Stellingen

1. Although McClintock and Cunningham in 1974 stated that the combined use of cumulative discounted expressions and economic values as discounted economic weights leads to a better definition of breeding goals than the use of economic values only, this economically sound concept unrightly is not adopted widely in animal breeding. *This thesis.*

2. Regarding crossbreeding systems for broiler, breeding goals should consist of both crossbred and purebred improvements, especially for reproductive performance; in addition to purebred information, inclusion of crossbred information in selection index gives an increase in genetic gain. *This thesis.*

3. Given the fast changing markets in and outside China, and the rapid shrink of domestic animal genetic diversity of the world, the local chicken breeds in China can make considerable contributions to human food security and food quality as well. *This thesis.*

4. The FAO's preference of conservation in accordance with utilization of animal genetic resources, conflicts with Chuang Tsu's philosophy: it is useful to be useless.

5. Considering the biological maximum for growth of broiler, the worldwide improvement of human welfare, and the public awareness of animal products, broiler breeding organizations should turn their emphasis on quality, versatility and ethical considerations. *This thesis.*

6. In contrast to research emphasis which has been given to statistical procedures, testing and selection schemes, and dissemination structures, Harris and Newman (1994) believe that animal breeding organizations get far more benefit from an economically sound breeding objective.

7. The significance of animal production in the present China is a good example that human welfare in developing countries can be effectively improved by the application of modern agricultural techniques.

8. Science and technology is the primary driving force behind economic and social development. *Deng Xiaoping, 1980s.*

9. Eternal truths will be neither true nor eternal unless they have fresh meaning for every new social situation. *Franklin Delano Roosevelt, 1940.*

10. A story about a western writer who has been in China for three times: his first one-week visit resulted in a book on China, his second one-month visit left an article on China, and his third one-year visit ended with no word on China.

11. It is much easier to say "west and east, together is the best" in a general sense than to make this combination for a real case.

Xiaosong Jiang

Propositions accompanying the Ph.D. thesis: *Broiler Breeding: Breeding Goals, Selection Schemes and the Usefulness of Local Breeds for China.* 22 December 1999, Wageningen, The Netherlands.

BROILER BREEDING

Breeding Goals, Selection Schemes

and the Usefulness of Local Breeds for China

Promotor: dr. ir. E. W. Brascamp
Hoogleraar Fokkerij en Toegepaste Genetica

Co-promotor: dr. ir. A. F. Groen
Universitair Docent, Departement Dierwetenschappen

Xiaosong Jiang

BROILER BREEDING

Breeding Goals, Selection Schemes

and the Usefulness of Local Breeds for China

Proefschrift
ter verkrijging van de graad van doctor
op gezag van de rector magnifius
van Wageningen Universiteit,
dr. C. M. Karssen,
in het openbaar te verdedigen
op Woensdag 22 December 1999
des namiddags te half twee in de Aula.

CIP-DATA KONINKLIJKE BIBLIOTHEEK, DEN HAAG

Jiang, Xiaosong

Broiler breeding: breeding goals, selection schemes and the usefulness of local breeds for China /
Xiaosong Jiang. – [S.I.: s.n.]
Thesis Wageningen University. – With ref.
- With summary in Dutch.
ISBN 90-5808-164-8
Subject headings: broiler/ breeding goals/selection/local breeds/China.

Xiaosong Jiang, 1999. Broiler breeding: breeding goals, selection schemes and the usefulness of local breeds for China. This dissertation considers three aspects of broiler breeding: definition of breeding goals, selection schemes for specialized lines, and the usefulness of local breeds for China. Economic values in broiler breeding were derived based on a deterministic model. A systematic design for the application of gene flow methodology to derive cumulative discounted expressions for production and reproduction traits was developed, and the effects of factors on the magnitude of cumulative discounted expressions were quantified. A breeding goal and a realistic scheme for the application of combined crossbred and purebred selection in a specialized dam line were defined, and the relative value of purebred and crossbred performance information in such a scheme was appraised. The potential role of local breeds in China in commercial breeding programs was discussed in relation to both providing high quality meat and meeting the objectives of genetic resource conservation. **Ph.D. Thesis**, Animal Breeding and Genetics Group, Department of Animal Sciences, Wageningen University, P.O. Box 338, 6700 AH Wageningen, The Netherlands.

