Genetic changes in layer breeding: Historical trends and future prospects

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Summary

In commercial egg type chicken breeding three and four way crosses are used to produce commercial layers. The primary breeders are using closed nucleus breeding programmes, with birds kept under maximum biosecurity. All grand parents and parents are produced from a closed nucleus for the world wide demand of commercial layers. The breeding goals have been focused for several decades on increasing number of eggs per hen housed. Additional traits have become more important during the last decade, i.e. feed efficiency, internal and external egg quality and general adaptability. Prior to each selection, weights for individual traits within the selection index are adjusted to meet market demands. Breeding stock and commercial layers have to be bred to perform adequately in a variety of systems ranging from large intensive cage units to free range management under different environmental conditions world-wide.

Despite intensive selection for egg production the decrease in genetic variation observed in closed commercial lines is not yet critical. Peak production is approaching the biological limit of one egg a day. During this period genetic and phenotypic variation have been significantly reduced. But for early production (sexual maturity) and late production (persistency) genetic variation is still high. In a mating scheme avoiding full and half sib matings no serious inbreeding depression is observed. To achieve continued future genetic progress, selection pressure will shift to other traits like internal and external egg quality and perhaps behaviour traits which still respond to selection.

Primary breeders are responding to this challenge by testing pedigreed cross-line hens in a wide range of environments and housing systems while the pure-line elite stock is kept under conditions of maximum biosecurity. Marker assisted selection is already part of commercial breeding programmes. In the past, blood typing has been used to improve Marek's resistance, whereas today anonymous microsatellites which are linked to traits of economic interest are used for selection. In particular, selection between full sib males can give a major improvement.

The whole industry is getting more specialised. While the genetic potential of the birds is improved management and nutrition have also to be adapted to changing demands. The general goal for the future is to breed chickens with the ability to function well within a wider range of production conditions and do not respond to the slightest stress.

Introduction

In recent years, we have come to expect more than 300 eggs and close to 20kg egg mass per year from a competitive laying hen, with a feed conversion ratio approaching 2.00. Those who are not directly involved in the genetic improvement of commercial laying hens may wish to know how egg production and feed efficiency are being improved and what the prospects for further improvements may be. Data from German random sample tests are used to document the rate of change in white-egg vs. brown-egg strains. Future prospects will be discussed based on actual results and selection strategies.

General breeding goals

All breeding plans for commercial breeding companies have one major objective in common: to increase the genetic potential of the stock to produce a maximum of saleable, high quality products at minimum cost in a given production system.

Breeders of egg-type chickens concentrate on four major objectives:

- low mortality and high adaptability to different environments
- maximum number of saleable eggs per hen housed
- low feed cost per egg or per kg egg mass
- optimal external and internal egg quality

As stated by Arthur (1986), all leading egg-type breeders today probably use a combination of cross-line and pure-line records for line improvement. Combinations of pure-line and cross-line data for breeding value estimation allow more genetic progress than selecting on pure-line or cross-line information (Wei, 1992). Especially for traits with low heritability, such as liveability and egg production, selection is not exclusively on the basis of pure-line information from the minimal disease environment of a typical breeding farm. Data from extensive field testing programmes with pedigreed test commercials are used for selection to reduce the impact of genotype x environment interactions.

Egg production is still the primary trait for the genetic-economic improvement of laying hens. The average production curve of a flock is usually described in terms of three parameters:

- age at 50 % production (average sexual maturity)
- peak rate of lay (and age at peak)
- persistency of production

For individual hens or sibs in group cages, the number of eggs is recorded on a 28-day basis, which offers the chance for detailed statistical analysis and combination of different part-periods for estimating variance and covariance components and for breeding value estimation.

Flock (1977) reviewed the early literature on part-period egg production and documented characteristic parameters for two commercial White Leghorn lines under long-term reciprocal recurrent selection (RRS), over a period of 5 years (1970 - 1974). In this breeding programme, production of two reciprocal single crosses (AB, BA) was recorded in twelve 4-week periods. Phenotypic and genetic parameters of egg production in different 8-week periods are shown in Table 1.

The heritability is high for age at first egg (A1E, $h^2 = 0.54$) and egg production to 28 weeks of age ($h^2 = 0.58$) reaches a low of 0.21 at peak production and increases again slowly during the second half of the laying year. Cumulative egg number has a higher heritability due to the variation in A1E rather than to the rate of production from A1E to the same age.

