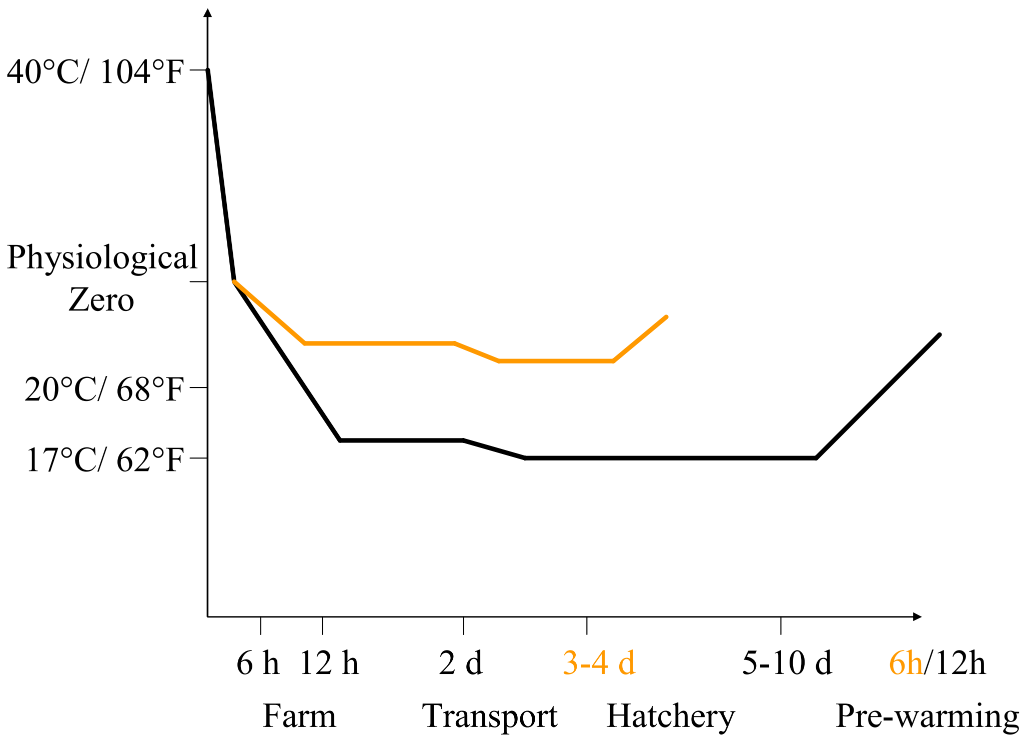
At the time a fertile egg is laid, there is already a small embryo floating on the yolk. The vitality of this embryo must be preserved during storage until the point in time when the incubation process starts. To achieve this, the eggs are handled carefully and temperature fluctuations avoided as much as possible under practical conditions (Barten, 2007). Beside this common practice, specific management procedures may help to minimise the loss of hatchability during extended egg storage.

This paper reviews recommendations for handling and storage of hatching eggs from layer breeders, with focus on ideas for prolonged egg storage.

Optimal egg storage condition

After oviposition the development of the embryo which started in the hen's body, has to be stopped. Therefore the egg should be cooled down below "physiological zero" (26 – 27 °C) (Funk and Biellier, 1944). This process usually happens inside the nest or on the egg belt. If the ambient temperature is higher (which is not uncommon during summer months), delayed cooling may be a problem. In this case eggs should be collected more frequently to assure that the temperature of the embryo is brought down from 40 °C body temperature to 26-27 °C within six hours. A temperature in the 37-27 °C range leads to unbalanced development and hence early embryonic mortality. Too quick cooling may also weaken the embryo. Further research is needed to determine whether this is due to retarded development or other factors (Schulte-Drüggelte and Svensson, 2011).

Figure 1: Optimal development of the egg temperature from oviposition until setting depending on the storage length



Source: Schulte-Drüggelte and Svensson (2011)

Once the cell division is stopped the egg needs to be further cooled down. This is necessary to control the deterioration of the albumen and necrotic cell deaths. Control means, that there are different optimal egg storage temperatures depending on storage length. Eggs which are set within 4 days of lay don't need to be kept at a temperature below 20 °C; in this case 21–22 °C is regarded as optimal. This relatively high temperature promotes the thinning of the albumen, which improves the gas exchange during early incubation. On the other hand, it is low enough to maintain the vitality of the embryo. In most layer hatcheries, it is common to store the eggs up to 10 days. For this storage length the recommended temperature is 16 – 18 °C.

Temperature ups and downs should be avoided, as they can cause early embryonic mortality (Bramwell, 2008). Ideally the hatching eggs experience only two temperature changes from the moment of lay until pre-warming (see figure 1).

The humidity during storage is not as important as the temperature, as its impact on hatchability is limited (Meijerhof, 2000). When eggs are stored only up to 10 days, 50 – 60 % relative humidity is sufficient. Higher humidity, up to 80 %, is not harmful. Above 80 % relative humidity growth and spread of bacteria and mould is likely to become a problem. Eggs scheduled for long storage benefit from higher humidity to avoid excessive moisture loss of the eggs. The target in this case is 70 – 80 % relative humidity.

Ideas for long storage

If eggs are scheduled for a long storage period, the hatchery manager can make use of different tools to minimise the negative impact on hatchability. These tools either aim to improve the vitality of the embryo or they support the quality of the egg contents or both (Reijrink, 2010).

The temperature during storage can be decreased down to 10-12°C. At lower temperature the water loss of the eggs is reduced and the deterioration of albumen slowed down (Walsh, Rizk and Brake, 1995).

