POULTRY GENETICS 1950-1997: SOME UNEXPECTED SIDE EFFECTS

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Summary

While the world's poultry breeders have provided the commercial industry with products demonstrating consistently improved performance and efficiency over the past half-century, this has not come without cost in terms of side-effects. These include ascites, obesity, leg problems and immune response problems in meat stocks, and Marek's disease and calcium metabolism in layers. While these are clearly disadvantageous, it is proposed that they may have been inevitable, given the demands of industry for ever-more-productive commercial products. Correcting the problems is being actively addressed by breeders in the last decade of the 20th century but there is little assurance that further examples will be avoided, based on the extremely competitive nature of the breeding business.

I. INTRODUCTION

The application of population genetics to poultry breeding has made a huge contribution to the poultry industry during the past half-century. Once the initial work of pioneer animal breeders and geneticists like Hutt, Lush, Lamoreux and others was confirmed by practical experience, breeders were able to practice selection on a scientific basis with the reasonable expectation of consistent progress. This process was driven quickly by ferocious competition at the level of commercial producers of eggs, broilers and turkeys, and, latterly, ducks as well.

Breeders' horizons, however much they may have wished otherwise, were inevitably reduced to providing competitive stocks just for the next generation. They have never had the luxury of considering the long-term consequences of selection practices, even if these were predictable, due to the necessity of generating a continuously competitive product.

So it should not come as a surprise that some unexpected consequences have arisen as an indirect result of selection procedures which have been, at least in the case of meat chickens, more extreme than most of those used in fundamental research studies on which practical selection procedures were based. Whether these consequences could have been predicted is debatable: some of them may have been but, because of the competitive nature of the poultry breeding business, it is doubtful if predictions would have resulted in any change in breeding policy.

This is not intended as a criticism of the primary breeding industry: the point is that they had little choice in the breeding strategies in which they were involved. During the preparation of this paper, my attention was drawn to the book "Why Things Bite Back: Technology and the Revenge of Unintended Consequences" (Edward Tenner, Princeton Univ.) Although not quoting the poultry industry as one of his examples, which is small fry in the big technology picture, Tenner identifies the introduction of DDT as a widely used pesticide, and the introduction of the kudzu vine, now considered a weed but originally used as a soil conditioning aid, in the US.

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A further example of wisdom after the event, but valuable comment nevertheless, was that by Emmerson (1996), who urged caution in the adoption by the poultry meat industry of some of the products of molecular genetics research, and a holistic approach to future breeding developments.

II. MAREK'S DISEASE

The classic work of Hutt and Cole at Cornell showed that resistance and susceptibility to an infectious disease could be altered by genetic selection. Over a number of generations they developed lines C and K which were resistant, and line S which was susceptible, to the complex which they described as Leukosis. As it turned out these lines exhibited resistance and susceptibility to both Lymphoid Leukosis (LL) and Marek's Disease (MD), once the two were differentiated in the late 1960's. For a review of this work see Cole and Hutt (1973).

Cole subsequently developed lines N and P, which were respectively resistant and susceptible strictly to MD (Cole, 1968). This selection program was based on a progeny test in which pedigreed chicks were exposed to a virulent MD virus at an early age. All mortalities, and remaining birds surviving to 8 weeks of age, were examined for MD lesions, and parents selected based on these data. The lines became clearly differentiated after only two generations and, as a result, several primary breeders began to undertake modified programs based on Cole's results. These programs had to be carried out at remote locations to minimize risk to valuable pedigree stocks. Sibs of the selected stocks were exposed to MD and selection of relatives based on the response of the exposed individuals. Clearly, this was an extremely expensive proposition for the breeders and when effective vaccines became available at economic prices most of these programs were quickly abandoned. The cessation of selection probably happened before resistance was fully developed. Subsequent research which identified MHC loci associated with resistance to MD was also applied by some primary breeding companies. It was shown that Cole's N-line was almost homozygous for B21, the allele associated in many studies with high levels of resistance to MD. However, there are questions concerning these so-called "resistant alleles" and some stocks containing them have been found to be relatively susceptible to MD (Hartmann, 1996).

Subsequently, variant MD viruses have been identified to which the standard vaccines afford little protection. Recent experience at one commercial egg production unit in New York state serves as an example. While it can be argued that the particular production systems in use at this location (multiple ages; no biosecurity between flocks; pullets and layers in close proximity) might predispose any stock to infection there is good evidence (see Gavora, 1989) that genetically resistant stocks perform better in the face of field challenge. However, economic and competitive pressures ensured that once vaccines were available genetic resistance to MD had a much reduced priority in breeding programmes.

