Opportunities and Challenges for Application of Poultry Science and Technology into the 21st Century[1]

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SUMMARY

Prospects are briefly reviewed for further advances in current poultry industry technology in the foreseeable future. It is concluded that in the most advanced industries progress should continue at a similar rate to the recent past in conventional genetics and breeding, nutrition and disease control. Significant benefits will also follow in the short-term from the application of molecular biotechnology to disease diagnosis and vaccine production. Technical advances now make it possible to produce transgenic chickens at acceptable success rates but applications of this technology to poultry breeding will not become significant till we have sufficient knowledge of the poultry genome, and especially the genes involved in production performance. For the undeveloped and less advanced industries it is argued that the level of advanced technologies to be implemented in those countries should be decided largely on market forces, informed by objective assessment of the diverse options available. The need for urgent international action on conservation of poultry genetic resources is also stressed.

I. INTRODUCTION

Before future prospects are considered it is necessary to comment briefly on the current poultry industry situation, which varies widely between regions and coutries, not least among those covered by the Federation of Far East and South Pacific Branches of the World's Poultry Science Association.

The so-called most advanced poultry industries of the revolution in the application of new knowledge in poultry science and technology, which began in the USA in the 1940's. Several countries in western Europe, as well as Australia, Canada, Israel, Japan, Korea and South Africa, quickly followed the USA lead in the 1950's and 60's and have continued to contribute to the growth of knowledge feeding the further development of poultry industry technology. Since the 1960's most other countries have developed a modern poultry industry of some kind but the modern component varies widely between countries in stage of advancement, and in size relative to their poultry production from less advanced technologies.

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The main driving force of this revolution has been the efficient application of quantitative genetics methods to poultry breeding for either egg or meat production. Thus the best current commercial layer strains produce twice as many(approx. 300) eggs of acceptable size and quality per bird in the pullet laying year as their pure breed counterparts of the 1940's and 1950's. Similarly the best commercial meat strains now reach an average slaughter weight of 2 kg at about 6 weeks of age with a feed conversion ratio(FCR) of less than 1.9 compared with over 13~14 weeks and over 3.0 for the same variables characteristic of the meat chickens of 40~50 years ago. While the revolution has been driven mainly by improvements in genetic potential of available strains, these performance levels could not be sustained at acceptable levels of cost without the very significant, concomitant progress in disease control, nutrition, husbandry and flock management systems, including those made possible by developments in electronics and information technology.

The current level of adoption of advanced poultry technology varies widely between countries. At some risk of over-simplifying the real situation we can consider the following categories of countries whose total national poultry production is supplied by production units utilizing predominantly the currently available advanced technology in the following proportions:

1. 100% 2. 50~100% 3. 25~50% 4. 0~25%

Clearly the opportunities and challenges facing countries and industries in these different categories vary enormously. All categories are represented in the Federation region.

Category 1 has two components, those which do primary breeding by application of modern quantiative genetics techniques and those which do not. The former includes less than 10 countries which supply most of the international market in breeding stock, as well as several countries which produce internationally competitive strains but do not market them internationally. Those which do not have a competitive primary breeding industry rely almost completely on the international suppliers for their breeding stock either as grandparents or parents of their commercial crossbreds. The "deficits" in categories 2 to 4 can be due either to the proportion of total poultry production which still comes from so-called pre-modern, extensive, small-scale or even village production units, or to the degree to which attempted application of modern technology is less than complete, or to a mixture of both. Full application of modern technology is taken to include the use of internationally competitive commercial strains.

While the full application of currently available advanced technologies will be a desirable goal in many situations because of the favorable benefit/cost ratio in providing increased levels of animal proteins in this way, it should be stressed that merely closing the gap to bring them to Category 1 level is not the only opportunity and challenge worth pursuing by the countries in categories 2 to 4. Examples of alternatives will be given in the following review. Before dealing with these less developed industries, however, I shall attempt to predict what further progress can be expected in the most advanced industries in the foreseeable future.

