Genotype x environment interactions in poultry with special reference to genotype nutrition interactions

Peter Horn, University of Kaposvár, Faculty of Animal Science
7400 Kaposvár, Guba S. str. 40. E-mail: phorn@mail.atk.u-kaposvar.hu

Introduction

The differencial expression of genotypes over environments is reflected by the genotype x environment (GxE) interaction phaenomenon. The term genotype x environment interaction is most commonly used to describe situations where different genotypes (breeds, lines, strains, progeny groups) respond differently to different environments. The environments or environmental factors are numerous, most important ones are climate, altitude, nutrition, housing systems, exposure to diseases, mating systems. The differences of the various genotypes in their responses to different environments not only include changes in mean performance in the measured traits but also include variability in performance in a given trait of interest.

The potential importance of GxE interactions to both the poultry breeder and the producer appears to have been recognized as early as 1936 by Munro (cit. Sheridan, 1990). He also noted that each individual phenotype is the result of an interaction between a specific genotype and a particular environment. The term GxE interaction is normally only used to refer to interactions occurring between, rather than within individuals.

Under field conditions (and experiments) in poultry breeding and production a classification of interactions may not be used directly but it is very useful to know the changes in ranking order of genotypes from one to the other environment and the relative magnitude of the genotypic, environmental and interaction effects, and in several cases their effect on the variance of the traits of interest (homogeneity of the performance of a certain population).

The basic concepts of GxE interactions, the classification of GxE interactions, and methods used, inclusive statistical procedures to be applied in GxE evaluations are summarized by Sheridan (1990) and Mathur (2003).

Genotype x environment interactions have been investigated in a number of studies in poultry and were summarized by Tindell et al. 1967, Horn 1982, Cahaner 1990, Hartmann 1990, Sheridan 1990 and Mathur 2003 in extensive reviews, covering a great sample of genotypes and environmental factors inclusive several traits dealt with in the published papers.

Most of the experiments reported compared layer type breeds of chicken strains, commercial hybrids, purebreds vs. crossbreds kept under different rearing and housing systems, climatic conditions etc. With broiler type chicken a large number of commercial and experimental strains were tested in different housing systems, managemental and climatic conditions simuntaneously. In some cases the nutritional environment was confounded in management effects. GxE interaction studies are very scarce with turkeys. Few trials were specifically designed to study genotype x nutrition interactions in chicken fowl and turkey.

In the following I will focus the discussion on broiler type chicken and turkey regarding genetic x nutrition interactions.

Genotype x nutrition interactions in broiler chicken

The papers published between the 1960-1980^{s} on genotype x environment interactions in commercial type broilers indicate that GxE interactions contributed only 0-5 percent to the total phenotypic variance in the most important traits (Horn, 1982). However sex as a genetically determined factor leads often to significant and economically important interactions. Female broilers perform better under unfavourabre conditions compared to males (crowding, cage v. floor rearing, high temperatures, hatching egg size x 49 day broiler weight relationships etc.).

Horn et al (1984) tested 5 different commercial broiler strains fed diets of high and low nutrient level till 49 days of age in 1978.. The mean live weight of males and females across genotypes respectively were 1.93 and 1.53 kg on high plane of nutrition, and 1.55 kg and 1.41 kg on low plane of nutrition.

The variances (in%-to total) were: genotypes 9%, feeding 41%, sex 33%. Genotype x feeding interaction was not significant (1%), sex x feeding interaction was highly significant (11%). The live weight of males across genotypes was reduced by 20.7% if raised on low plane of nutrition, in females the depression in growth reached only 7.7% leading to the highly significant SxN interaction, indicating different nutritional requirement for growth for male and female broilers.

More recently Havenstein et al (1994) compared the performance of broilers representing 1957 and 1991 types fed typical 1957 and 1991 diets simultaneously, to measure the effect of genetic, sex and nutritional factors on growth, livability and feed conversion.

Using the average of both sexes the body weight of the 1991 type broilers feed 1991 diet exceeded those of the 1957 type broilers fed 1957 diets by 3.7 4.2 3.9 3.5 and 3.2 times at 21, 42, 56, 70 and 84 day of age. The 1991 type broiler fed 1991 type diet was 3.0, 3.4, 3.1, 2.9 and 2.1 times larger than the 1957 type broiler fed 1991 type diet. The impact of genetic factors on growth was highly significant at all times.

The 1991 diet increased the body weight of the 1957 type broiler between 20-26% compared to the 1957 diet. For the 1991 type broilers the tendency was similar till the age of 42 days (18-26%).