The long-term effects of the use of vaccines and/or development of genetically resistant stocks are hard to define. One view might be that without them the incidence of MD would be much higher. However, another view expressed by Gavora (1996, Personal Communication) is that the evolution and emergence of highly virulent MD viruses may be partly due to the greater resistance of the birds, brought about by a combination of genetic selection and the use of vaccines.

While the new, highly virulent, MD viruses are partly controllable by the use of polyvalent vaccines, this is an expensive process. The prospects of improved vaccines
developed with the aid of molecular genetics technology, or highly resistant chicken genotypes, seem equally remote today.

III. ASCITES

In older texts on poultry diseases, ascites is usually described as a condition restricted to high altitudes, resulting from reduced partial pressure of oxygen, leading to oxygen depletion in the birds.

In the past two decades ascites has been reported in high performance meat stocks at sea level. While still associated with oxygen demand the contemporary ascites is the result of excessive oxygen demand rather than diminished supply.

Julian (1995) has provided excellent documentation of the development and pathology of the modern condition and has described it as Pulmonary Hypertension Syndrome (PHS).

The phenomenon of extremely rapid growth, resulting from many generations of selection for growth, appetite and related traits, dramatically increases the demand for oxygen in the metabolic process. Rapid growth on its own may result in development of PHS but it will be aggravated by other factors such as low environmental temperature, sub-optimal air quality and/or ventilation and, of course, altitude.

There is good evidence of genetic variability in the incidence of PHS (Schlosberg et al., 1996; McKay, Personal Communication, 1996) so there is no reason why breeders should not produce PHS-resistant varieties and, indeed, most commercial breeders are presently practicing selection for just this objective. However, this will almost certainly be at the expense of further gains in growth since the PHS seems to be at least partly a consequence of rapid growth in the first place. In addition, PHS-resistant stocks may not be much of an advantage in areas where the condition is not a problem.

IV. OBESITY

For at least a quarter of a century, selection of meat chickens was based on mass selection with the primary criterion being weight-for-age or some variant. Secondary criteria included such traits as leg strength and body conformation. While some limited attention was paid to reproductive capability most gains were accomplished by environmental and nutritional manipulation.

In the early days of the broiler industry the vast majority of chickens were purchased whole by the consumer and abdominal fat could be easily hidden at point of sale. During the 1970's, it became apparent that the reputation of chicken as a low-fat meat choice could no longer be sustained as a generality. Large fat deposits in the subcutaneous and abdominal areas became obvious and were identified as an industry problem. The abdominal fat pad in particular was targeted for at least two reasons. First, it was clearly evident to consumers who purchased whole birds, since processors were at pains to leave as much fat with the carcass as possible to enhance "yield". Secondly, those customers purchasing cut-up chickens, primarily the fast food operations like KFC, declined to accept the abdominal fat pad as part of their purchase. Not only was it aesthetically undesirable but it also led to adulteration of cooking oil (largely unsaturated) with quantities of saturated fat with a consequent reduction in its "life".

Although body fat synthesis is "expensive" in terms of substrate required, it requires substantially less "effort" than synthesis of muscle protein. In many cases, dietary lipid becomes body lipid without degradation and re-synthesis. Since the substrates, feed
carbohydrate and fat, are limited only by appetite, those birds with the largest appetites could "afford" to lay down excessive fat in order to achieve the superior body weight demanded by the selection criteria.

During the 1970's and 1980's breeders began to address this problem in various ways. Substantial publicly funded research provided ample guidelines (e.g. Pym and Nicholls, 1979; Whitehead and Griffin, 1984; Leenstra and Pit, 1988a,b; Leenstra, 1988). The cost in nutrients meant that the most obese birds were also the least feed-efficient. So, fortuitously, breeder and consumer interests coincided and selection for improved feed efficiency and/or reduced obesity met the requirements of both parties.

However, selection for these new criteria demanded greatly increased cost and complexity in the selection programmes of meat breeders. To select for feed efficiency directly involves individual measurements of feed intake. Selection for reduced abdominal fat pad weight may involve the slaughter of subject birds and breeding from relatives. Both necessitate the use of partly or fully pedigreed populations which many breeders did not have in the period of mass selection based on weight-for-age.

V. THE "LAZY" IMMUNE SYSTEM

Cook (1996) proposed a challenging hypothesis: "Current selection for growth and feed efficiency invariably selects for immune suppression". Maatman et al. (1993) has shown that broilers tend to be less responsive to antigens than Leghorns and Siegel (1996) coined the term "Lazy Immune System" to describe the phenomenon. The apparent susceptibility of broiler chickens to a wide variety of relatively mild viral and bacterial infections lends support to Cook's hypothesis. Infections such as Infectious Bronchitis, Newcastle Disease, Infectious Laryngotracheitis and E.coli are examples. For most of them, the consequences in broilers are much more severe than in layer stocks in comparable conditions. In addition, broilers often respond relatively poorly to vaccines administered to protect them from these pathogens.