II. PROSPECTS FOR FURTHER PROGRESS IN ADVANCED INDUSTRIES

Conventional Genetics - Eggs

The conventional wisdom for some 40 years has been that the limit to genetic improvement in egg production in a normal 24 h light cycle would be one ovulation and egg per 24 h(Fairfull and Gowe, 1990; Sheldon and Yoo, 1992). With production in the best commercial strains now averaging about 300 eggs per bird in the pullet year this limit, operating at peak of lay, would appear to be imminent. Nevertheless, while it is clear that responses to convintional selection have decreased significantly, a further increase to 320~325 eggs per bird is possible but it will take between 20 aand 40 generations to achieve (Sheldon and Yoo, 1993). However, it is possible to overcome this limit in 24 h light cycles by selecting for interval between eggs in continuous light(Sheldon and Yoo, 1992). The response in rate of lay in 24 h cycles using this approach should be twice as fast in the next 20~40 years as the attenuated response that would result from the conventional approach(Sheldon and Yoo, 1993). After that time further response should still be possible from the continuous light approach while the conventional approach should have reached its limit. In addition the rate of lay in such strains can be maximised by using an appropriate ahemeral cycle less than 24 h for the production environment, subject to related problems of low egg size being corrected. It appears therefore that genetic improvement in egg production should be able to continue for the foreseeable future at a similar rate to that achived in the recent past. At present, however, there is little evidence that the new approach of selection in continuous light or in ahemeral cycles is being used yet by the breeding companies.

Conventional Genetics - Meat

No evidence has been reported suggesting that the long-continued response to selection for early growth rate has reached its limit. Further response in growth rate can therefore be expected but at a much slower rate as more of the available selection pressure is used to improve leanness of carcass, efficiency of feed utilisation, meat yield, incidence of skeletal abnormalities and reproductive performance(Pym, 1993). In relation to these breeding goals Leenstra(1993) emphasises the importance of reducing the increasingly important waste disposal problem by increasing overall biological efficiency, including reduction of mortality from all causes. She further considers that improving both product quality, including reductions in medication levels, and animal welfare aspects, may require genotype-environment interactions to be reconsidered, becuse of a need to adapt breeding stock to the local environment in regard to husbandry or product specification. While these integrated breeding goals will become more complex, it is clear that they will continue to deliver steady increases in the economic efficiency of poultry meat production well into the next century.

Molecular Genetics

Without doubt this is the most exciting and fastest developing area of poultry science and technology, and the one with the greatest potential for revolutionary advances in productive manipulation of the genome of poultry and other avian species. At the last Federation conference I reviewed the rapid advances in molecular biotechnology generally and its potential applications in poultry(Sheldon, 1990). Since then very significant progress has been made in the two fields of poultry gene mapping and techniques for producing transgenic chickens.

In 1992 the first poultry linkage map of 100 autosomal molecular marker genes was published by Bumstead and Palyga(1993) and this year the first Z linked map of 13 molecular markers was reported(Levin *et al.*, 1993). The first International Workshop on Mapping the Poultry Genome was held in 1992. Some 20 laboratories around the world are now involved in an agreed international collaborative program to develop the map of the poultry genome as quickly as possible. It is highly likely that within the next year or two a consensus map having 200~400 molecular markers at 10~20 centiMorgan intervals will be available. This will facilitate locating known poultry genes on the map and their subsequent study and manipulation. More importantly it will enable the detection, location and eventual manipulation of so-called quantitative trait gene loci with significant effects on poultry production performace. Sheldon and Yoo(1993) and Tixier-Boichard(1993) have recently reviewed this subject.

Prospects for producing transgenic chickens have been dependent on the development of gene transfer techniques suitable to poultry. Recent progress in key areas has ensured that routine production of transgenic chickens is now feasible. Naito(1993) has reviewed the significant improvement in the Perry embryo culture technique, the evidence for successful gene transfer without using retroviral vectors, i.e. by direct injection of exogenous DNA into the fertilised ovum or by transfer of blastoderm cells, and possibilities for use of pimordial germ cells for this purpose. Carsience *et al.*(1993) have also recently reported a very significant improvement in the success rate for gene transfer by the blastoderm cell transfer method. In addition some progress is being made in my laboratory and by others in developing a chicken embryo stem cell system which is the preferred method for manipulation and transfer of DNA. While the routine production of transgenic chickens is now feasible we still lack knowledge of the relevant genes affecting prouction traits which would be the main candidates for gene transfer. This knowledge will come from gene mapping and related programs of research. The time scale for full productive application of this technology thus extends beyond the end of this decade and well into the 21st century.