The advantage of the 1991 diet decreased rapidly thereafter to 4.2% till 84 days of age in the case of males and 11.8% for females. Strain, diet, sex effects were all significant throughout the experimental period. Strain x diet sex x diet interactions were all significant between 42-70 days of age ($P<0.05$).

In a repeated experiment Havenstein et al (2003) compared the performances of a typical commercial broiler of 2001 with a 1957 type (the same control strain as used in the 1994 trial) broiler fed with typical 2001 and 1957 type diets. In the average of both sexes the body weight of the 2001 type broilers fed 2001 diet were 4.22, 4.96, 4.8, 4.30 and 3.86 times heawier than those 1957 type birds on the 1957 diet at 21, 42, 56, 70 and 84 days of age respectively. The 2001 type birds on the 2001 diet were 3.81, 4.62, 4.45, 3.92 and 3.43 times larger as the 1957 type broilers on the 2001 diets at the same ages. The 2001 type broiler on the 1957 diet were 3.47, 3.94, 3.69, 3.40 and 3.13 times heavier as 1957 type birds on the 1957 type diet.

The 2001 type diet increased the growth performance of 2001 type broiler by 21-32% for the various ages measured over that observed with the 1957 diet. The relative difference in BW between the 2001 type broiler, on the 2001 diet versus the 1957 diet indicated that the change in diet increased growth rate by 10.8, 7.4, 9.7, 9.6 and 12% at the ages measured.

Highly significant differences were observed in BW due to strain, sex and diet at all ages. The strain x diet, and sex by diet interactions were significant ($P<0.05$) at all ages. The percentage proportion of the variance attributable to the main factors and interactions were not presented.

The two trials conducted by Havenstein et al (1994, 2003) indicate that 85-90% of the increase in body weight (till 56 days of age) came about due to genetic selection accomplished by the breeding companies, and 10-15% improvement was attributable to better nutrition improving growth performance.

Zhao et al (2004) evaluated genotype x diet interactions on growth of both layer and broiler type male chicken. Layers were fed broiler diet and vice versa from day 1 to 41. The live weight of layer chickens increased by 35% fed the broiler diet, whereas the weight of broilers decreased by 51% fed the layer ration, clearly indicating pronounced genotype x nutrition interaction. More details inclusive endocrinological implications, will be presented in this session later by Decuyperc et al.

Genotype x nutrition interaction in turkey

Commercial turkey diets in Europe normally have a higher amino acid: energy ratio than diets in the USA. Turkeys selected in the UK have been reared on low ME but high amino acid: ME ratio feed programmes based on wheat. Us diets are based on maize with higher ME contents but lower amino acid: ME feed programmes (Swalander, 2001). Commercial strains were compared and were reared using typical UK diets (fast) and US (slow) amino acid: energy ratios. Strain A a fast growing bird selected in the UK showed a significant response to higher nutrient density and exhibited heavier live weight on the fast feed programme, while strain C a slower growing type showed no response to the higher nutrient density, leading to significant (P<0.05) diet x strain interaction in growth. The results suggest that birds selected under diverse nutritional environments have different optimal nutritional requirements, and their performance under commercial conditions may change according to the feeding programme used (Swalander, 2001).

The differences in diets between, the UK and US hovewer seemed not to be large enough in the short term to lead to significant differences in heritability estimates, ranking of sires, and genetic correlations between growth traits in the same turkey populations selected and maintained in the UK and US simultaneously (Swalander, 2001).

With the objective to asses the contribution of long term genetic selection practiced by turkey breeding companies and that of nutrition (feeding management) improvement achieved during the last decades on growth of the turkey, two extreme genotypes were tested fed on two distinctly different diets. In the trial BUT Big6 type commercial heavy strain available in 1999, and a Bronze type strain was used, bred since 1965 as a genetic reserve population in Hungary, and which were widely used in commercial production in Hungary till the mid 1960s. Both populations were reared till 20 weeks of age on typical diets representing the standard feeds used in 1967 and 1999 (Horn et al, 2001).

The differences in live weight were all highly significant (P<0.001) between genotypes, sexes and nutritional management treatment groups (Table 1).

The relative differences in weight increase in both sexes as birds get older when BUT males and females are related to Bronze males and females (Bronze type=100%).

The BUT toms were 1.95, 2.50, 2.77, 2.99 and 3.13 times heavier at 4, 6, 10, 16 and 20 weeks of age compared to Bronze toms fed the 1999 diet. On the 1967 type diet the respective advantage of the BUT toms decreased to 1.64, 2.00, 2.15, 2.76 and 3.05 respectively.