Cook bases his hypothesis on the environment in which selection takes place. Most primary breeders attempt to simulate commercial conditions, at least as far as stocking density and nutrition are concerned, for their selection environment. While they may go to considerable lengths to ensure absence of some pathogens like Mycoplasma, others are undoubtedly present. But the main danger, according to Cook, is the high concentration of endotoxins present as a consequence of the birds contact with faeces and litter, which are heavily laden with bacteria. The endotoxins may be ingested, inhaled, or enter via skin abrasions to cause immune stimulation. Cook states: "The bird that grows the best and converts feed most efficiently, and thus the bird selected for the breeding programme, is the bird least likely to have an immune response to the immune stimulants."

One of the main components of the immune system affected is macrophage number and effectiveness. Cook states that immunologists have great difficulty harvesting these cells from contemporary broilers. Considerable work by Klasing in California, Cook and associates in Wisconsin, and Siegel and associates in Virginia have demonstrated interactions between nutrition and the functioning of the immune system. To add a genetic component to this equation is a natural extension and methods must be found to include some criterion of immunological function in selection programmes. When these relationships become better understood there is good reason to anticipate that progress at the commercial level could become a reality.

However, this is another reminder to us of the warnings sounded by Tenner, that it will be unwise to regard even broad immunological criteria in isolation from the overall
"success" of the birds in evolutionary terms. Attempting to move too fast has, in the past, most likely disturbed both developmental and genetic homeostasis.

VI. LEG WEAKNESS IN CHICKENS AND TURKEYS

Dire warnings have been sounded for at least four decades that growing chickens and turkeys are becoming so heavy that their legs can no longer support their body mass. Body weights at slaughter, or at specific ages, for both species have at least doubled since serious selection began to be practiced on populations used in commercial industry. Accompanying these developments has been a steady increase in the numbers of lame and/or crippled birds, and this is amplified when, for example, broiler chickens are grown to roaster weights of 3.0 to 4.0 kg.

Breeders have always given attention to leg strength as a secondary selection criterion, usually in the form of an independent culling level. With chickens this has been important because among the breeding population natural mating must be accomplished and, while this does not apply to turkeys, selection has been undertaken strictly in order to prevent lameness. Nixey (Personal Communication, 1996) has observed that in his experience, although the modern turkey is no longer able to mate naturally, it is much more stable in terms of ability to maintain suitable posture than the contemporary chicken at an equivalent stage of development. Originally, most of the selection work aimed at leg strength and posture was undertaken by skilled handlers who were able to distinguish the desirable from the undesirable by direct observation. When the various forms of leg aberrations were distinguished more sophisticated means of identification became available. For example, the lixiscope, used by Ross Breeders, is able to identify early signs of tibial dyschondroplasia.

In view of the very large gains in body weight and the relatively low level of leg problems we may regard this as a qualified success story: things could have been a lot worse had it not been for the arduous work of the expert handlers who observed the early generations of chickens and turkeys.

VII. CALCIUM METABOLISM IN LAYERS

Today's layer yields over 20 kg of egg mass by 500 d of age. Of this, approximately 2.0 kg is egg shell comprising >90% calcium carbonate, slightly more than the hen's body weight. In addition to synthesizing approximately 5.0 g of calcium carbonate for each day's egg the hen must also maintain the integrity of a complex skeletal system. Failure of any component of the calcium metabolism or mobilization systems may result in poor egg shell quality, cage-layer fatigue (osteoporosis) or brittle bones, in a variety of combinations.

Selection for shell quality in layers has been directed mainly at egg shell thickness or at various indexes related to it, e.g. egg specific gravity, shell deformation, breaking strength. In addition, body weight has been reduced in order to achieve improved feed conversion efficiency. The skeleton has been ignored to a large extent. As egg yields continue to rise calcium demand for this alone increases proportionately and the risk of imbalance between dietary calcium, shell demand and skeletal demand also rises.

While this has not, at this point, resulted in long-term, insoluble problems, it represents an area in which future challenges lie.
VIII CONCLUSIONS

Commercial geneticists have wrought massive changes in the performances of laying hens, meat chickens and turkeys during the past half-century. Selection programmes are driven by the industry's insistence on continuous improvements in primary commercial traits like egg production and feed efficiency in layers, and rapid growth, body conformation and feed efficiency in meat birds.

Some of the side-effects might have been predicted, but commercial pressures may have limited the breeders' ability to respond until the effects became economically unacceptable. When this has occurred breeders have had to re-direct their selection strategies and, in most cases, add complexity to their programmes. Stocks have responded as desired but progress in the primary commercial traits will inevitably slow down. Some of the side-effects, for example the immune responsiveness of meat chickens, have yet to be addressed.

REFERENCES