Table 1 shows the results of a recent trial with eggs from a grandparent flock stored 16 days at different temperatures.

Table 1: Hatchability of eggs from a commercial White Leghorn flock, stored at different temperatures (source: female line of LSL)

Number of eggs set	Temperature during storage	% Hatch of eggs set
595	15.5-16 °C	66.4
598	13.5-14 °C	70.1

However, a temperature below 15 °C is not recommended for commercial practice. In many situations the extra cooling is not cost-efficient and creates other problems when it comes to setting, like egg sweating or/and a long pre-warming time. Very good hatching egg planning would be required to handle this tool successfully. Egg sweating, i.e. condensation of water on the eggshell, may happen e.g. when cold stored eggs are brought to a warm setter room. Egg sweating must be avoided by any means, because it allows micro-organisms to multiply on the wet surface, penetrate the shell and contaminate the egg. In most cases it helps to limit the temperature difference between cool and warm room to max. 11 °C.

A simple approach to preserve hatchability is to turn the eggs during storage like it is done during incubation. If there is no automatic equipment installed, turning by hand three times each day is sufficient. If the eggs are kept on cardboard trays instead of setter trays, they can be stored upside down – with the pointed end up. This keeps the yolk and the embryo in a central position and protects the latter during storage (Mayes and Takeballi, 1984). Eggs should preferably not be transported this way, because it might cause loose air cells. Of course they should be set in the incubator with the pointed end down. Turning the eggs back up just before pre-warming/setting is early enough.

Pre-storage incubation is another procedure successfully applied in several commercial layer hatcheries. Its mode of action is based on the fact that the developmental stage of the embryo at point of lay is not optimal for long storage. In nature, it would be altered by periodical warming of the eggs during the time the hen sits on the nest to produce the next egg of the clutch. In the hatchery it is possible to achieve similar results by incubating the eggs for a short time soon after lay. This leads to a stage of development where the embryo is less susceptible to cell death during the storage period (Fasenko *et al.*, 2001; Lourens, 2006).

Pre-storage incubation cannot improve, but it can help to maintain hatchability. Therefore it makes sense to use this technique if eggs are scheduled for a storage period which would usually reduce hatchability significantly. This will depend on local conditions and may differ between strains, age of flock and storage conditions.

Table 2 shows the results of a recent hatchery trial, where we compared two egg positions during storage in combination and low oxygen and pre-storage incubation against untreated controls. Eggs from a grandparent flock of commercial White Leghorns (LSL) were used and stored for 20 days before incubation. For the low oxygen treatment, the eggs were stored in a gas tight cabinet with nitrogen and 1 % oxygen. Pre-storage incubation was practiced in a single stage setter on day 1 of storage and lasted 6 hours, including 5 hours with an egg temperature between 99 and 100 °F.

Table 2: Average hatch of fertile eggs after 20 days storage at 16° C with different treatments

Number of eggs set	Egg position: pointed end	Storage treatment	Early embryonic mortality %	% Hatch of fertile eggs
600	up	Low oxygen	11.3	74.0
598	up	control	17.4	62.8
750	down	Pre-storage incubation	18.0	58.0
599	down	control	21.7	47.5

In this experiment, storing the eggs upside down improved hatch of fertile eggs by 15.3%, pre-storage incubation of eggs stored normally 11.5%, and low oxygen treatment of eggs stored upside down by 11.2%. Assuming that differences between trays can be ignored, these differences are statistically highly significant and of practical interest.

Discussion and conclusions

On a research level many experiments have been made with altered air composition during storage to preserve egg quality (Mayes and Takeballi, 1984; Reijrink, 2010). The results are often promising (including our own results in table 2), but so far none of these techniques have become routine practice in the industry. The main reason is that the technique is complex and costly and would probably only pay back in PS – hatcheries routinely storing the eggs for more then 14 days.

More applicable is a low egg storage temperature, the storage of hatching eggs with the pointed end up or pre-storage incubation. If pre-storage incubation is practiced, it should be preferably done with fresh eggs up to two days after lay. In case the eggs have not been properly cooled after oviposition, the effects of pre-storage incubations may be negligible or even negative, because the embryos are already at an advanced stage of development.

Zusammenfassung

Empfehlungen für die Lagerung von Bruteiern

Um die Brutfähigkeit von befruchteten Eiern auch bei längerer Lagerung so weit wie möglich zu erhalten, ist darauf zu achten, dass die Eier innerhalb von sechs Stunden nach der Eiablage auf weniger als 26°C und innerhalb von zwölf Stunden auf die anschließende Lagertemperatur von 16-18°C abkühlen. Die Eier sollten möglichst geringen Temperaturschwankungen ausgesetzt werden. Eine relative Luftfeuchtigkeit von 70-80% ist zu empfehlen.

Zur Verbesserung der Schlupfrate bei längerer Lagerung ist es zusätzlich möglich, die Lagertemperatur von Anfang an niedriger zu wählen (15°C), Eier mit der Spitze nach oben zu lagern oder sie am Anfang der Lagerungszeit vorzubrüten. Versuche, die Luftzusammensetzung während der Lagerung zu verändern, sind vielversprechend, aber diese Verfahren sind noch nicht praxisreif.

References

Barten, M. (2007): Poor performance due to transportation! World Poultry Vol. 23 No. 8.

Bramwell, K. (2008): On-farm egg storage: Avoid pre-incubation. International Hatchery Practise. Vol.23 No.3.

Fasenko, G.M., V.L. Christensen, M.J. Wineland and J.N. Petite (2001): Examining the Effects of Prestorage Incubation of Turkey Breeder Eggs on Embryonic Development and Hatchability of Eggs Stored for Four or Fourteen Days. Poultry Science 80: 132-138.