The same tendencies are apparent regarding the female parameters, although on both diets used the relative superiority in growth of the BUT type females is even more pronounced as in males at all times of measurement (Table 2).

The relative improvement in weight of the turkeys as influenced by nutrition, type of the birds and sex is presental in Table 3.

The 1999 type feeds improved growth compared to the 1967 feeds in all treatment groups, but the relative reactivity of the birds show great differences depending on genotype, sex and age. The improved diets induced more gain in weight in the case of the 1999 type turkeys, much less reactivity could be observed of Bronze turkeys. The effects of feeding on weight increased till 10 weeks of age and decreased rapidly thereafter in both sexes regarding the BUT large type birds.

Bronze females showed the least response in growth to improved feeding with no marked age dependent pattern. Bronze males behaved similarly as BUT birds regarding the age dependent reactions to improved nutrition, although the improvement in growth was significantly less compared to BUT birds. On Table 4 the variances attributable to the various sources influencing weight are summarized, showing clearly that nutrition shows a clear declining tendency by age. Sex variance increases as expected and genetic effects dominante influencing growth. Nutrition x genotype interactions are very marked, but loose importance as nutritional effects decrease towards the second part of the rearing period. Sex x genotype components of variance gain in magnitude parallel to the variance of sex as turkeys get older.

The most important part of the turkey carcass is the breast fillet. The weight of the breast fillet of the turkeys is summarized on Table 5 for each treatment combination. Differences between genotypes, sexes, and nutritional treatment combinations were statistically significant in all age groups.

Genetic factors were the most important in determining the growth of the breast as shown in Table 6. The superiority of the 1999 type BUT birds compared to the Bronze type turkeys in breast weight increased in both sexes during the rearing period between 6-20 weeks of age.

The 1999 type diet increased the magnitude of the superiority of the BUT genotype over the Bronze type turkeys in both sexes and for all age groups. The breast weight of the BUT toms was 5.83 times heavier on the 1999 diet, and exceeded 5.26 times on the 1967 diet the respective performance of the Bronze toms. The corresponding superiority indicators of the BUT females were 6.01 and 5.81. Selection improved the breast growth twice as much as that of live weight at 20 weeks of age.

Advances in nutrition improved the weight of the breast fillet much less compared to the effect of selection. BUT large type turkeys showed a much greater reactivity as Bronze type turkeys. The effect of improved nutrition showed a clear declining tendency by age in BUT turkeys, but at the end of the fattening period the effect of the improved nutrition on breast weight was still nearly twice as effective as in the case of live weight (+19.8% across sexes vs. 11.7%).

For the Bronze turkeys no clear cut age related tendencies could be observed, improved nutrition had a smaller impact on breast muscle growth in males compared to females (Table 7.).

The percentage proportion of the variances attributable to the main factors and their interactions studied it can be concluded that the genetic effects clearly dominate the growth of the breast muscles. Nutritional effects loose importance as the rearing period advances, sex effects show the opposite trend. Nutrition x genotype is an important interaction component till 16 weeks of age. The sex x genotype interaction component increases parallel with the growing impact of the sex variance in influencing breast weight as birds get older (Table 8).

Conclusions

Experiments considering different breed sv. lines, types of broilers and turkeys revealed significant genotype nutrition interactions. The magnitude and practical significance of these interactions are different for various traits related to meat production. The importance and impact on variance of the nutrition x genotype interaction is often age dependent, in several traits such as growth, and related traits. In most cases nutrition-genetic interactions are of practical importance when considerable differences exist between genotypes involved and nutritional levels tested. In broiler and turkey comparisons no changes in ranking order occurred in growth between genotypes tested in different nutritional environments. The differences in mean performance between genotypes may change however significantly, reaching levels of practical importance. The importance and impact on variance of the nutrition x genotype interaction is often age dependent in growth and correlated traits. Both in broilers and turkeys nutritional and GxN interaction effects are much more significant and of practical importance in younger birds. During the rearing periods later on compensatory mechanisms under strong genetic influence (appetite) lead to the diminshered impact of different improved diets on growth and closely correlated traits. It is often overlooked that male and female birds represent distinctly different genotypes greatly deviating in very many physiological characteristics, phaenotypic performance. In most cases in meat type poultry sex x nutrition interactions (and sex x other environmental factor interactions) are more important to consider in practice as classical GxE interactions. There is little dought that more and more detailed knowledge accumulating in poultry physiology and chicken genomics will lead us closer to better understand the bases of GxE interactions (see the papers of Decuypere et al. and Groenen at this session) and provide nutritionists and practical breeders with more powerful tools to handle GxN interactions for the benefit of an even more qualitative and effective poultry meat production.