Nutrition

Steady advances will continue in future in the mainstream areas of nutrition research such as macro- and miciro-nutrient requirements for egg or meat production, techniques for measuring true nutritive value of feed ingredients or complete feeds, evaluation of potential alternative feed ingredients, refinement of restricive feeding regimes for broiler breeder or layer performance, and interaction of feed ingredients with quality of end product. The main potential for more significant advances in application of nutritional technology would appear to depend on developing a much more substantial base of knowledge on the nutritional biochemistry and physiology of growth and reproduction in the chicken. These aspects of basic research have tended to be neglected in the past relative to empirical, applied research and the current climate for research funding in most of the world does not favour such basic work. Therfore, the knowledge gap will not be corrected sufficiently untill well beyond the year 2000. The challenge is to emphasise these areas of basic work now and to generate the national, regional and other international collaborations necessary to solve specific problems.

In the meantime, several areas of applied research, will provide opportunities for profitable industry application especially if they are given more attention than in the past. The first and probably most neglected area is that of defining specific nutrient requirements for specific commercial strains of layer or meat chickens. The concept of setting nutrient requirements for a small set of standard genotypes has always had its inherent difficulties. In addition the current commercial genotypes are quite different from those used to define most of the nutritional standards now in use. As this dynamic situation of changing genotypes is sure to continue indefinitely into the future the question will need continuous attention. At present the literature does not give a clear indication even of the magnitude of the problem, which Gous(1993) has recently discussed in relation to the use of simulation modelling for estimating the nutritional requirements of broilers.

A second area, the search for alternative and cheaper feed ingredients, will assume greater importance as the competition between human and animal use for certain ingredients, mainly grains, inevitably becomes more intense. This is expected to become a serious problem even for most of the present Category 1 countries which can supply all or most of their own poultry industry feed requirements. It will be more seious for countries in any category which have to import their poultry feed ingredients and probably worse for those which have to import both human and animal feeds. It will be exacerbated of course for these importing countries as they seek to lift the proportion of their poultry production which is supplied by a fully-developed modern industry. Market forces will no doubt largely determine the rate of change to alternative feed ingredients and indeed when it will be more appropriate for an importer of poultry feed ingredients to import the final poultry product instead. Ample opportunities exist for development of optimal regional or wider international marketing arrangements providing they are not bedevilled by government or other subsidies.

A third area which has been receiving considerable attention in recent years and seems to have much more potential for application in the futrue is the use of specific feed additives (mostly enzymes at present) to improve the utilisation of particular feed ingredients(e.g. Wiseman, 1992;Inborr *et al.*, 1993;Martin and Farrell, 1993).

Disease Control

The genetic potential for performance of poultry strains kept under current intensive housing systems cannot be realised without the complex of disease control measures, mainly vaccination, developed over the past 50 years. The poultry diseases situation will continue to be an extremely dynamic one. New infectious diseases or more virulent strains of exsting diseases will continue to emerge and new genotypes often prove to be more susceptible to new or pre-existing disease conditions e.g. ascites or skeletal abnormalities in modern broiler strains. Fletcher(1988) has reviewed the problem of emerging diseases in the fully developed poultry industries which exist mainly in cold or temperate climates, while Sheldon and Gilchrist(1992) dealt with it in relation to hot climates.