Funk, E.M. and H.V. Biellier (1944): The minimum temperature for embryonic development in the domestic fowl (Gallus domesticus). Poultry Science 23: 538-540.

Lourens, S. (2006): Heating eggs before storage increases hatchability. World Poulty. Vol.22 No.4: 22-23.

Mayes, F.J. and M.A. Takeballi (1984): Storage of Eggs of the Fowl (Gallus domesticus) before Incubation. World's Poultry Science 40: 131-140.

Meijerhof, R. (2000): Moisture loss during storage. World Poultry Special 2000: 8-9.

Reijrink, I. (2010): Storage of hatching eggs - Effects of storage and early incubation conditions on egg characteristics, embryonic development, hatchability and chick quality. Ph.D. Thesis, Wageningen University, The Netherlands.

Schulte-Drüggelte, R. and S. Svensson (2011): Hatchery Management Guide. LTZ.

Walsh, T.J., R.H. Rizk and J. Brake (1995). Effects of storage for 7 or 14 days at two temperatures in the presence or absence of carbon dioxide on albumen characteristics, weight loss and early embryonic mortality of broiler hatching eggs. Poultry Science 74: 1403–1410.

Author's Address

Robert Schulte-Drüggelte
Lohmann Tierzucht GmbH
Am Seedeich 9-11
D 27472 Cuxhaven, Germany
e-mail: schulte-drüggelte@ltz.de

Valine and Isoleucine: The next limiting amino acids in broiler diets

**Etienne Corrent (Ajinomoto Eurolysine S.A.S.) and
Dr. Jörg Bartelt (Lohmann Animal Health GmbH & Co. KG)**

Drastic genetic changes have occurred in many commercial broiler lines during the last years with regard to performance. This genetic improvement needs a corresponding adjustment of our knowledge about amino acid nutrition in broilers. Additionally, today broiler feed formulators are not only focused on minimising the costs. They also have to take into consideration environmental issues and the impact of feed on broiler health. Reducing excess dietary crude protein (CP) is an important way of addressing these issues. The least cost formulation of the diet according to the ideal protein concept is the best way to supply an economic and a balanced amino acids feed for broiler, which can help to reduce the nitrogen excretion during the rearing period.

What are the next limiting amino acids in broiler diets?

To reduce dietary crude protein levels in broiler feed, it is necessary to know which indispensable amino acids become limiting in diets and what the requirement of broilers is. The usage of feed use amino acids (methionine sources, L-Lysine sources, L-Threonine) in broiler feed is well established. Depending on the requirement assumed for each amino acid, Valine, Isoleucine, Tryptophan and Arginine are generally considered as the next limiting amino acids in broiler feed. Indeed, the amino acid composition of protein differs between feedstuffs and can impact the order in which amino acids become limiting in diets.

The study carried out by Fernandez *et al.* (1994) on 8 – 21 day-old chicks determined which amino acids were limiting in corn soybean meal based diets. Amino acid levels of the control diet were according to an ideal protein specification. The authors used the deletion method (amino acid supply was reduced one after another) and observed average daily gain (ADG) and gain:feed ratio (G:F) of the birds. They confirmed that Methionine, Lysine and Threonine were the 1st limiting amino acids for broiler performance. It can be seen that Valine was the 4th limiting amino acid for broilers ahead of Arginine and Tryptophan for G:F (figure 1). Results for weight gain gave the same ranking of limiting amino acids.

Corzo *et al.* (2007) confirmed experimentally that Valine was the 4th limiting amino acid in corn-soybean meal diets for 21 – 42 days broilers. In contrast, Berres *et al.* (2010) formulated a corn-soybean meal diet without CP restriction by using L-Lysine, DL-Methionine and L-Threonine. The ratios of digestible amino acids to lysine were: 75% (Met + Cys), 65% (Thr), 18% (Trp), 70% (Val), 65% (Ile), 106% (Arg) at a CP-level of 18.7%. This diet led to poor body weigh gain which was improved significantly when L-Valine or L-Isoleucine was supplemented to Val:Lys and Ile:Lys ratio of 75% and 68%, respectively, during day 14 – 35. The limitation of Isoleucine before Arginine in corn-soybean meal diets when at least 2% of meat-and-bone meal is present in diet formulation for heavy broilers was demonstrated by Corzo *et al.* (2008).

In broiler diets with poultry by-product meal, Corzo *et al.* (2009) observed Valine to be limiting before Isoleucine until Isoleucine inadequacy starts to prevail, making further Valine supplementation futile.

Valine and Isoleucine requirement in the literature

To better understand the amino acid requirements of broilers, knowledge of their carcass and feather amino acid contents is helpful. Stilborn *et al.* (1997) estimated the feather amino acid contents from broilers. The authors found a Val:Lys ratio of 198% at day 14. This ratio increased to 338 % day 28 and up to 378% at day 112. The corresponding Ile:Lys ratios were 145%, 234% and 283%. It shows the impact of both amino acids for synthesis of feather protein. In the carcass (without feather) an average Val:Lys and Ile:Lys ratios of 79% and 60%, respectively, can be measured (GfE, 1999).
An exhaustive literature review show that there is a huge variability in published requirements with Val:Lys = 81% ± 19.7 and Ile:Lys = 70% ± 17.0 (figure 2)

Figure 1: Order of limiting amino acids in the protein of a corn-soybean meal diet for chick growth (FERNANDEZ *et al.*, 2004). Columns with different letters are significantly different ($p < 0.05$)