Results from a recent analysis of two commercial brown-egg pure-lines (Savas, 1998) may serve to illustrate under which conditions selection for egg production continues today. Under the conditions of breeding farms, with minimal disease status and single cage management, non-inbred pure-lines may peak around 94% and stay over 90% for about 20 weeks. If kept for a full laying year, they would average close to 300 eggs per survivor.

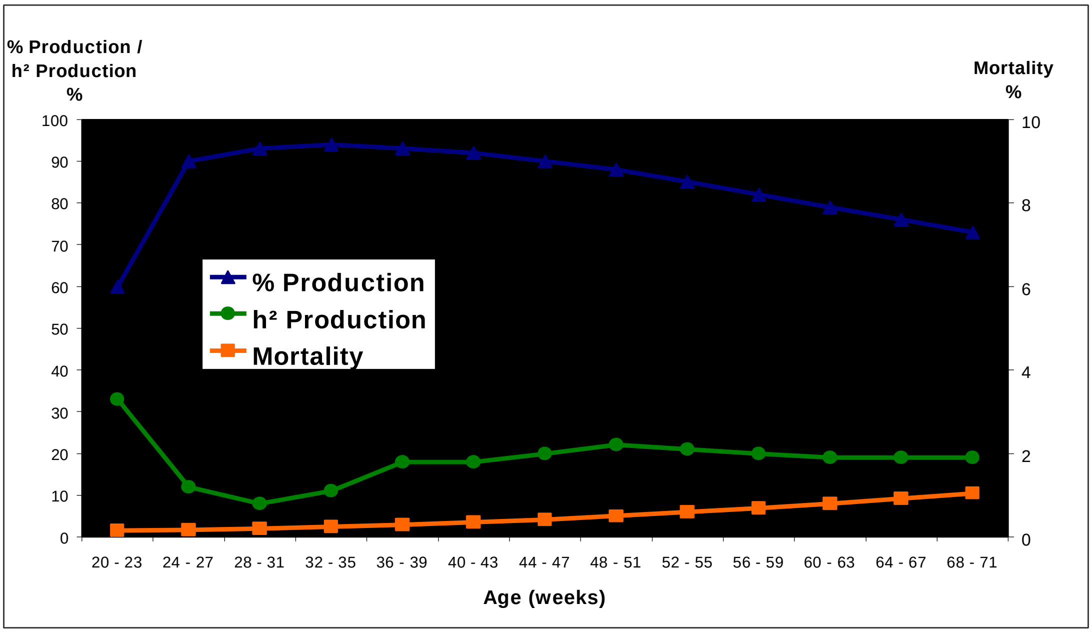
Table 1 *Phenotypic and genetic parameters of egg production in different part periods (Flock, 1977)*

Trait* Age	Mean $\bar{x}$	SD		CV (%)		Average
		s_P	s_G	s_P / $\bar{x}$	s_G / $\bar{x}$	h^2
A1E	163.4	7.8	5.5	4.8	3.4	.54
E 21 - 28	31.3	7.7	5.5	24.4	17.5	.58
E 29 - 36	51.3	4.2	1.7	8.3	3.3	.23
E 37 - 44	49.5	5.3	2.1	10.8	4.2	.21
E 45 - 52	46.8	6.8	2.7	14.6	5.8	.24
E 53 - 60	43.5	8.6	3.5	19.7	8.0	.25
E 61 - 68	40.5	10.4	4,0	25.6	9.8	.25
E 21 - 36	82.6	9.3	5.8	11.3	7.1	.49
E 21 - 44	132.1	12.1	6.5	9.1	5.0	.40
E 21 - 52	178.9	16.2	8.1	9.0	4.5	.36
E 21 - 60	222.4	21.8	10.5	9.8	4.7	.35
E 21 - 68	262.9	29.0	13.6	11.0	5.1	.35
P A1E - 44	89.5	6.7	2.9	7.5	3.2	.27
P A1E - 68	83.3	9,0	4.1	10.8	5.0	.33

* A1E = age at first egg, days
E = number of eggs, weeks of age
P = rate of lay from A1E to given age

In Figure 1 the heritabilities for rate of lay in different four-week periods of a production cycle are shown relative to rate of lay and mortality. These results are from the brown-egg pure-line data analysed by Savas (1998).

