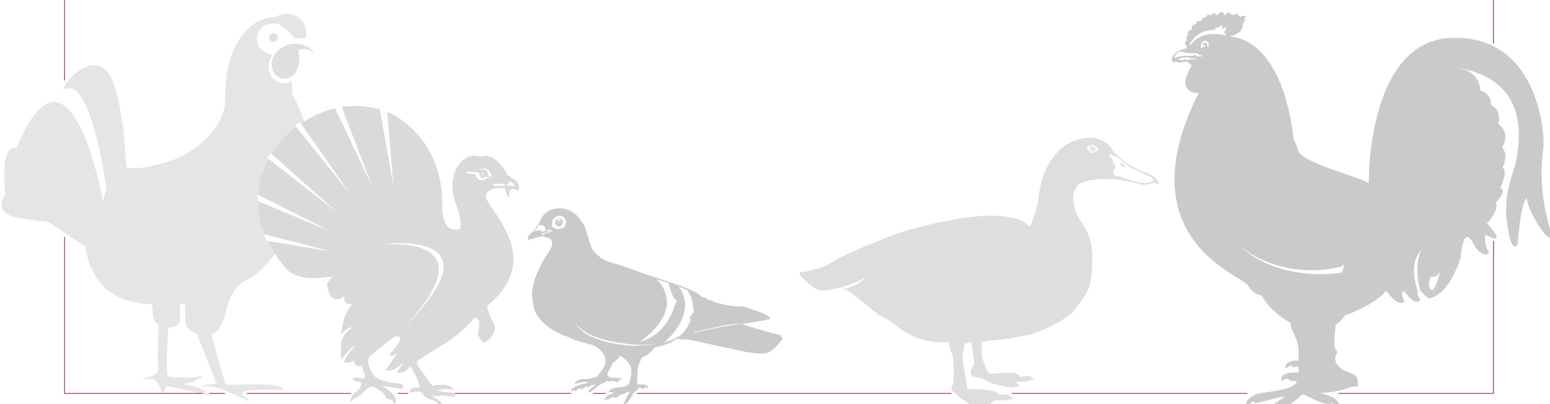
Poultry genetics and breeding in developing countries



Poultry genetics and breeding in developing countries

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DISTRIBUTION, MANAGEMENT AND PRODUCTIVITY OF POULTRY GENOTYPES

In most developing countries, there are two parallel poultry industries: one using high-performing commercial layer or broiler genotypes; and the other based on lower-performing, dual-purpose indigenous breeds.

The proportions in these two categories vary widely among countries, but in lower-income countries, indigenous stock comprises as much as 90 percent of the poultry population (Pym, Guerne Bleich and Hoffmann, 2006).

The critical distinction between the two forms of production relates to management: commercial stock are generally reared in confinement and housed in flocks ranging from 100 to 200 birds (small) to more than 10 000 birds (large). The birds are usually given compounded feeds, and the larger facilities are normally located close to urban areas. Indigenous stock are typically kept by families in rural and sometimes peri-urban areas, in small semi-scavenging flocks of ten to 30 birds, which are fed with household scraps and small amounts of other feed. Women and children are usually responsible for managing family flocks (Sonaiya, Branckaert and Gueye, 1999).

Performance differences between the genotypes are often very large.

Commercial layers developed from imported parent stock have the capacity to lay more than 300 eggs per year, while indigenous hens often lay only 40 to 60 eggs per year (Sørensen, in FAO, 2010). As well as the large difference in genetic potential to produce eggs, a very significant cause of the five- to eightfold difference in annual egg production is the time – 17 weeks – that a broody indigenous hen spends hatching a clutch of eggs and rearing the chicks to about seven weeks of age. During this time, she does not lay, which shortens the remaining time available for further egg production and means that she can produce only about 3.5 clutches per year.

Quantity and quality of feed is another significant factor in the disparity in annual egg production between the two genotypes. Commercial genotypes are normally provided with carefully compounded feeds, which include nutrients in the correct proportions for maximizing egg production. They are usually also fed *ad libitum*. The energy and protein intake of indigenous birds in scavenging flocks is determined by the scavenging feed resource base, and is usually quite limited, particularly in the dry season.

To maximize egg production, the capacity for broodiness has been bred out of commercial-strain layer hens. They are therefore incapable of natural reproduction, and their value in a village environment is thus quite limited.

The growth rate of indigenous genotype chickens is also generally much slower than that of commercial broilers. While broilers under typical confinement rearing may reach 2.0 kg live weight at five weeks of age, indigenous-breed male birds often weigh no more than 1.0 kg at 20 weeks (Sørensen, in FAO, 2010). This is a reflection of true genotype differences, but also of rearing environment, in which feed quantity and quality is the major factor.

Despite their lower productivity, in the village environment, the indigenous genotype birds have a number of advantages:

- The hens become broody, so can reproduce without the need for artificial incubation and brooding.
- They are agile and can run fast, fly and roost in trees, so can escape predators.
- They have been shown to be more resistant to bacterial and protozoan diseases and to parasitic infestations than commercial broilers or layers are.
- Their meat and eggs are generally preferred to those from commercial birds, not only by rural communities but also often by urban dwellers.

COMMERCIAL SELECTION FOR MEAT AND EGG PRODUCTION

The dramatic gains in poultry meat and egg production from individual birds in commercial flocks over the past 50 years are largely due to genetic selection in the nucleus breeding flocks of large global poultry breeding companies and the rapid transfer of these gains to the commercial cross-bred progeny.

This has been facilitated by high reproductive rates, short generation intervals, reduced environmental variation, large population sizes to minimize the detrimental effects of inbreeding, and the use of several differentially selected sire and dam lines.

To date, much of the improvement in performance has been derived from the application of quantitative genetic selection, with limited use of molecular technologies.

The large majority of commercial broilers and layers in developing countries have been produced from imported grandparent or parent stock originating from large global breeding companies. There are also a few smaller breeding operations that supply stock to regional markets.

Broilers

The continued annual productivity gains of commercial broiler flocks are a reflection of the complex and coordinated approach adopted by breeders to maximize performance. Breeders have selected for such traits as growth rate, breast meat yield, food utilization efficiency, skeletal quality, heart and lung function, and livability. This has had considerable positive effects on bird welfare, as well as on the environmental impact of production.

Over the past 30 years or so, genetic selection for growth rate, feed efficiency, yield and livability is estimated to have reduced the feed required to produce 1 tonne of chicken meat from 20 to 8.5 tonnes, a 2.4-fold reduction (McKay, 2008). ***This has had profound positive impacts on the environment and on the availability and cost of poultry meat to the human population.***

Breeders continue to pay attention to growth, feed efficiency, meat yield, skeletal quality, general robustness and disease resistance.