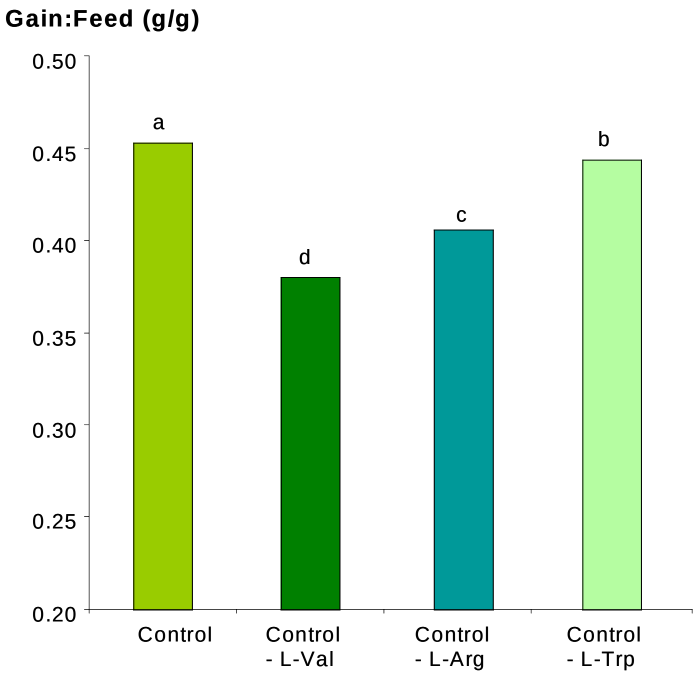
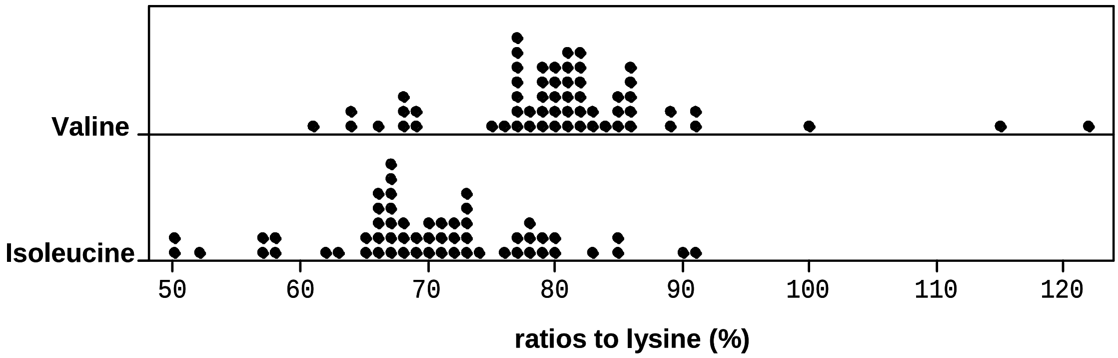


Figure 2: Compilation of available published requirements for valine and isoleucine expressed as Val:Lys and Ile.Lys ratios. Each point represents one published requirement.



The Valine requirement of broilers as a ratio to Lysine

Due to the wide variation in published requirements, it is very difficult to interpret and reach conclusions about the Valine and Isoleucine requirements of broilers. In order to investigate this further, a database was built in which the available data on the Valine and Isoleucine responses and requirements of broiler were compiled. It could be found in world literature 28 valine and 66 isoleucine trials (articles or abstracts from scientific journals). To enter a trial in the database, the following minimum information was required:

1. Ages of the tested chickens
2. Composition of the basal experimental diet. Nutritional values (apparent metabolisable energy and amino acid expressed in true digestible [TD]) were re-calculated with INRA-tables (Sauvant *et al.*, 2004) so that the analysis could be based on complete amino acid profiles drawn from common source and to remove the variability arising from published values (expected ≠ analysed).

3. Measures of growth performance: average daily gain, average daily feed intake, gain to feed ratio. Carcass weight and yield, breast meat weight and yield were also entered when they were available.

The expression of the requirement as Val:Lys and Iso:Lys needs to test if TD Lysine level is sub-limiting. This was done by graphical comparison to the TD Lysine requirement at different ages of modern broiler genotypes (adapted from Ross 308 (2007) and Cobb 700 (2008) management guides). In a second step, the TD amino acid profiles of basal diets were compared to Baker and Han (1994) in order to determine if any amino acids other than Valine or Isoleucine were limiting in the diet. In addition, because a 2-level study does not allow the determination of a requirement, such studies were eliminated from the compilation. At the end only ten published studies could be selected for the evaluation of Val:Lys ratio. The table 1 gives the experimental design of these studies.

Table 1: Experimental designs, recalculated nutritional values of the basal feed and broiler performance of the best treatment in each of the 10 trials kept for the determination of the TD Val:Lys requirement of broilers