Figure 1 Heritabilities of rate of lay compared to average rate of lay and mortality in different four-week periods (Savas, 1998)



Due to the biological limit of one egg per day, genetic variation between families is low around peak (24 to 35 weeks of age). This illustrates why data recording has to be extended to the more informative later periods. If data recording has to be extended, the time of selection has to be postponed to a period when reproduction rate is already lower. The longer generation interval therefore has a major effect on annual rate of genetic progress. To compensate for these disadvantages additional traits of high economic value like late egg quality (shell strength and colour) can be used to improve the total profitability of the stock. For rate of mortality a similar trend as for egg production can be observed. In the first third of the production cycle weekly mortality is very low. With increasing length of the production period, monthly losses increase. Mortality records from late periods are more informative and are being collected from an extensive field testing programme. The field tests are designed to represent typical production environments around the world to minimize the effects of genotype x environment interactions and to improve liveability under a wide range of conditions.

Historical data of German random sample tests can be used to document for Lohmann LSL (as for other strains) a continuing improvement of total productivity (Table 2). Egg mass output has been improved by more than 2 kg within 15 years, with no major changes in body weight but a significant improvement in feed efficiency. Income over feed cost has been improved by about 4DM per hen if constant feed and egg prices are assumed.

Table 2 Historical trend for Lohmann LSL layers in German random sample tests

Years ending	Egg Mass (kg/Hen Housed)	Body Weight (kg)	FCR. (kg/kg)	IOFC* DM
1980 – 82	17.70	1.94	2.46	10.90
1983 – 85	18.50	1.87	2.39	11.91
1986 – 88	18.67	1.83	2.35	12.32
1989 – 91	18.80	1.88	2.32	12.63
1992 – 94	19.77	1.96	2.25	13.84
1995 – 97	19.93	1.80	2.10	15.15

* Egg income over feed cost: $1.60 * EM - 0.40 * EM * FCR$

Rates of genetic progress

Methods to measure genetic trends are an essential part of animal improvement schemes. Several methods can be used, such as comparison with control lines, overlapping use of sires in the population over time and repeated matings of the same sires and dams. Such estimates may be biased and are only useful for internal purposes to predict genetic changes per trait in each line. On an individual farm, genetic and environmental effects can usually not be separated. The most commonly used basis for strain comparisons are random sample tests, from which data from several years can be used to calculate rates of progress for different strain crosses. The estimates per strain are not free of environmental trends, but the differences between strains in rate of progress are mainly genetic. Data from five German random sample testing stations have been used to estimate changes in egg production and feed efficiency over11 years. Trends are calculated as pooled linear regressions for five white-egg and five brown-egg strains over the 11-year period 1984/85 to 1994/95 (Hartmann and Heil, 1985; Heil and Hartmann, 1995), using a linear model including strains, stations and years.

Table 3 shows the strain means and the average regression coefficients (per10 years) for the white- and brown-egg layers. The increase in mortality can be attributed to ‘animal welfare’: most stations are no longer beak trimming and experience more cannibalism, especially in brown-egg strains. During this 11-year period, the white-egg strains have made more progress in egg output and the brown-egg strains have improved more in feed efficiency. Progress in egg mass and feed efficiency during the decade from 1985 to 1995 was lower than during the previous decade. This may be due mainly to decreasing response as stocks approach physiological limits (1 egg in a 24-hour day). Egg weight cannot be increased beyond market needs. Most breeders have also increased their selection pressure for traits such as shell strength and shell colour in brown-egg strains, which would account for slower progress in egg mass and feed efficiency but a higher percentage of marketable eggs.

Table 3: Means of five brown-egg and five white-egg strains and linear changes (Δ) in German random sample tests 1984/85 - 1994/95