It is certain the poultry strains will be improved further by genetic tools, and we will have more diverse genetic stocks available in the years to come. It seems also very probable that as world population increases – and several other factors to be considered – alternative feed resources have to be utilized in formulating poultry feeds as at present, thus poultry diets will be more variable as nowadays (Farrel, 2005). In the future it will be essential to find optimal genotype x nutrition or sex x nutrition combinations to maximize efficiency, and reach the highest product quality standards in a given geographic area or market niche. To sum up GxN and SxN interactions and more broadly GxE interactions will have to be considered in poultry meat production and research in the future probably more as at present.

References

Cahaner, A. (1990): Genotype by environment interaction in poultry. Proc. 4th World Conf. of Genetics. Appl. Livestock Prod. 13-20. Edinburgh.

Decuypere, E., Onagbesan, O., Swennen, Q., Buyse, J., Bruggeman, V. (2005): The endocrine and metabolic interface of genotype-nutrition interaction in broilers and broiler breeders. In this same Proceeding.

Farrell, D. J. (2005): Matching poultry production with available feed resources: issues and constraints. World's Poultry Sci. Journ. 61. 299-307.

Groenen, M. A. M. (2005): Sequence and comparative analysis of the chicken genome: A new challenge for poultry breeding and nutrition. In this same Proceeding.

Hartmann, W. (1990): Implications of genotype-environment interactions in animal breeding: genotype location interactions in poultry. Worlds Poultry Sci. Journ. 46. 197-218.

Havenstein, G. B., Ferket, P. R., Scheideler, S. E., Larson, B. T. (1994): Growth, Livability, and Feed conversion of 1957 vs. 1991 Broilers when Fed Typical 1957 and 1991 Broiler Diets. Poultry Sci. 73. 1785-1794.

Havenstein, G. B., Ferket, P. R., Qureshi, M. A. (2003a): Growth, Livability, and Feed Conversion of 1957 vs. 2001 Broilers when Fed Representative 1957 and 2001 Broiler Diets. Poultry Sci. 82. 1500-1508. p.

Havenstein, G. B., Ferket, P. R., Qureshi, M. A. (2003b): Carcass Composition and Yield of 1957 vs. 2001 Broilers When Fed Representative 1957 and 2001 Broiler Diets. Poultry Sci. 82. 1509-1518.

Horn, P. (1982): Genotype-environment interactions in chickens. Proc. 2nd World Conf. Genet. Appl. Livestock Prod. Vol. 5. 699-708.

Horn, P., Ballay, M., Sütő, Z. (1984): Effects of artificially induced environmental factors on broiler performance and their interaction with genotype and sex of the broilers. Proc. XVII. World's Poultry Congr. 169-171. Helsinki.

Horn, P., Herendy, V., Kustos, O., Sütő, Z. (2001): Interactions between genotype, sex and nutrition on growth in turkeys. Proc. 2nd Poultry Genetics Symposium. 4-9. Gödöllő.

Mathur, P. K. (2003): Genotype-Environment Interactions: Problems Associated with Selection for Increased Production. In. Poultry Genetics, Breeding and Biotechnology. (Eds. Muir, W. M., Aggrey, S. E.) 83-99. CABI Publ.

Munro, S. S. (1936): The inheritance of egg production in the domestic fowl. I. General considerations. Sci. Agric. 16. 591-607. (Cit.: Sheridan, A. K. (1990).

Sheridan, A. K. (1990): Genotype x Environment interactions. In: Poultry Breeding and Genetics. (Ed. Crawford, R. D.). 897-912. Elsevier.

Swalander, L. M. (2001): Genotype by environment interaction from a breeders perspective. Proc. 2nd Poultry Genetics Symposium. 68-76. Gödöllő.

Tindell, L. D., Moore, C. H., Gyles, N. R., Johnson, W. A., Dreesen, L. J., Martin, G. A., Siegel, P. B. (1967): Genotype environment interactions in broiler stocks of chickens. 1. The importance of stock by location and stock by trial interactions. Poultry Sci. 46. 603-611.