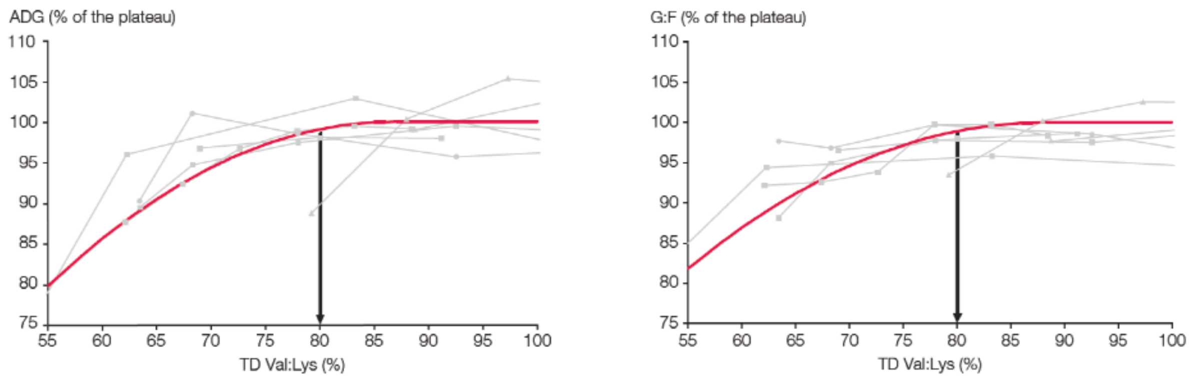
	Allen and Baker 1972 Exp. 1	Allen and Baker 1972 Exp. 2	Men-donca *et al.* 1989	Le-clercq 1987	Bae *et al.* 1999	Eker-mans *et al.* 2001	Corzo *et al.* 2004 Exp. 2	Thorn-ton *et al.* 2006 Exp. 2	Thorn-ton *et al.* 2006 Exp. 2	Corzo *et al.* 2007 Exp. 3
Age range, days	8-14	8-14	21-42	20-40	8-22	7-21	42-56	21-42	21-42	21-42
Genetics	New Hampshire x Columbian Plymouth Rock		-	ISA 220	Arbor Acres	-	Ross 308	Ross 508	Ross 508	Ross 708
Sex	M	M	-	M	M	MF	M	M	F	M
Nutritional Values										
AME, kJ/kg	18.2	18.6	13.1	13.1	17.0	12.7	13.3	13.0	13.0	13.1
CP, %	14.3	16.6	15.2	15.6	17.3	23.8	17.3	14.6	14.6	17.3
TD Lys, %	0.93	0.93	0.90	0.57	1.07	1.18	0.75	0.93	0,93	0.95
TD Thr:Lys, %	69	69	74	80	73	66	98	73	73	67
TD SAA:Lys, %	74	74	84	77	83	79	103	87	87	82
TD Ile:Lys, %	65	65	75	91	73	76	100	74	74	74
TD Leu:Lys, %	443	443	140	207	110	193	221	131	131	124
TD Arg:Lys, %	128	128	124	135	114	108	126	110	110	139
TD Val:Lys, %	38-59	54-75	69-91	107-154	20-104	89-228	79-107	63-136	63-136	62-88
Best performance										
ADG, g/d	5.2	5.0	54.1	78.1	28.6	36.4	103.6	69.6	60.0	66.2
ADFI, g/d*	11	11	113	134	43	53	246	178	174	141
G:F, g/g	0.471	0.463	0.482	0.585	0.670	0.693	0.422	0.411	0.349	0.485

M = males, F = females, TD = true digestible, *ADFI = average daily feed intake

In order to estimate the TD Val:Lys ratio which optimises ADG and G:F ratio of broilers, the performance in the ten selected trials were represented in a curvilinear plateau model. The meta-analytical model took into account a trial effect by estimating a plateau for each trial separately. The results are presented graphically in figure 3.

There is a clear response in ADG and G:F ratio to increased TD Val:Lys ratios, which validates the selection procedure. The TD Val:Lys ratio of 80% appears as a minimum to optimise broiler growth and feed efficiency.

Figure 3: Effect of TD Val:Lys ratio on ADG and G:F



The compilation of the data for carcass parameter shows a strong effect of TD Val:Lys ratio on weight of carcass and breast meat (Corzo *et al.*, 2004; 2007). However, carcass yield (Thornton *et al.*, 2006, Corzo *et al.*, 2004; 2007) and breast meat yield (Leclerq, 1998, Thornton *et al.*, 2006, Corzo *et al.*, 2004; 2007) were not affected. As carcass weight and breast meat weight increased together with increased Val:Lys ratios, the ratio between breast meat and carcass weight did not change. However, meeting the bird's requirement for Valine is of key importance in ensuring the optimal usage of Lysine which is well known to increase breast meat yield (Berri *et al.*, 2008).

The Isoleucine requirement of broilers as a ratio to Lysine

As explained above, trials must be selected based on TD Lysine, deficiency in one or more amino acids, lack of other information or number of levels for TD Ile:Lys ratio. As result, from 66 published trials only 6 trials fulfilled the conditions in order to evaluate the TD Ile:Lys ratio. The mean characteristics of the trials selected are presented in table 2. The 6 trials differ in the broilers' ages, sex, genetics and nutritional values of the feed. This explains the differences in ADG, ADFI and G:F ratio between the trials.

In order to estimate the TD Ile:Lys ratio that optimises ADG and G:F ratio in broilers, growth performance of the six trials were compiled using the same method as for Valine. The graphical results of this compilation are presented in figure 4.

There is a clear response in ADG and G:F ratio to increased TD Ile:Lys ratios, which validates the selection procedure. A minimum TD Ile:Lys ratio of 67 appears to be necessary to optimises broiler performance.