White-egg strains*	Mort. %	Egg no. HH	Egg wt. g	Egg mass kg/HH	Feed g/d	FCR kg/kg	Body wt. g	IOFC** DM
Lohmann	3.8	304	63.1	19.19	120	2.29	1896	13.13
Hisex	5.2	298	62.3	18.60	118	2.31	1839	12.57
Dekalb	3.7	299	61.3	18.29	115	2.30	1879	12.44
Shaver	3.8	294	62.6	18.42	118	2.34	1944	12.23
Babcock	3.8	290	61.4	17.81	113	2.32	1853	11.97
Average	4.0	299	62.5	18.69	117	2.30	1882	12.55
Δ / 10 years	+ 0.6	+ 14	+ 2.5	+ 1.70	– 2	–.24	– 10	+ 3.62
Brown-egg strains	Mort. %	Egg no. HH	Egg wt. g	Egg mass kg/HH	Feed g/d	FCR kg/kg	Body wt. g	IOFC* DM
ISA	5.4	296	65.2	19.33	121	2.30	2180	13.14
Lohmann	5.6	296	65.4	19.33	121	2.30	2217	13.14
Hisex	5.1	291	65.6	19.11	123	2.35	2281	12.61
Tetra	4.9	292	65.1	19.03	124	2.38	2272	12.33
Dekalb	5.1	290	64.1	18.59	124	2.44	2292	11.60
Average	5.2	295	65.0	19.17	122	2.33	2219	12.59
Δ / 10 years	+ 3.2	+ 11	+ 1.2	+ 1.11	– 8	– .28	– 280	+ 3.11

* White-egg strains 309 entries, brown-egg strains 368 entries in total

** Egg income over feed cost: $1.60 * EM - 0.40 * EM * FCR$

Selection intensity and inbreeding

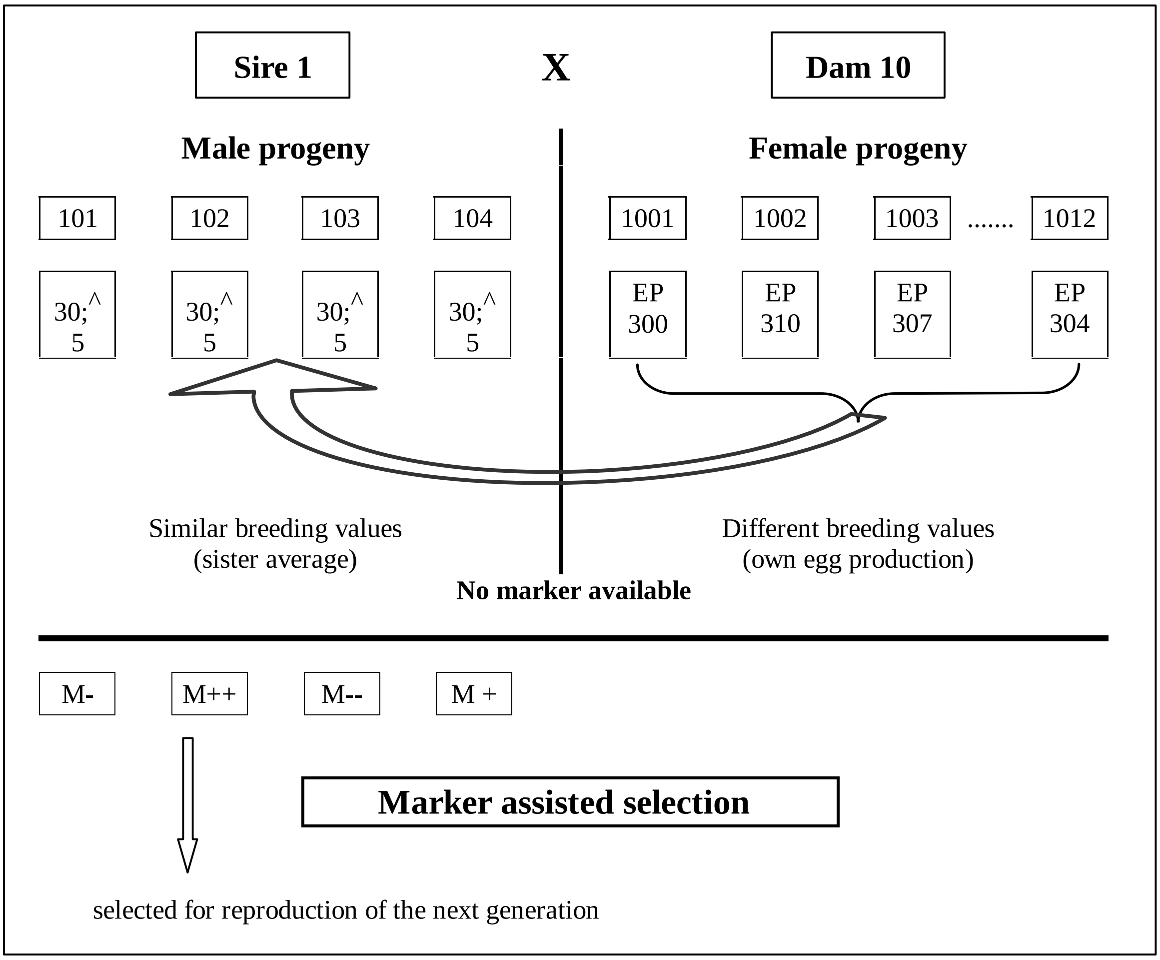
In view of the large number of traits involved in egg-type breeding, selection for any single trait cannot be very intense. Two conflicting objectives are: (1) to maximize selection intensity for traits which significantly affect the saleability of the product, but (2) to control the tendency of the animal model breeding values to put more emphasis on family information than desirable for a low rate of inbreeding. The answer is to keep large nucleus populations, from which e.g. 80 sires and 640 dams per line are selected in each cycle, with restrictions on the number of selected sons per sire.