Layers

In commercial flocks, egg number, size, shell and internal quality, and layer livability, persistency of production and feed efficiency continue to improve, owing to ongoing selection for these and correlated traits.

Current average annual egg production is well in excess of 300 eggs per hen, and continues to increase by more than one egg/hen/year, while the annual feed requirement for producing 300 eggs is declining by about 200 g/hen. With some 6 billion layer hens worldwide, this translates into savings of more than 1 million tonnes of feed per year.

At present, layer breeding programmes focus on robustness and disease resistance, as reflected in significant improvements in livability and welfare. Considerable attention is also given to uniform size and colour of eggs and to freedom from shell and internal defects.

Both broiler and egg breeding programmes are now concentrating on molecular marker-assisted selection (genomics). This approach provides a means of identifying and selecting for or against the genes affecting production traits, particularly those that are difficult to measure, and for the genes affecting disease resistance.

GENETIC APPROACHES TO IMPROVED PERFORMANCE IN SUB-OPTIMAL CONDITIONS

The non-genetic factors mitigating against good performance from poultry in developing countries typically include:

- high temperatures;
- sub-optimal nutrition;
- increased disease challenge;
- sub-optimal housing and management conditions.

All genotypes are affected by these factors. Alongside efforts to improve the physical environment, possible genetic approaches include:

- selection in commercial genotypes for improved tolerance to prevailing conditions;
- cross-breeding between commercial and indigenous genotypes;
- introgression of genes from commercial genotypes, via back-crossing or cockerel exchange programmes;
- selection for improved performance in indigenous genotypes.

Selection in commercial genotypes

The genetic stock from which the large majority of commercial broilers and layers in developing countries are derived was selected for production under relatively ideal management conditions in temperate climates. Little if any emphasis has been given to tolerance to high temperatures or to sub-optimal management and feeding conditions.

High ambient temperature is probably the main factor limiting the performance of commercial broilers and layers in medium to large-scale production units in tropical developing countries. Other factors can be addressed at moderate cost by establishing appropriate management strategies, but the cost of facilities and the availability of a secure and reliable electricity supply make shed cooling problematic.

A relatively simple approach to improving heat tolerance in commercial stock, without having to develop separate full selection lines, is to incorporate single genes affecting feather cover into the parent lines of stock to be used in high-temperature regions. Reduced feather cover facilitates loss of body heat. Genes shown to be effective in conferring heat tolerance include naked neck *(Na),* scaleless *(sc)* and frizzle *(F)* (Cahaner *et al*., 2008). Commercial lines that express some of these genes are now available in some countries.

Irrespective of selection for heat tolerance, commercial broiler and layer genotypes require good management and feeding to realize their genetic potential for meat or egg production. They are not capable of good performance under semi-scavenging village conditions.

Several approaches have been used in efforts to incorporate the genes associated with superior egg and meat production in commercial strains into stock intended for use in less optimal environments. Such environments range from semi-scavenging village production systems, where virtually the only inputs are household scraps, through small-scale to medium-scale commercial operations, where birds are confinement-reared and fed with compounded diets, but are exposed to high ambient temperatures.

Cross-breeding

In many regions, local indigenous and commercial genotypes have been crossed in attempts to provide birds that are tolerant to local conditions while also capable of reasonable performance. In nearly all cross-breeding programmes, the cross-bred bird exhibits considerably better egg production and/or growth rate than the indigenous breed parent, but problems can be encountered with:

- loss of broodiness in hens, making them incapable of reproducing naturally;
- the need for maintaining separate parent lines/breeds and for the annual replacement of F1 cross-bred chicks;
- the need for additional inputs (particularly feed) to achieve the birds’ genetic potential for production;
- a change in appearance and “type”, which affects the birds’ acceptability to farmers and the consumers of poultry eggs and meat;
- erosion of the genetic resource.

Introgression and cockerel exchange

Another strategy for improving the performance of local populations is through introgression of genetic material. This can be achieved though back-crossing or cockerel exchange programmes.

Experience has shown that for a back-crossing programme to be sustainable, increasing levels of supplementary feed and improved management and disease control are required as the frequency of exotic genes increases. Cockerel exchange programmes involve distributing cocks of improved breeds to smallholders. However, several reports have concluded that this type of improvement has not changed the basic populations, except for contributing to a larger variation in plumage colour (Besbes, 2008).

Selection within indigenous breeds

Selection for improved production within indigenous breeds or ecotypes is problematic for the following reasons:

- Effective selection depends on accurate recording of pedigree and performance.
- All birds should be subject to similar environmental variation.
- Egg production under cage confinement may be poorly correlated with reproductive performance under semi-scavenging conditions.
- The components of reproduction under semi-scavenging conditions are very complex, making selection under these conditions exceedingly difficult.

Despite considerable genetic variation in most indigenous breeds for egg and meat production, the complexity of the production system and of the desirable traits presents considerable obstacles to effective selection for improved performance. There are examples where performance has been improved through this approach, but they are few and the gains have been modest (Sørensen, in FAO, 2010).

GENETIC DIVERSITY AND CONSERVATION OF GENETIC RESOURCES

There is widespread concern in developing countries that as a result of replacement of low-producing breeds, urbanization, crossbreeding and the stamping out of flocks in response to outbreaks of disease, the world is losing valuable and irreplaceable poultry genetic material.

Concerns about a loss in genetic variability in commercial poultry strains have also been voiced following dramatic global reductions in the number of commercial poultry breeders and the number of populations under selection over the last 20 years (Arthur and Albers, 2003). ***A major concern is that the reduced genetic variability could place the industry in jeopardy in the event of a major disease outbreak involving new virus strains.***

The State of the World's Animal Genetic Resources, *published by FAO, found that of 2 000 avian breeds for which data were available, 30 percent were reported at risk, 35 percent not at risk, and the remainder were of unknown risk status* (Hoffmann, 2008).

In the past, genetic diversity was largely determined by phenotype. Recently, DNA analysis has provided an invaluable new technology for determining the relationships among individuals, breeds and ecotypes. Clustering methods using microsatellite markers have been effectively applied to assign individuals to their breed of origin, and to determine the degree of genetic diversity between populations.

Recent studies have shown a large range of within-breed or ecotype heterozygosities, of 28 percent for a fancy breed, 40 percent for white-egg layers, 45 to 50 percent for brown-egg layers, 50 to 63 percent for broilers, and 67 percent for a population of village chickens (Tixier-Boichard, Bordas and Rognon, 2008).