However, it is important to notice that in four trials (Hale *et al.*, 2004, Kidd *et al.*, 2004, exp. 4, 5, 6) the authors used blood cells (animal product). Blood have a specific imbalance in their amino acid profiles, which is characterised by a relative high Valine and Leucine content and particularly poor level of Isoleucine. This raw material is often used in Isoleucine dose-response trials because it easily creates an Ile deficiency. It is well documented that the imbalance between these three amino acids (all

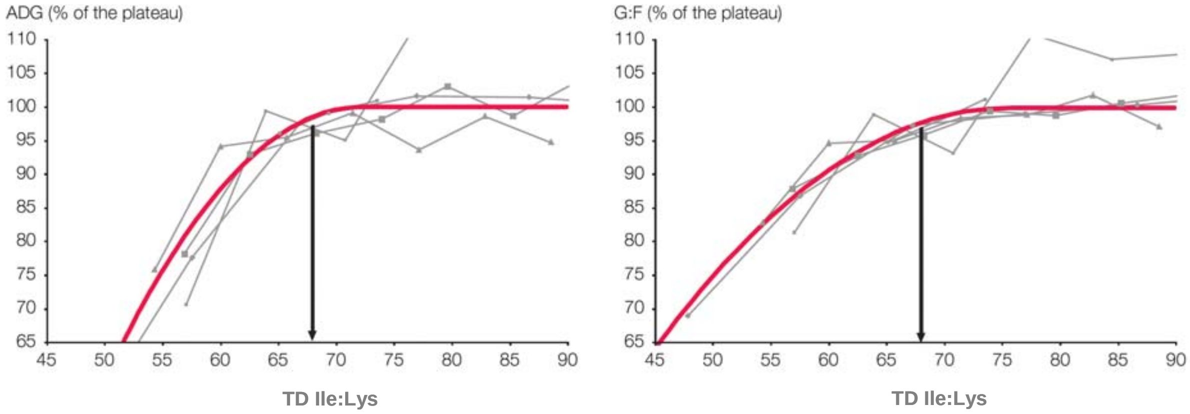
Table 2: Experimental designs, recalculated nutritional values of the basal feed and broiler performance of the best treatment in each of the 6trials kept for the determination of the TD Ile :Lys requirement of broilers

	Corzo *et al.* 2004	Hale *et al.* 2004 Exp. 2	Kidd *et al.* 2004 Exp. 4	Kidd *et al.* 2004 Exp. 5	Kidd *et al.* 2004 Exp. 6	Corzo *et al.* 2008 Exp. 2
Age range, days	42 - 56	30 - 42	18 - 30	30 - 42	42 - 56	35 - 54
Genetics	Ross 308	Ross 508	Ross 308	Ross 308	Ross 308	Ross 708
Sex	M	F	M	M	M	M
Nutritional values						
AME, kJ/kg	12.6	12.6	13.8	12.7	12.7	13.0
CP, %	15.6	15.7	17.7	16.2	15.1	16.7
TD Lys, %	0.81	0.87	0.88	0.87	0.73	0.95
TD Thr:Lys, %	90	79	79	79	88	69
TD SAA:Lys, %	89	96	98	94	99	77
TD Val:Lys, %	98	92	105	91	107	76
TD Leu:Lys, %	202	177	195	175	209	147
TD Arg:Lys, %	122	114	119	115	126	100
TD Ile:Lys, %	65 - 95	48 - 96	57 - 91	54 - 89	57 - 98	65 - 74
Best performance						
ADG, g/d	93.8	60.4	59.1	79.4	52.8	99.0
ADFI, g/d*	226	142	104	157	177	208
G:F, g/g	0.415	0.436	0.578	0.524	0.302	0.483

M = males, F = females, TD = true digestible, *ADFI = average daily feed intake

branched-chain amino acids) is a factor that impacts animal response in broilers (D'Mello and Lewis, 1970 a,b, Burnham *et al.*, 1992) and piglets (Wiltafsky *et al.*, 2010). D'Mello and Lewis (1970a) observed in growing broilers (7-21 days) that circulating levels of Isoleucine and Valine were lowered by an excess of Leucine. In addition, Valine and Isoleucine requirement increased with Leucine supply (D'Mello and Lewis, 1970b). Burham *et al.* (1992) observed that dietary Leucine set at 1.76 times the requirement level depressed chick growth. However, an excess of Valine does not seem to impact bird's response to Isoleucine (D'Mello and Lewis, 1970a). Therefore, further trials in order to estimate the optimal Ile:Lys ratio in broiler diets without blood cells or high Leucine level are needed.

Figure 4: Effect of TD Ile:Lys ratio on ADG and G:F



Practical implication for broiler diets

This review concerning the Valine and Isoleucine requirements of broilers allows to update the ideal amino acid profile (table 3) proposed by Ajinomoto Eurolysine S.A.S. in 2004.

Table 3: Proposed ideal amino acid profile for broilers (true digestible AA relative to Lysine)

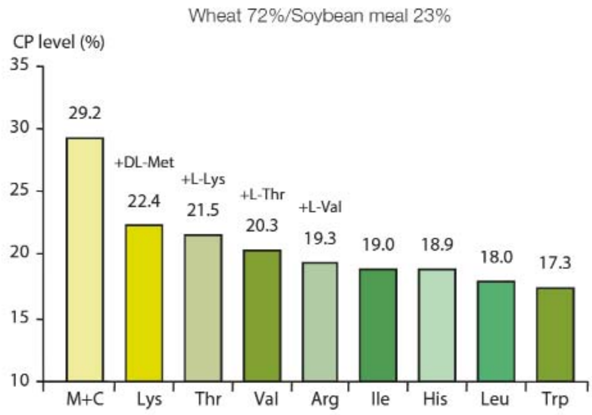
Lysine	100
Sulphur amino acids	75
Threonine	65
Valine	80
Isoleucine	67
Arginine	105
Tryptophan	17
Histidine	40
Leucine	105
Phenylalanine + Tyrtosine	105

By using a minimum specification for each of these amino acids in formulations, it is possible to progressively determine the next limiting amino acid in broiler feed, and to establish the extent to which it is possible to reduce dietary crude protein through supplementation with amino acids. As an example, three grower broiler diets (14 – 28 days) were formulated to contain 13.4 MJ/kg AME and 1.05% TD Lysine, using the amino acid profile presented in table 3. The first simulations are based on wheat-soybean meal diet and the second ones on corn-wheat-soybean meal diet (figure 5).