Conventional approaches to the investigation of existing or emerging poultry diseases, and subsequent provision of adequate control methods, mainly vaccines, would have continued to provide the efficient protection which the future developed industry requires, as in the past. However, the new molecular biology and recombinant DNA technology, referred to above in relation to gene mapping and transgenic chickens, has opened the way to development of much more accurate and more rapid diagnostic procedures as well as more efficient and safer vaccines. Significant poultry industry applications were already beginning to flow from this approach some years ago(Sheldon, 1990), and Gavora(1992) has given some more recent examples. Thus more efficient disease diagnosis and control by vaccines are now assured, and this will occur in the immediate future. Ultimately control of poultry diseases will also be assisted by molecular transfer of genes for disease resistance. While we have slightly more information on potential candidate genes for such manipulation than we do on genes for egg or meat production(Gavora,1992;Kuhnlein and Zadworny, 1993), the time scale for widespread industry applications is similarly well into the 21st century rather than in the next 7 years. In the meantime direct selection for immune response or marker assisted selection, utilising molecular markers or known genes associated with disease resistance, i.e. in conventional breeding programs, has more prospect for application in the short term(Gavora, 1992; Abplanalp, 1993;Hartmann, 1993).

Animal Welfare

One of the most serious challenges that the developed industries, at least in Western Europe, North America and Australasia will continue to face will be the pressures arising from changing community attitudes to animal welfare. Because of limitations of time and space I cannot review these issues in any detail here. Even in the most affected countries it seems unlikely that the most extreme philosophical views on animal rights and animal liberation will become accepted by the general population. Nevertheless, poultry scientists and technologists should continue to seek objective, scientific measures of stress and relevant behavioural traits. These can then be applied to poultry kept under current or proposed systems of housing and husbandry. More importantly poultry scientists should insist that the public debate on poultry welfare must be conducted as objectively as possible, i.e., relying on scientific knowledge where it is available but recognising where such knowledge still needs to be obtained before objective recommendations and decisions can be made. An increase in basic and applied research on poultry behaviour and welfare is clearly necessary if objective answers to many current welfare questions are to be obtained in the next 10~20 years.

The Challenge of Genetic Resources Conservation

The adverse impact of implementation of modern poultry breeding technology on conservation of poultry genetic resources has been evident virtually from the beginning. Serious concern has been expressed by many people in many countries over some 30 years now and some attempts made to correct the situation (Sheldon *et al.*, 1979; Sheldon, 1981a,b) but without any real success so far(Crawford, 1993).

The worst aspects of the problem occur in the Category 1 countries in which the effective number of primary breeders of commercial poultry has been reduced by a factor of 20 or more, and in countries importing all their breeding stock reduced to virtually zero. For example in Australia in the early 1950's there were some 200 independent breeders and hatcherymen. By the early 1960's about 10 Australian breeding companies were supplying almost the whole Australian market and by 1990 there were effectively only 4. By this year the effective number was still less, as 3 of the 4 took advantage of the new opportunity to import breeding stock from the main international breeding companies. The impact of this trend throughout the world on loss of poultry genetic material in Category 1 countries has had two main components, Firstly, the immense gene pool of all the unimproved historic breeds previously used to supply the egg and poultry meat markets was drastically reduced. However, the size of the world, even national, gene pools of these breeds still tend to be maintained at satisfactory levels for most breeds by the activities of many small-scale hobby or fancier breeders, in spite of the reduction in the numbers of such people in modern urbanised societies. The second component is much more serious, i.e., the irretrivable loss of very large numbers, perhaps the majority, of improved modern strains of poultry as a result of the continuing contraction of the effective number of breeding companies to very small numbers. Such a waste of resources that may have taken up to 40 generations of costly selection to develop is very difficult to justify by any criterion. The problem is compounded by frequent loss of similar selection or other genetic research material from research institutions as funding for their maintenance is withdrawn. Breeding companies and national governments have so far generally tended to deny that they have any responsibility in this matter. As a result of the efforts of a few concerned individuals the United Nations Food and Agriculture Organization(FAO) is only now starting to develop a global inventory of poultry genetic stocks(Crawford, 1993). But urgent conservation action for much of the above material has been needed throughout the past 30~40 years. Unless such action can be generated urgently through regional and broader international collaborations, i.e., in advance of FAO survey results and any follow-up action, these wasteful and avoidable losses will continue.