Studies in Africa have suggested that village chickens do not seem to exhibit a typical breed structure. While there is a high degree of between-bird variation in a village, differentiation between populations is observed only among those separated by large geographical distances. There is therefore considerable exchange of birds among adjacent villages. This suggests that many countries' claims to have a significant number of breeds or ecotypes of indigenous village-type chickens in a region may well be found by molecular measures to be based on a minimal degree of genetic diversity.

An integrated approach to breed characterization is required, and data on production systems, phenotypes and molecular markers should be combined to facilitate this. A comprehensive description of production environments is needed, to improve understanding of the comparative adaptive fitness of specific animal genetic resources.

The characterization of defence mechanisms against pathogens should be a priority, given the significance of the threats posed by epizootics and climate change. Field and on-station phenotypic characterization is therefore highly desirable.

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Contribution of indigenous genotypes to production and consumption of poultry meat and eggs

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LOCATION AND DISTRIBUTION OF INDIGENOUS BIRDS

Despite the lower productivity of indigenous poultry genotypes compared with that of commercial strains, indigenous genotypes still comprise a large proportion of the overall poultry population in many developing countries, frequently in excess of 80 percent. In rural villages in most countries, the majority of families have small flocks of poultry, mainly chickens but sometimes other species including ducks, turkeys and guinea fowls, which provide family needs for poultry meat and eggs. These birds are invariably indigenous genotypes, or cross-breeds with a significant indigenous genotype component.

Because chickens account for more than 90 percent of the total poultry population in most countries, and because only limited information on other poultry species is available, the following discussion focuses on chickens.

In most countries, flocks of indigenous breed birds are not found in significant numbers in urban or peri-urban areas, owing to the lack of scavenging opportunities. In some countries, there are restrictions on small-scale scavenging flocks in urban and peri-urban areas, because of the risk of disease transmission (particularly HPAI) to the human population and to commercial poultry flocks.

THE RETENTION OF INDIGENOUS POULTRY BREEDS

Their low productivity raises the question as to why indigenous chicken genotypes in rural regions have not been replaced by commercial genotypes. There are several reasons for this:

- Most indigenous genotypes still go broody, and can thus hatch their own eggs without recourse to artificial incubation and hatching, which are necessary for nearly all commercial genotypes.
- Most indigenous breed hens have strong mothering instincts and rear their young up to an age when they can fend for themselves under a scavenging management system.
- Most indigenous chicken genotypes are light-bodied, alert and can run fast and fly. They are thus more able to escape from predators than commercial genotypes, particularly meat chickens.
- In most countries, the meat and eggs from indigenous genotypes are generally preferred to those from commercial broilers and layers, not only by rural but also often by urban dwellers, who will pay a premium for these products.
- Indigenous genotypes have been shown to be more heat-tolerant and resistant to bacterial and protozoan diseases and parasitic infestations than commercial broilers or layers.
- Commercial broilers and layers perform far less well under scavenging than under commercial confinement rearing and feeding conditions. This poor performance and the cost of chicks make it uneconomic to rear commercial broilers under scavenging conditions.
- Although most regions have significant numbers of sector 3 small-scale commercial confinement rearing and feeding operations with broilers or layers, the cost and risk associated with setting up and operating such enterprises are prohibitive for most poor rural families.

The performance of indigenous genotypes improves under commercial confinement rearing and feeding conditions, but generally not to an extent that makes production economically viable, mainly owing to the cost of compounded feed. However, if the premium paid for eggs and meat is sufficiently high, this form of management in medium-sized units can be justified. This is to some extent self-limiting, because if the market is flooded with indigenous meat and eggs, the premium paid for them will fall.

CONTRIBUTION TO DOMESTIC PRODUCTION AND CONSUMPTION OF CHICKEN MEAT AND EGGS

The poor productivity of indigenous birds means that their total contribution to poultry meat and egg production and consumption is considerably lower than their numerical contribution to the overall poultry population. However, because of their large numbers, their estimated contribution to meat consumption can be quite high in many countries (Pym, Guerne Bleich and Hoffmann, 2006).

Based on published reports of flock structures, productivity and egg management in several countries, a study to estimate indigenous chickens' contribution to the overall consumption of chicken meat and eggs found that in countries where indigenous birds comprised about 80 percent of the total chicken population, adult indigenous breed hens accounted for about 20 percent of the total chicken population The study assumed that broilers and layers each made up about 10 percent of the standing population, that layers were replaced annually, and that there were four batches of broilers per year.

The study then estimated indigenous chickens' contribution to egg and meat consumption, based on:

- average egg production of between 40 and 60 eggs/hen/year from 3.5 clutches per bird;
- the preference in most communities for hatching the eggs to produce chicks, rather than eating the eggs;

- a generally high hatching rate of approximately 80 percent;
- a high chick mortality rate, with between 60 and 70 percent of chicks dying in the first seven weeks of life, meaning that an average of only one or two chickens are eaten per hatch of eggs.

The indigenous breeds' contribution to egg consumption was found to be low, at about 10 percent, while that to meat consumption was much higher, at about 50 percent.

Although these estimates are imprecise, in the absence of other published figures they provide a reasonable basis for comparisons of the production and consumption of indigenous and commercial genotypes. As countries develop and their populations become more urbanized, the proportions of meat and egg consumption from commercial genotypes increase. In rural regions, however, there are strong arguments for retaining indigenous genotypes in small family scavenging flocks.

The productivity and profitability of small-scale family poultry production are critically linked to bird mortality rates, particularly among young chicks. These are normally very high owing to predation, disease, malnutrition and climate exposure. Mortality rates have been shown to reduce dramatically when chicks are reared in confinement with the hen, are creep-fed for the first couple of weeks after hatching, and are vaccinated against Newcastle disease (Alders and Pym, 2008). Adopting these procedures will minimize losses and ensure that indigenous poultry genotypes continue to be important in rural communities for many years to come.

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Commercial selection for meat and egg production

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Breeding for meat and egg production is an exceedingly complex process involving effective and accurate selection for numerous traits in the sire and dam lines to ensure that the final cross-bred commercial bird possesses all the required attributes. As a consequence, breeding programmes are very costly.

A large population with significant numbers of active and reserve sire and dam lines is required to permit the full exploitation of genetic variation in the component traits and to reduce the effects of inbreeding. This makes it difficult for smaller breeding operations to compete effectively with large global breeding companies, although smaller breeding companies are viable suppliers to niche markets in some areas.