Selection intensities (*i*) in commercial layer breeding programmes are typically between *i* = 1.5 and 2.0 (10 - 5% males and 15 - 10% females), resulting in approximately 0.5 % increase in inbreeding per generation (Ameli *et al.*, 1991). This slow rate of inbreeding cannot explain decreasing rates of genetic progress in closed populations.

Biotechnology
Marker assisted selection is already part of commercial breeding programmes. In the past blood typing has been used to improve specific disease resistance. For example Marek's resistance and general liveability have been improved by eliminating birds with blood groups which are known to be a marker for high susceptibility to diseases. These breeding efforts have been accompanied by eradication of vertically transmitted diseases from pure-line populations.

Today a lot of money is spent in searching for DNA based markers, mainly anonymous microsatellites, which are linked to traits of economic interest. Special matings and testing schemes have to be set up to search successfully for markers. If in one population a marker for an important trait has been found there is no guarantee that this marker can be used in other lines or products. Based on the assumption that most of the important traits are determined by a very large number of genes or loci, a single marker can only determine a small part of the genetic variation for a trait in a given population.

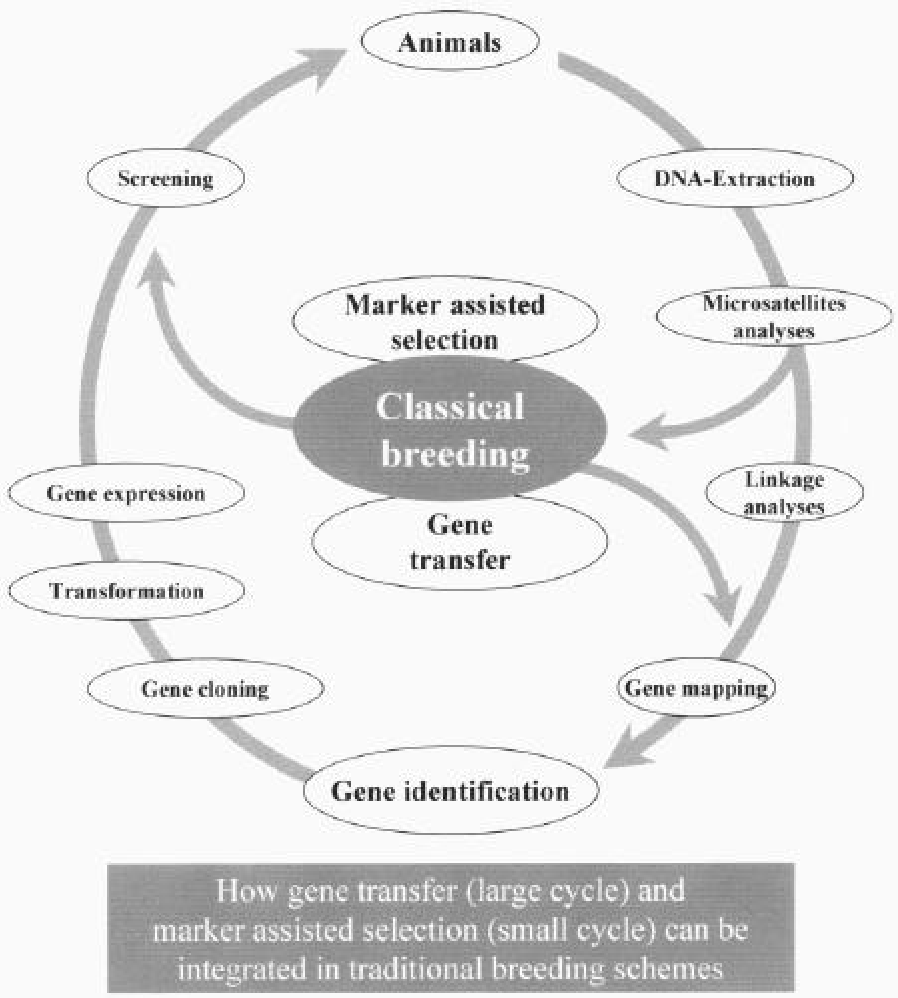
Figure 2 Selection of males with and without DNA-based markers for egg production (EP) traits within one full sib family