It can be seen that the lowest CP level that could be achieved without any feed use amino acid was 29.2% with wheat and soybean meal. When DL-Methionine was added to the formulation, the lowest CP level that could be reached was 22.4% and the next limiting amino acid was Lysine. When L-Lysine was offered, the CP level dropped to 21.5% and Threonine became limiting. In both simulations, sulphur amino acids, Lysine and Threonine were the first limiting amino acids. L-Threonine supplementation allowed an additional reduction of approximately one percentage point of CP in both diet types. Then, in these vegetable diets, Valine was the next limiting amino acid before Arginine and Isoleucine, as already described at the beginning of this article. The supplementation of L-Valine allowed a further reduction of one percentage point of dietary CP.

In contrast, Isoleucine at 67% TD Ile:Lys ratio is the next limiting amino acid after Threonine in feed containing blood meal, followed by Arginine and Valine (figure 6).

Figure 5: Dietary CP level (%) in standard grower broiler diet (soybean meal was gradually replaced by wheat or corn). Ranking of limiting amino acids (from left to right) and lowest crude protein level achievable without supplementation with the corresponding amino acid.



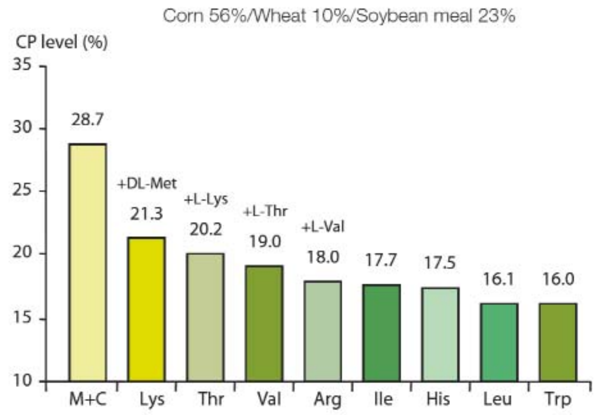
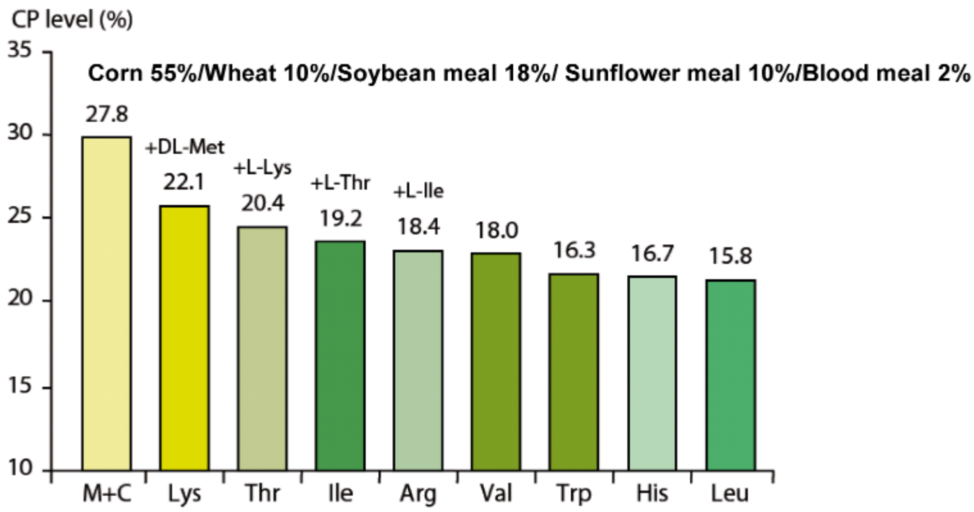


Figure 6: Dietary CP level (%) in standard grower broiler diet with blood meal and sunflower meal (soybean meal was gradually replaced by corn). Ranking of limiting amino acids (from left to right) and lowest crude protein level achievable without supplementation with the corresponding amino acid.



Conclusions

1. Valine is the 4th limiting amino acid in vegetable broiler diets based on wheat or corn
2. Isoleucine becomes the 4th limiting amino acid, when blood cells or blood meal are used in formulations.
3. The TD Val:Lys and TD Ile:Lys requirements of broilers are 80% and 67%, respectively, to optimise performance.
4. Knowing the requirements of individual amino acids, feed formulators have more flexibility to reduce dietary crude protein levels.
5. L-Valine supplementation in combination with L-Threonine provides the opportunity to formulate technically, economically and environmentally better broiler feed.

Zusammenfassung

Valin und Isoleucin:– Die nächst-limitierenden Aminosäuren im Broilerfutter

Im Rahmen einer Literaturstudie wurde geprüft, welche Aminosäuren nach dem Threonin im Broilerfutter limitierend sind. Dabei wurden die publizierten Studien zum Val:Lys - bzw. Ile:Lys Verhältnis einer Meta-Analyse unterzogen. Für die Auswertung wurden nur Dosis-Wirkungs-Studien verwendet, bei denen der Lysingehalt sub-limitierend war, keine weiteren Aminosäuren (außer Valin bzw. Isoleucin) im Mangel vorlagen und mehr als zwei Stufen getestet wurden.