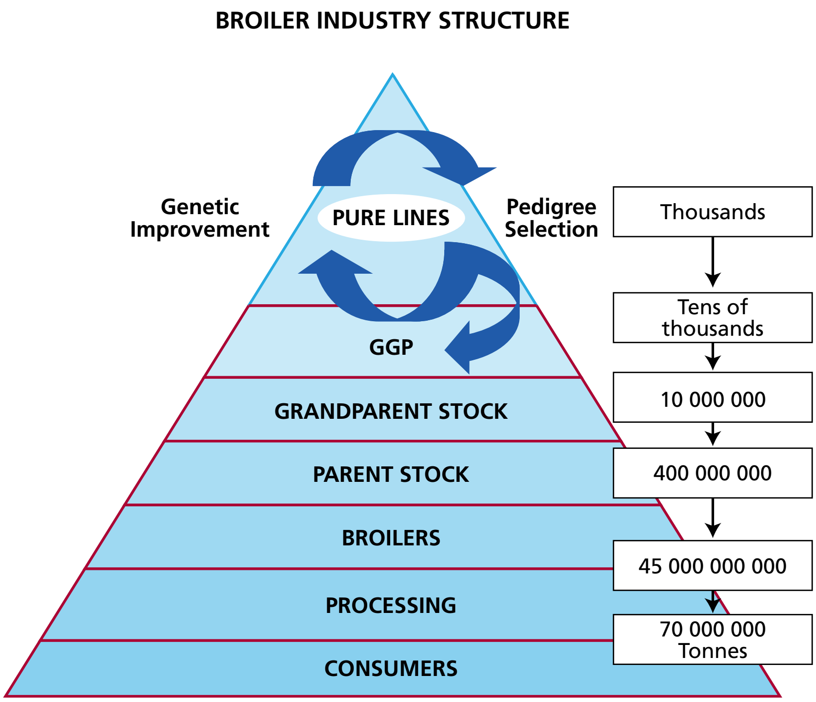
BROILER BREEDING PROGRAMMES

In commercial broiler breeding programmes, selection addresses the following areas:

- *Feed utilization efficiency:* As feed accounts for about 70 percent of production costs, the efficiency with which birds convert feed to body weight is an important trait for direct selection. To enable the selection of birds from the same conditions as their progeny are expected to perform in, some breeding companies have started to replace single-bird cage selection with selection of individual birds from group floor housing, using transponders on the birds and feeding stations to record food consumption.
- *Breast meat yield:* Because of the relatively high price of breast meat in developed countries, considerable efforts have been directed towards improving this trait. Approaches include sib selection based on conformation and, more recently, indirect measurement technologies involving real-time ultrasound, magnetic resonance imaging, computer-assisted tomography and echography.
- *Ascites:* Breeding for rapid growth and high breast meat yield resulted in an inadequacy in the cardio-pulmonary system's capacity to oxygenate the increased blood flow associated with the increased muscle mass. This led to a significant increase in ascites in broiler flocks during the 1990s, particularly during winter. Prior to this, ascites was normally encountered only un-

FIGURE 1

Numbers of birds and generations involved in the transmission of selection response from nucleus lines in commercial broiler breeding programmes to the commercial broiler progeny



Source: McKay, 2008.

der cold, high-altitude conditions. Selection based on oximetry and plasma levels of the cardiac-derived troponin-T enzyme was demonstrated to be effective in reducing susceptibility to ascites, and this procedure has been adopted by commercial broiler breeders. Levels of ascites in the field are now greatly decreased, even at high altitudes.

- *Skeletal abnormalities:* The very rapid growth rate of broiler chickens puts an enormous strain on their immature cartilaginous skeletons, resulting in high incidence of leg and skeletal abnormalities. Selection based on gait, morphology and X-ray imaging has done much to reduce the expression of conditions such as *tibial dyschondroplasia, spondylolisthesis* and *valgus* and *varus deformation* in most commercial strains of broilers, but skeletal abnormalities continue to be a major focus in most breeding programmes.

To permit the transmission of genetic improvement from the nucleus breeding populations (where all selection takes place) to the billions of cross-bred commercial broilers, significant multiplication through grandparent and parent populations is needed, as shown in Figure 1. The time lag between selection in the nucleus lines and gains in the commercial broiler is typically about four years.

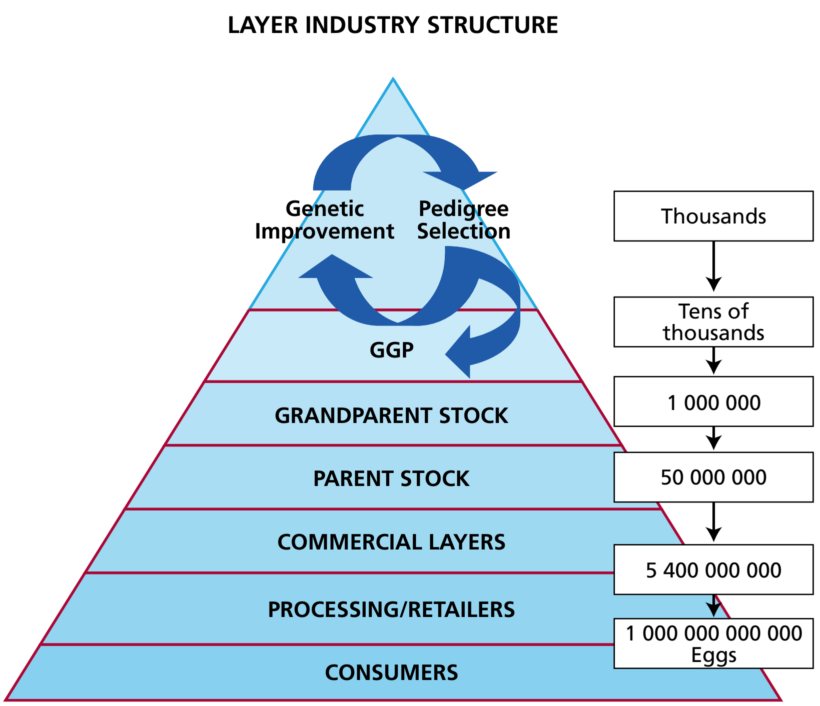
LAYER BREEDING PROGRAMMES

In commercial layer breeding programmes, selection addresses the following areas:

- *Egg production and size:* Genetic improvement in egg production and size is challenged by the highly canalized nature of the trait as determined by diurnal photoperiodic constraints; negative genetic correlations between egg production and early egg size; variation in the rate of increase in egg size with age; and the need to predict persistence of lay in birds selected for breeding before the third phase of production. High-capacity computers and sophisticated statistical packages involving Best Linear Unbiased Prediction (BLUP) procedures have been used to predict persistence in the laying performance of birds in current flocks, allowing selection to take place earlier and the maintenance of a relatively short generation interval.
- *Egg quality:* Shell quality is defined in terms of strength, colour, shape and texture; the first three have moderate to high heritabilities, so respond readily to selection. Shell colour is determined almost exclusively by genotype, and selection is typically based on measurement using reflectance spectophotometry. There are cultural preferences for eggs of different colours. Shell strength is a critical factor affecting profitability. Breeders have selected for improved shell strength by measuring shell thickness, specific gravity (of fresh eggs), shell deformation, and other indirect and direct parameters. Shell texture and shape aberrations and blood and meat spot inclusions are selected against by culling birds producing these eggs. Albumen quality has been improved by selecting for increased albumen height measured using a Haugh unit micrometer.
- *Selection in barn and free-range environments:* Effective selection for egg numbers and quality was not feasible in the past, when birds were housed under group pen conditions in barns, or free-range. Recently, technologies have been developed for attaching transponders to the birds and the nest box, with sensors that allow egg production to be recorded and eggs to be traced back to the hen that produced them, for quality measurement.

FIGURE 2

Numbers of birds and generations involved in the transmission of selection response from nucleus lines in commercial layer breeding programmes to the commercial layer progeny



Source: McKay, 2008.

The transmission of genetic improvement from the nucleus breeding populations (where all selection takes place) to the many millions of cross-bred layers involves significant multiplication through grandparent and parent populations, as shown in Figure 2.

RECENT EMPHASES IN COMMERCIAL BROILER AND LAYER BREEDING PROGRAMMES

Genomics: The sequencing of the chicken genome and the genetic variation map for chickens, developed in 2004, have had a profound impact on commercial broiler and layer breeding programmes. There are now some 3.3 million identified single nucleotide polymorphisms (SNPs) in the chicken genome, which provide large numbers of potential markers for quantitative trait loci (QTL) mapping and associated studies, allowing more accurate selection for multiple traits.

Genomics will not replace traditional selection methods, but will allow more accurate selection decisions to be made, and breeding companies have recently made considerable investments in bioinformatics. The greatest impact of this will be on difficult-to-measure traits such as disease resistance and sex-limited traits, and those with low heritability. Large international poultry breeding companies have recently committed to a combined initiative to evaluate and implement genome-wide selection in their respective breeding programmes.

Transgenics: There are three approaches to producing transgenic chickens: i) using viral vectors to introduce foreign DNA into the genome; ii) direct injection of DNA into the newly fertilized zygote; and iii) using a cell-based approach to make modifications to the genome. Of these, the last approach, using primordial germ cells, appears the most promising for successful targeted changes to the genome.

Although transgenic technologies open up exciting possibilities for poultry breeding, their application is impeded by consumers' reluctance to accept eggs and meat from transgenic commercial poultry.

Selection for disease resistance: Breeding for disease resistance can be effective through direct selection for resistance and immunity parameters by measuring the response of relatives. However, the use of molecular markers is preferred, to avoid the expensive and labour-intensive tests involved in defining resistance in the live bird. A huge global research programme is under way to identify the molecular basis of disease resistance to the wide array of viral, bacterial, protozoan and fungal diseases affecting poultry.

However, in spite of the enormous global effort involved, the molecular approach to disease resistance in poultry flocks has so far had only a modest impact. Two areas where relatively good response has been obtained are selection for resistance to Marek's disease, based on the Major Histocompatibility Complex (MHC) haplotypes, and selection for resistance to avian leukosis virus, based on receptor differences in the identified genes. Combined molecular and traditional sib-selection approaches have yielded significant improvements in general robustness in a number of commercial meat and egg strains.

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Genetic approaches to improved performance in sub-optimal conditions

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SELECTION IN COMMERCIAL LINES OF POULTRY

When producing poultry stock for developing countries, large global breeding companies tend to promote the strains that are used in developed countries, most of which have temperate climates, claiming that these strains are suitable for all environments. However, most of these strains have been selected for increased productivity and general robustness under relatively good management and nutrition conditions, generally without significant temperature stress. If they prove to be tolerant to sub-optimal conditions it is usually owing more to chance than to directed selection. To maximize performance, the companies often promote improved management standards and practices in the target countries.

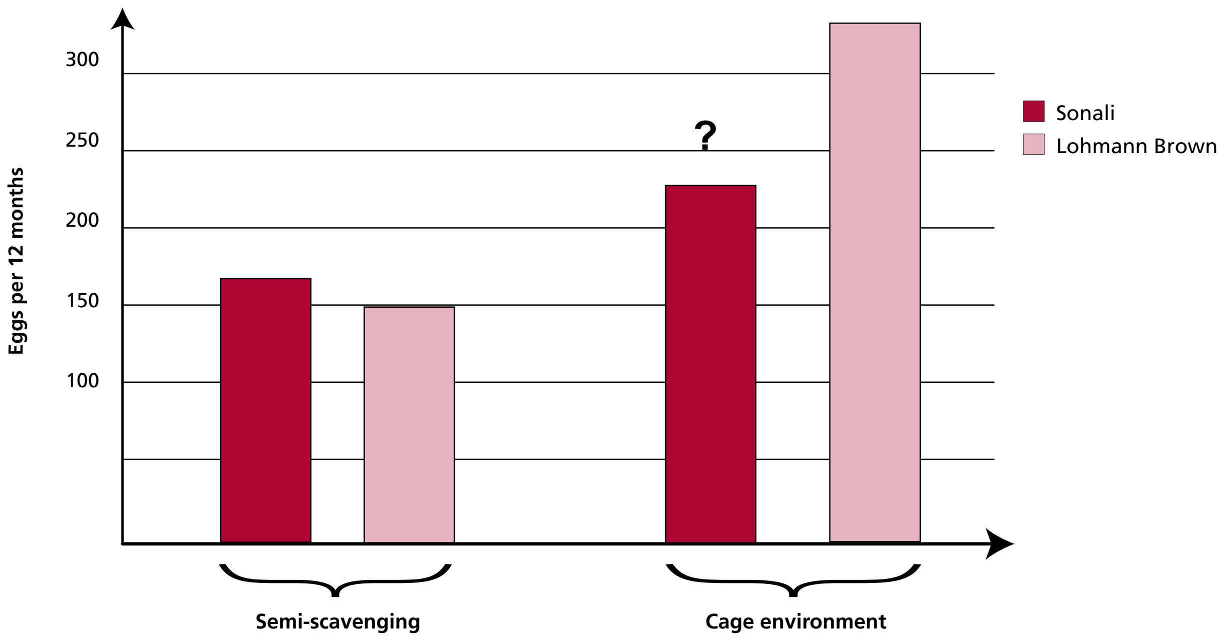
Given the very wide range of nutritional factors that affect performance, large companies have not attempted to breed birds with tolerance to specific nutritional deficiencies, but a case could be made for selecting birds for increased tolerance to heat stress (Cahaner, 2008). Heat stress has a marked impact on performance, particularly the growth of broilers, owing to their high metabolic heat output. High temperatures are a feature of most developing countries, and maintaining reasonable house temperatures is either too costly or simply not possible, owing to a limited or lacking power supply and other factors. As a result of this susceptibility to heat stress in broiler strains, it is standard practice in many tropical developing countries to market the birds at an early age and low weight, before heat stress becomes a major problem.