Based on preliminary results from the collaboration with different research institutes in Europe there is a high probability that classical selection can be improved and rate of progress enhanced by using DNA-based microsatellite markers for selection. In particular, selection between full sib males can give a major improvement because, at the time of selection, only parental breeding values and pure line and cross line sister information is available. As the performance test is sex-limited, all full sib males have the same breeding values for economically important traits (Figure 2). If markers are available, the best male out of a set of full-brothers can be selected for reproduction to generate the next generation. With lower rate of inbreeding more genetic progress can be achieved if only the best male from each full-sib family is used for reproduction.

In figure 3 different steps of an enhanced breeding programme using marker assisted selection or even gene transfer are demonstrated.

Figure 3 Breeding and gene technique



Currently we are analysing DNA segments which might be linked with genes that regulate performance. Searching for linkage between marker and genes will be the major task for the near future because, unless we have analysed genes it is not worthwhile to use gene transfer to produce better birds. In comparison to mice and rats it is much more complicated to produce transgenic chickens. In some research institutes first steps are still in an experimental stage with very low success rates (Sang, 1999).

Field testing

Progress in electronic animal identification will enable us to do more data recording in commercial environments. Performance testing in the breeding farms can be supported by data input from pedigreed commercial layers in customer farms, and flock records can be replaced by reliable single bird evaluation as well as in cage and floor systems. The reduction of random human errors and the reduced labour intensity for data recording will be the first steps. Egg production and behaviour can be recorded in floor systems without trap nesting.

We are looking for possibilities to breed more robust chickens with a capacity to adapt to different systems of feeding, housing and management, i.e. the chicken of the future is supposed to live and lay well within a wider range of production conditions. Future genetic selection will be based on a combination of production characteristics, immune parameters, disease incidence and stress response. By this procedure we hope to succeed in reducing the incidence of diseases gradually from generation to generation, thereby reducing the need for medication and improving the well-being of the birds.

Conclusions

- After more than 40 years of intensive selection, the available pure-lines still show enough variation for further improvements.
- Accuracy and efficiency of data recording can be further improved by electronic equipment. More sophisticated statistical procedures will help to extract a maximum of information from pure-line and cross-line data from different environments.
- Efforts to improve the persistency of shell strength will be supported by improved liveability and disease resistance. A slow but steady increase in egg production, mainly due to improved persistency instead of higher peak rate, can be predicted for the next years.
- Further improvements in external and internal egg quality can be expected. An increase in percentage of yolk and percentage solids will be important for further processing.
- Testing pedigreed cross-lines in alternative housing systems will support selection for improved adaptability to alternative housing systems. Reduction of feather pecking and cannibalism under conditions of alternative housing systems without beak trimming will be one of the major challenges for breeding programmes in layers.
- Continuous selection will be enhanced by using microsatellite markers and expressed sequence tags to estimate genetic merit at the DNA level.

Breeders have to look at the world market for a specific product to define breeding goals and to determine priorities. In view of the apparent reduction in rate of progress, breeders of egg-type chickens will have to intensify testing programmes to improve accuracy of breeding value estimation and selection.

While the genetic potential of the birds is improved, management and nutrition also have to be adapted. Changing consumer demands will drive the adjustment of future breeding goals. In this context we expect that more attention will be directed to animal welfare related traits such as bone strength or resistance to osteoporosis (Whitehead, 1999). Although antagonisms between major selection goals and fitness are less obvious in highly productive layers than in fast growing broilers and turkeys, we have to keep a critical eye on liveability and stress resistance of layers, especially in alternative housing systems.

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