Ⅲ. PROSPECTS FOR PROGRESS IN LESS DEVELOPED INDUSTRIES

As indicated in the foregoing the advanced industries involve a complex interaction of advanced technology in genetics and breeding, nutrition and feeding, husbandry and flock management, and disease control. To these can be added quality control of the end products being marketed. The prospects for futrue progress across this complex of technologies are predictably as good for the immediate future as in the recent past. Therefore the present gap between the advanced and undeveloped or indigenous industries is almost certain to become larger. If closing the gap to convert the undeveloped industries in Category 2~4 countries above to advanced industry status as soon as possible were clearly the preferred goal, this forecast would make the task more difficult and more costly. The bigger the gap the bigger the problem would be(Category 4).

Fortunately the poultry industry situation in these countries is much more dynamic than this scenario, with many diverse options still to be explored and developed. This certainly applies to Category 2~4 countries. Even Catgory 1 countries may still have alternative options worth exploring. A few examples will suffice to demonstrate that potential diversity may be more a stregth than a weakness.

The modern advanced poultry industries are highly productive but also relatively high cost on most components of the technology, i.e. genetic strain, vaccines, quality feed, housing. They are, however, less labour intensive, though the level of technical skill required is higher. Overall the relative cost of the labour component is probably lower than in less intensive, less developed industries with their much smaller production units. This factor is a big advantage in the advanced industries of high labour cost countreis but not an important disadvantage in the undeveloped industries of lower labour cost countries. Therefore the overall higher costs of a higher technology industry will be a positive deterrent to converting to it from an undeveloped industry, unless the market price of the product is sufficient to yield a net profit on the operation. In practice then decisions on the level of technology to develop will depend on economic and market factors in the particular country or even region within a country.

At one extreme the national economic and social cirumstances might favour opting for the advanced industry completely. At the other extreme they might dictate staying with an undeveloped, indigenous industry. In theory a more or less continous range of combinations of levels of technology for the different components is possible. In practice the range will be more restricted. For example it is unlikely that an internationally competitive genetic strain would ever be farmed under village conditions or that a strain of village chickens would be farmed under all the high technology conditions of the advanced industries. However, it is clear that many genotypes between these two extremes can be produced or are already available, and have the potential for good productivity because of their better suitability to the local environment, including feeds, heat tolerance, disease restistance and consumer preference(Lee, 1990 ; Mukherjee, 1990). More research in this aspect should be encouraged including regional collaboration where appropriate. Of similar importance are attempts to develop feasible and effecive vaccine delivery systems for village chickens especially for Newcastle disease. The collaborative work in this area between Australia and Malaysia is an excellent example of effective regional collaboration on an important problem. Regardless of the genotype being used, or levels of feeding and housing, the availability of less expensive but effective vaccines is an essential requirement for the furher development of all poultry industries. The application of molecular biotechnology referred to earlier will be a major factor in meeting this objective. Again the recent collaboration between Australia and China in developing specific pathogen free poultry facilites and modern poultry disease diagnostic facilites in China is a good example of what can be achieved by regional collaboration.

Providing quality feeds at less cost will be a continuing problem for the countries in Categories 2~4, for both the advanced and less developed components of their poultry industries. The search for and use of alternative feed ingredients is even more important here because of the need to avoid having to import many of the costly, standard feed ingredients used by the advanced industries in Category 1 countries. While much work has been done already it will need to be intensified for the indefinite future if all the people of these countries are to have access to desirable levels of animal protein in the form of eggs and poultry meat. A further area requiring continuing research and development is the provision of local housing systems at lower capital cost and more suitable to both local conditions, including climate, and the poultry genotypes being used.

The opportunities for improving poultry productivity in countries with less advanced industies at present are clearly as diverse as the countries themselves. The challenge for each country will coutinue to revolve around finding the best balance of technologies which will enable the optimum utilisation of national human and other resources. If they can achieve this, and are assisted in it by regional and international collaboration, the world will be richer for the diversity retained, the increased production gained, and the lessons learned in the process. In addition, to end with a geneticist's viewpoint, the cause of conservation of the world gene pool of poultry genetic resources will have been promoted very significantly.

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