GENOTYPE-ENVIRONMENT INTERACTION

Studies have demonstrated genotype-environment interactions by measuring the growth or egg laying performance of different strains when subjected either to good management, high-input conditions or to harsh, low-input conditions (Besbes, 2008). Nutrient intake is typically one of the major differences between the two conditions. In almost all the cases studied, commercial stock performed considerably better than indigenous stock under good conditions, but only marginally better, or the same, under low-input, harsh conditions (Tadelle, Alemu and Peters, 2000; Singh *et al.*, 2004).

An example of this is the comparison of egg laying performance between Lohmann Brown and Sonali hens under optimal (German Random Sample Test) and semi-scavenging conditions

FIGURE 1
Effects of breed and environment interactions on egg production



Source: Sørensen, 1999.

(Sørensen, 1999). The Sonali hens are F1 crosses between Rhode Island Red males and Fayoumi hens. Figure 1 shows the relative performances of the two strains in the two environments. The Lohmann Brown produced 303 eggs in 12 months under the optimal conditions of the German Random Sample Test, but only 140 eggs under semi-scavenging conditions, where the Sonali produced 156. The Sonali was not tested under the German Random Sample Test, but its production was estimated at slightly more than 200 eggs (Sørensen, personal communication).

There is therefore a persuasive argument for applying genetics to produce stock that perform well under the less than optimal conditions prevailing in many developing countries. First, however, any improved management conditions that have been demonstrated to result in improved performance and that are cost-effective and sustainable should be applied, particularly those that improve the survival rate of young birds (confinement early rearing with the hen, with supplemental feeding and vaccinations), the supplemental feeding of growing and older stock with locally available feedstuffs, and ongoing disease prevention measures.

BREEDING FOR PERFORMANCE UNDER SUB-OPTIMAL CONDITIONS

Given the complex processes and inputs involved in genetic improvement, there is little point in attempting to improve the performance of a breed with inherently low production potential. Selection of the breed(s) to use is therefore critical, and involves a good understanding of each breed's specific attributes and a clear definition of the breeding goals.

Small-scale, semi-scavenging operations require dual-purpose birds that produce both eggs and meat. The opportunities for selecting for improved egg production are limited by the hen's hatching each clutch of eggs and rearing the chicks to about six or seven weeks of age before recommencing lay. The production system is complex, and emphasis on one component could have negative repercussions on another. Two obvious requirements are for broodiness and mothering ability. Some breeds/ecotypes are renowned as good layers and mothers, and are thus suitable candidate breeds, at least as the hens in any proposed cross-breeding programme. It is rather more difficult to apply effective selection at the individual bird level because of possible marked differences in the impacts of nutritional and disease factors on individual birds' performances. Nonetheless, there is a good case for culling poor-performing hens, although there is often limited opportunity to exert any selection pressure in smallholder situations, where all surviving hens are needed to maintain flock size.

The greater interest in meat than egg consumption in many developing countries justifies an emphasis on growth rate and body conformation, in all stock in single-breed operations, and in males in cross-breeding programmes. This should be balanced against the available feed resources. If the latter are limited, heavy body weight may be a disadvantage, as the bird may obtain sufficient nutrients to meet only maintenance requirements, with nothing left for growth.

In small-scale commercial operations involving confinement rearing and supplementary feeding, there is a persuasive argument for using commercial improved breeds/strains of broilers or layers. However, their suitability depends on the level and quality of feeding and the birds' likely exposure to extreme climatic conditions. Where feeding is sub-optimal and commercial diets are either not available or considered too expensive, there is a case for using local or other genotypes. One important factor is the relative prices paid for the meat and eggs produced by the different genotypes. Where a significant premium is paid for meat and eggs from indigenous breeds, the confinement rearing and feeding of these birds can be justified, in spite of their considerably lower productivity.

For all small-scale production systems in tropical developing countries, tolerance to high temperature is a key requisite in the birds. One of the most effective ways of improving heat tolerance is through the incorporation of single genes that reduce or modify feathering, such as those for naked neck *(Na)*, frizzle *(F)* and scaleless *(Sc)*, as well as the autosomal and sex-linked dwarfism genes, which reduce body size (Cahaner *et al.*, 2008). These genes are segregating in some indigenous populations, as there is natural selection for heat tolerance as an important component of reproductive fitness. There is also a good case for incorporating these genes into existing commercial lines, as the inputs and time required for this are minimal compared with those required to develop a high-producing, heat-tolerant line from a base population (Cahaner, 2008).

BREEDING APPROACHES

Cross-breeding

Genetic improvement can be achieved through cross-breeding, with or without genetic selection in the parent lines; through upgrading by repeated back-crossing to a superior parent breed; or through within-line selection. The cross-breeding approach normally involves a two-way cross between an improved exotic and a local breed, with the aim of combining the better production capacity of the former with the latter's adaptability to harsh environments. This system also maximizes the expression of heterosis, or hybrid vigour, in the cross, normally reflected in improved fitness characteristics.

Examples of this approach are the Bangladesh and Indian cross-breeding programmes, which are described in some detail by Sørensen (FAO, 2010). Briefly, the Bangladesh programme is based on crosses between Rhode Island Red (RIR) males and Fayoumi females to produce the F1 Sonali cross-bred. RIR is a United States breed that has been used by many commercial breeding companies globally as the base population for their brown-egg lines; Fayoumi is an Egyptian breed with reasonable egg production under difficult environments, and is particularly known for its genetic resistance to disease. The cross-bred Sonali fowl has proved to be the highest-yielding and most profitable breed combination in several comparisons under semi-scavenging conditions in Bangladesh (Rahman *et al.*, 1997).

The Indian programme is based on crossing Aseel breed males with CARI Red hens to produce cross-bred CARI Nirbheek hens. The native breed Aseel is well adapted to tropical conditions and is known for its high majestic gate and dogged fighting qualities, which make it capable of protecting itself against predators; the female CARI Red has been selected for improved egg production capacity under tropical conditions. In the field, CARI Nirbheek hens receiving about 30 g of supplementary feed per day were able to produce 163 eggs a year, with a survival rate of 90 to 95 percent (Singh *et al.*, 2004).