Zhao, R., Muehlbauer, E., Decuypere, E., Grossmann, R. (2004): Effects of genotype-nutrition interaction on growth and somatotropic gene expression in the chicken. General and Comparative Endocrinology. 136. 2-11.

Table 1: Mean live weight of the turkeys as influenced by age, nutrition sex, and genotype

Genotype and sex	Live weight (g)									
	Age in weeks									
	4		6		10		16		20	
	Type of feed (year)									
	1999	1967	1999	1967	1999	1967	1999	1967	1999	1967
BUT male	986	702	2590	1825	6725	4472	13897	11679	19141	17017
Bronze male	505	426	1034	908	2421	2080	4638	4232	6118	5578
BUT female	868	643	2137	1604	5242	3910	10194	8258	12625	11393
Bronze female	410	373	782	739	1714	1588	3172	2995	3891	3626

(Horn et al. 2001)

Table 2: The relative improvement in live weight of turkeys for males and females (BUT vs. Bronze, Bronze=100%) as affected by diets fed

Genotype and sex	Relative improvement in weight (%)									
	Age in weeks									
	4		6		10		16		20	
	Feeding type (year)									
	1999	1967	1999	1967	1999	1967	1999	1967	1999	1967
BUT vs. Bronze male	195	164	250	200	277	215	299	276	313	305
BUT vs. Bronze female	211	176	273	217	306	246	321	275	324	314

Table 3: The relative improvement (%) in bodyweight of turkeys due to the 1999 type diet fed compared to the 1967 diet used

Genotype and sex	Age in weeks				
	4	*6*	*10*	*16*	*20*
BUT male	40.4	41.8	50.4	10.4	12.5
BUT female	34.9	33.9	59.6	19.4	10.8
Bronze male	18.5	13.9	16.4	9.6	9.7
Bronze female	9.9	5.8	7.9	5.9	7.3

Table 4: The percentage proportion of the variance in live weight of the turkeys attributable to the various sources

Sources	Variance %					
	Age in weeks					
	4	6	10	14	16	20
Nutrition(N)	11.7	7.4	8.1	3.4	0.5	0.7
Sex (S)	3.4	4.1	5.5	7.2	8.9	12.8
Genotype(G)	68.3	75.4	80.6	82.0	81.7	78.3
NxS	0.8	0.6	0.6	0.4	NS	NS
NxG	10.1	9.2	4.7	4.2	0.5	0.5
SxG	NS	0.5	0.4	1.6	7.1	6.2
NxSxG	NS	NS	NS	NS	NS	NS

All indicated percentages were statistically significant ($P<0.05$ - $P<0.001$) components

Table 5: The weight of the breast fillet (g) as affected by nutrition, sex and genotype of the turkey at 6, 16 and 20 weeks of age

Genotype and sex	Age in weeks					
	6		*16*		*20*	
	Feed types (year)					
	1999	1967	1999	1967	1999	1967
BUT male	486	303	3261	2600	4834	4054
BUT female	367	274	2389	1901	3306	2744
Bronze male	127	118	632	604	929	880
Bronze female	100	88	480	436	550	472

5 birds/treatment combination were slaughtered and dissected at
6, 16 and 20 weeks of age

Table 6: The relative superiority (%) in breast fillet weight of BUT 1999 type turkey compared to Bronze 1967 types depending of feed used (the performance of the Bronze type = 100)

Genotypes and sex	Age in weeks					
	6		*16*		*20*	
	Feeding type (year)					
	1999	1967	1999	1967	1999	1967
BUT male vs. Bronze male	382	256	515	438	583	526
BUT female vs. Bronze female	367	311	497	436	601	581

Table 7: The relative improvement (%) in breast fillet weight of turkeys due the 1999 type diet fed compared to the 1967 diet

Genotype and sex	Age in weeks		
	6	*16*	*20*
BUT male	60.4	25.4	19.2
BUT female	33.9	25.6	20.4
Bronze male	7.6	4.6	7.5
Bronze female	13.6	10.0	16.5

Table 8: The percentage proportion of the variance in breast fillet weight of the turkeys attributable to the various sources

Sources	Variance %		
	Age in weeks		
	6	**16**	**20**
Nutrition (N)	6.7	2.0	1.2
Sex (S)	3.2	4.8	6.5
Genotype (G)	74.7	85.0	83.9
NxS	1.1	NS	NS
NxG	9.7	3.1	1.6
SxG	1.2	4.2	5.7
NxSxG	NS	NS	NS

All indicated percentages were statistically significant ($P< 0.05$ - $P< 0.001$) components