Es konnte eine Val:Lys – bzw. Ile:Lys Relation von mindestens 80% bzw. 67 % (Basis: wahr verdaulich) abgeleitet werden, bei denen die tägliche Lebendmassezunahme und die Futterverwertung optimiert werden konnte. In Rationen, die auf Weizen, Mais und Sojaextraktionsschrot basieren, wird Valin nach dem Threonin limitierend. Enthalten die Rationen Blutzellen oder Blutmehl, begrenzt Isoleucin nach dem Threonin die Proteinsynthese.

References:

AJINOMOTO EUROLYSINE S.A.S. (2004): Amino acid nutrition of the broiler chicken. Update on lysine, threonine and other amino acids. Ajinomoto Eurolysine Information No. 27.

ALLEN, N.K. and D.H. Baker (1972): Quantitative efficacy of dietary isoleucine and valine for chick growth as influenced by variable quantities of excess dietary leucine. Poult. Sci. 51: 1292-1298.

BAE, S.H., J.H. KIM, I.S. SHIN and I.K. HAN (1999): Partition of amino acid requirement of broilers between maintenance and growth. V. Isoleucine and valine. Asian-Australas. J. Anim. Sci., 12: 388-394.

BAKER, D.H. and Y. HAN (1994): Ideal amino acid profile for chicks during the first three weeks posthatching. Poult. Sci. 73: 1441-1447.

BERRES, J., S.L. VIEIRA, M.T. KIDD, D. TASCHETTO, D.M. FREITAS, R. BARROS and E.T. NOGUEIRA (2010): Supplementing L-Valine and L-Isoleucine in low-protein diet corn and soybean meal all-vegetable diets for broilers. J. Appl. Poult. Res. 19: 373-379.

BERRI, C., J. BESNARD and C. RELANDEAU (2008): Increasing dietary lysine increases final ph and decreases drip loss of broiler breast meat. Poult. Sci. 87: 480-484.

BURNHAM, D., G.C. EMMANS and R.M. GOUS (1992): Isoleucine requirements of chicken: the effect of excess leucine and valine on the response to isoleucine. Br. Poult. Sci. 33: 71-87.

CORZO, A., E.T. MORAN Jr. and D. HOEHLER (2004): Valine needs of male broilers from 42 to 56 days of age. Poult. Sci. 83: 946-951.

CORZO, A., M.T. KIDD, W.A, DOZIER III and S.L. VIEIRA (2007): Marginality and needs of dietary valine for broilers fed certain all-vegetable diets. J. Appl. Poult. Res. 16: 546-554.

CORZO, A., W.A. DOZIER III, M.T. KIDD and D. HOEHLER (2008): Impact of dietary Isoleucine status on heavy-broiler production. Int. J. Poult. Sci. 7: 526-529.

CORZO, A.; R.E. LOAR II and M.T. KIDD (2009): Limitations of isoleucine and valine in broiler chick diets. Poult. Sci. 88: 1934-1938.

D'MELLO, J.P.F. and D. LEWIS (1970a): Amino acid interactions in chick nutrition. 2. Interrelationships between leucine, isoleucine and valine. Br. Poult. Sci. 11: 313-323.

D'MELLO, J.P.F. and D. LEWIS (1970b): Amino acid interactions in chick nutrition. 3. Interdependence in amino acid requirements. Br. Poult. Sci. 11: 367-385.

EKERMANS, L.G., K. STEENKAMP and I.C. SWARTS (2001): The response of chickens to increasing levels of valine. 13th Eur. Symp. Poult. Nutr. (Blankenberge, Belgium). Pages 294-295. Conference Proceeding.

FERNANDEZ, S.R., S. AOYAGI, Y. HAN, C.M. PARSONS and D.H. BAKER (1994): Limiting order of amino acids in corn and soybean meal for growth of the chick. Poult. Sci. 73: 1887-1896.

GfE (1999): Empfehlungen zur Energie- und Nährstoffversorgung der Legehennen und Masthühner (Broiler)/Ausschuss für Bedarfsnormen der Gesellschaft für Ernährungsphysiologie. DLG Verlag, Frankfurt am Main.

HALE, L.L., S.J. BARBER, A. CORZO and M.T. KIDD (2004): Isoleucine needs of thirty-to forty-two-old female chickens: growth and carcass responses. Poult. Sci. 83: 1986-1991.

LECLERQ, B. (1998): Specific effects of lysine on broiler production: comparison with threonine and valine. Poult. Sci. 77: 118-123.

MENDONCA C.X. Jr. and L.S. JENSEN (1989): Influence of valine level on performance of older broilers fed a low protein diet supplemented with amino acids. Nutr. Rep. Int. 40: 247-252.

SAUVANT, D., J.M. PEREZ and G. TRAN (2004): Tables of composition and nutritional value of feed materials. Wageningen Academic Publishers, INRA Editions and AFZ, Paris.

STILBORN, H.L., E.T. MORAN Jr., R.M. GOUS and M.D. HARRISON (1997): Effect of age on feather amino acid content in two broiler strain crosses and sexes. J. Appl. Poult. Res. 6: 205-209.

THORNTON, S.A., A. CORZO, G.T. PHARR, W.A. DOZIER III, D.M. MILES and M.T. KIDD (2006): Valine requirements for immune and growth responses in broilers from 3 to 6 weeks of age. Br. Poult. Sci. 47: 190-199.

WILTAFSKY, M.K., M.W. PFAFFL and X.F. ROTH (2010): The effects of branched-chain amino acid interactions on growth performance, blood metabolites, enzyme kinetics and transcriptomics in weaned pigs. Br. J. Nutr. 103: 964-976.

Corresponding author:

Dr. Jörg Bartelt
Lohmann Animal Health GmbH & Co. KG
P.O. Box 446
27454 Cuxhaven
Germany
joerg.bartelt@lohmann.de