Upgrading through back-crossing

Poultry genetic improvement programmes through repeated back-crossing of female offspring with the superior-performing male parent breed, or through cockerel exchange programmes in which males of improved breeds are distributed to smallholders, have not been particularly successful. In both cases it is necessary to retain separate populations of parent birds, and the progeny often lose the capacity for broodiness, so cannot hatch or rear their young. This is a major shortcoming given the purpose for which the birds are being produced. In addition, the survival of improved breed males is often threatened by their lack of adaptation to the environment and its dangers. Not the least of these dangers is the attractiveness of these birds to other farmers, resulting in frequent thefts for breeding or eating. These limitations also apply to cross-breeding programmes.

Within-line selection

Within-line selection for increased growth or egg production involves complex procedures that have to be undertaken at a central breeding station (Besbes, 2008). The need for a sufficiently large population, pedigree recording, accurate measurement of individual performance and the capacity to minimize environmental variation makes it impossible for individual farmers to run an effective selection programme. Even when the necessary resources are available at a central breeding station, response is generally slow, and the logistics for distributing selected stock to farmers pose considerable difficulties. Economies of scale are very relevant, as evidenced by the dramatic reduction in the number of poultry breeding companies globally over the past 20 years.

There is certainly need for stock with the capacity to perform well under the less than optimal environments typically encountered in developing countries. The link between performance and nutritional and other management inputs means that any genetic improvement in performance capability must be matched by increased inputs. Genetic improvement through cross-breeding or back-crossing undoubtedly results in improved egg and/or meat production (provided it is accompanied by increased nutritional and other management inputs), but account should be taken of:

- the increased complexity of running several different lines;
- the birds' probable loss of broodiness and capacity to rear their young;
- the impact that it may have on farmers' interest in the chickens and on consumers' interest in their meat and their eggs.

Although within-line selection avoids most of these problems, to be effective, it needs to be conducted at a central breeding station, and to be well organized and funded. The choice of breed(s) for the base population is critical to the success of the enterprise.

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Genetic diversity and conservation of genetic resources

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BREED DEVELOPMENT AND GENETIC DIVERSITY

Globally, there is enormous genetic diversity within most poultry species resulting from:

- the activities of poultry fanciers and breeders around the world over many years;
- the prodigious numbers of small semi-scavenging flocks kept by subsistence farmers in developing countries;
- commercial breeders' efforts to produce high-performing meat and egg production lines of birds.

Many of the breeds developed over hundreds of years were selected for morphological and appearance characteristics as much as for production purposes. This is demonstrated by the huge numbers of chicken breeds and ecotypes found globally.

The principal features of poultry that permit rapid increases in the numbers of breeds and ecotypes in all countries are their very high reproductive rates and short generation intervals. Paradoxically, it is this capacity that now threatens the survival of many earlier-developed breeds. The need for high production efficiency, combined with the complexity and cost of running effective breeding programmes has resulted in commercially selected lines of broilers and layers replacing several of the breeds previously kept for productive purposes; over the past 20 years, there have also been dramatic reductions in the numbers of commercial breeding companies and genetic lines.

In any discussion of genetic diversity, "breeds" are essentially cultural concepts rather than physical entities. This is because breed standards have long been defined by phenotype, which may or may not involve significant differences in genotype. It is only recently that molecular tools capable of defining the degree of genetic diversity between different breeds have been developed. It is therefore necessary to adopt a broad definition of breed, until the term has been defined by a more objective measure.

Poultry breeds can be categorized into several different groupings according to present and past usage. Russell (1998) differentiates poultry breeds as: industrial or commercial lines; breeds used in traditional agriculture, historical breeds including old landraces; game breeds used primarily for cockfighting; ornamental breeds or those used mainly for exhibition; and experimental lines. Within these breeds there are many feather colour and comb variations (Simianer and Weigend, 2007), suggesting that a huge degree of genetic diversity is available, and posing questions regarding how best to allocate the limited resources for conserving this wide diversity as effectively as possible.

BREED CATEGORIES AND RISK STATUS

There is currently considerable concern regarding the number of poultry breeds that are either extinct or at risk of extinction. This information has been obtained from the *State of the World's Animal Genetic Resources* (FAO, 2007b), the first ever assessment of domestic animal diversity. The assessment process included updating the Domestic Animal Diversity Information System (DAD-IS) global databank, which now contains breed-related information on 16 avian species, with 3 505 country breed populations and about 2 000 breeds. Chicken breeds make up the vast majority (63 percent) of total avian breeds, followed by ducks (11 percent), geese (9 percent) and turkeys (5 percent); indigenous or local breeds make up most of the world's poultry genetic diversity. Breeds have been categorized according to whether they occur in one country (local), several countries in the same region (regional transboundary), or several regions (international transboundary). The proportions of each of these categories vary considerably from region to region (see Hoffmann, 2008 for details).

As noted by Hoffmann (2008), population data are frequently missing, which makes risk assessment extremely difficult. The absence of data is a result of the difficulties with monitoring small livestock and the general low importance that most governments attribute to poultry, despite their important roles for food security, rural livelihoods and gender equity. For 36 percent of reported avian breeds, the risk status is unknown; 35 percent are reported as not at risk, and 30 percent as at risk. Of 2 000 reported avian breeds, 9 percent – mainly chickens (83 percent) – were reported as extinct (FAO, 2007b). Most of these extinct breeds were from Europe (Figure 1).

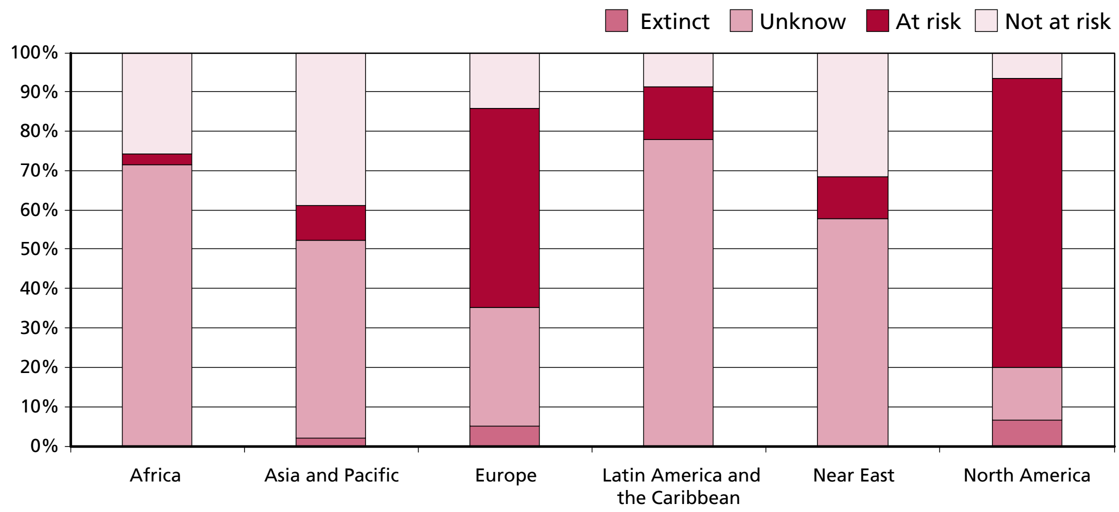
The regions with the highest proportions of avian breeds classified as *at risk* are North America, with 73 percent of total avian breeds, and Europe and the Caucasus, with 51 percent. Among the different avian species, the proportions of breeds at risk are 36 percent for chickens and turkeys, 31 percent for geese, and 25 percent for ducks.

CONSERVATION OF POULTRY GENETIC RESOURCES

Indigenous poultry breeds' importance for subsistence farmers in many developing countries, combined with many consumers' preference for their eggs and meat, suggests that these genetic resources are not under immediate threat. However, gradual erosion of the genetic integrity of the stock, through cross-breeding and upgrading programmes, is cause for concern. In addition, the actual genetic variation between so-called different breeds of indigenous birds in neighbouring regions has sometimes been shown to be minimal, owing to long-term exchanges of breeding

FIGURE 1

Risk status of local and regional chicken breeds, by region



Source: DAD-IS.

stock among villages. Substantial genetic diversity among village chicken populations is observed only in populations separated by wide geographical distances (Tixier-Boichard, Bordas and Rognon, 2008).

Poultry fanciers in developed countries play a vital role in the retention of genetically diverse populations of poultry species. The high reproductive rate and short generation interval of most species mean that viable breeding populations can be maintained at reasonable cost. Most "pure breeders" are motivated by the pleasure that the stock and the breeding enterprise bring them, but they are without doubt a largely untapped and vital source of avian genetic resources and diversity. These breeders and the smallholder poultry farmers in developing countries provide important means for the *in vivo* conservation of poultry genetic resources.

Recently, poultry genetic resources have suffered significant losses due to the termination of commercial lines associated with breeding company take-overs and the global consolidation of commercial poultry breeding operations. There have also been significant losses of experimental lines, most of which are generated at research institutions; it is becoming increasingly difficult to find the funds necessary for retention of these lines.

As well as *in vivo* conservation, genetic material is also conserved *in vitro*, mainly through cryo-preservation of semen. Under this approach, repeated back-crossing is required to re-establish a breed, which may take up to seven generations. In addition, the original genome of the lost breed can never be fully restored through this approach, owing to the loss of mitochondrial DNA. Although cryo-conserved embryos allow the complete re-establishment of a breed, this is not possible for avian species at present. Cryo-conservation of isolated embryonic cells, primordial germ cells or blastoderm cells may be an option in the future, but is currently too costly for genetic conservation programmes (Hoffmann, 2008).

CONSERVATION PROGRAMMES

From the FAO database, it is estimated that about 25 percent of chicken breeds are included in conservation programmes, but there is no information about the nature or efficiency of these programmes. According to country reports to FAO, only 15 percent of countries (half of them developing countries) have poultry conservation programmes (*in vivo and in vitro*), covering 63 percent of local breeds and 11 percent of national populations of transboundary breeds. The Global Databank shows that 195 poultry breeds (of which 77 percent are chickens, 9 percent ducks, 9 percent geese and 3 percent turkeys) have conservation programmes, but some of these data are out of date. Hoffmann (2008) provides details of country-specific programmes that may not be recorded in the Global Databank.

MEASURING GENETIC DIVERSITY

Recently, there has been a major shift from the differentiation of poultry breeds according to morphological and feather colouring characteristics, to differentiation based on measurements at the molecular level. The use of molecular markers can provide quantified criteria for assessing genetic diversity, either within or between populations. However, although they can be used to study relatedness between populations, provide information on past history of populations, detect introgressions and contribute to the genetic definition of a breed's entity, molecular markers do *not* provide information on phenotypes and special adaptive traits.

Appropriate sampling is critical to the molecular characterization of a breed for comparative purposes; a minimum of between 30 and 50 individuals is required. Determination of the chicken genome in 2004 (Hillier *et al.*, 2004) has facilitated the use of molecular markers for breed/ecotype characterization. Although genome knowledge is less complete for other poultry species, linkage maps are available for ducks, quails and turkeys, and reference to the chicken genome is generally an efficient approach for studying gene order and gene structure. The availability of molecular markers is therefore not a limiting factor in most poultry species. Highly polymorphic microsatellite markers are preferred because they provide much information for a limited number of loci; most studies use between 20 and 30 markers. Molecular tools for studying genetic diversity using single nucleotide polymorphisms are likely to be developed further.

GENETIC DIVERSITY WITHIN BREEDS AND POPULATIONS

As reported by Tixier-Boichard, Bordas and Rognon (2008), studies using microsatellite markers have shown large variations in heterozygosity, ranging from 28 percent for a fancy breed to 67 percent for a village population, but the average value (of about 50 percent) is rather lower than that observed in domestic mammals. The highest levels of within-population diversity were found in wild ancestor species, unselected local populations, a few standardized breeds kept in large populations, and some commercial broiler lines. A range of values were obtained for European fancy breeds, reflecting the variability of population history within this type of population. Expected values for heterozygosity range from 50 to 63 percent for broilers and 45 to 50 percent for brown-egg layers, to about 40 percent for white-egg layers, which exhibit the lowest levels of all commercial lines. These studies suggest that there is a significant reservoir of genetic diversity within local breeds of chickens.

MONITORING OF GENETIC POPULATIONS

The *Global Plan of Action for Animal Genetic Resources* (FAO, 2007a) identifies the need for country-based strategies to ensure that inventory and monitoring activities can be linked to and coordinated with action plans such as agricultural censuses or livestock population surveys. Monitoring requires the regular checking of population status and the evaluation of trends in the size and structure of breeds/populations, their geographical distribution, risk status and genetic diversity. Because of their important contribution to poultry meat consumption in rural regions of developing countries, it is highly desirable that local breed chicken populations are monitored. Such monitoring will contribute to the planning of national development policies in these countries.

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