Aan mijn ouders
Aan Bing en Yuguo

Preface

First of all, I am most grateful to my co-promotor, Dr. ir. Ab Groen, for his insightful supervision and day-to-day guidance. Without it, the completion of this thesis would never be possible. Apart from his guidance on animal breeding, the more important I learnt from him is how to become thoughtful, strategical, logical and efficient as a scientist. His help also made my stay in Wageningen a great pleasure. Words can never be sufficient to express my debt to him.

It is my great pleasure to thank my promotor, Prof. Dr. ir. Pim Brascamp, for accepting me as a visiting researcher, which initiated this Ph.D. research project afterwards, also for his constant concern of this research project, and for his close supervision during the period Ab was on sabbatical leave. His guidance was very educational and enjoyable.

The animal breeding and genetics group of Wageningen University, and the people at this group, are highly appreciated for their help in different aspects, which contributed to this thesis as well. I would like to express my gratitude to Prof. Dr. ir. Johan van Arendonk and Dr. ir. Tette van der Lende, for the courses I followed and for their help whenever I needed. I greatly appreciate the help from the secretaries, Ms. Ada Wiggerman and Ms. Maria Lippelt. My thanks also go to Ing. Piet de Groot, Ir. Bart Ducro, Ir. Alex Hulzebosch and Ing. Henk Vos, for their assistance in various aspects. I enjoyed sharing offices, and talks and discussions with Ir. Freddy Fikse, Prof. Dr. Ron Pearson, Dr. Hiro Hirooka, Ir. Bernardo Vargas and Ir. Pim van Hooft. Helpful were also discussions and talks with Ir. Piter Bijma, Dr. ir. Marco Bink, Dr. ir. Henk Bovenhuis, Ir. Dirk-Jan de Koning, Ir. Jaco Eisen, Dr. ir. Egbert Kanis, Dr. ir. Erwin Koenen, Ir. Delphin Koudande, Ir. Jascha Leenhouwers, Dr. ir. Sijne van der Beek, Ir. Liesbeth van der Waaij, Ir. Jan-Thijs van Kaam, Ir. Birgitte van Rens and Dr. ir. Ant Vollema. The other people at this group are acknowledged for their help although their names are not mentioned one by one.

I like to give my thanks to Dr. ir. Ella Luiting, for her help resulting in my first stay at this group. I also owe to the administrative and technical staff at Zodiac for their assistance in different ways. Staff members at the Dean's office and Liaison office are acknowledged for taking care of the financial, visa and other issues for me.

I very much appreciate the cordial atmosphere created by Ab, Rita, and their kids.

Enjoyable talks with my Chinese friends in Wageningen who specialized in different fields broadened my mind from time to time. My special thanks also go to those who

brought me companionship and friendship that made my daily life enjoyable and pleasurable.

The coauthors of Chapter 2, Dr. Derek Emmerson and Ir. Addie Vereijken, deserved my many thanks for their cooperation. I am very obliged to the anonymous reviewers for their comments on Chapters 2, 3, 4 and 5, which polished the articles.

I would like to express my sincere appreciation to Prof. Xiangpin Qiu and Prof. Fantong Zeng of Sichuan Agricultural University of China, for their guidance during my Master study period, which initiated my career as a researcher. My employer, Sichuan Academy of Animal Sciences, is acknowledged for its help in various ways for me to fulfill this project.

Finally, I take this opportunity to show my gratitude to my dear wife Bing and son Yuguo. I am indebted to them so much for the long time separation. Their patience and encouragement are indispensable for the accomplishment of my study. I write this word with deepest affection and from the very bottom of my heart.

Xiaosong Jiang

Wageningen, The Netherlands
December 1999

Contents

Chapter 1

General Introduction

X. JIANG

Animal Breeding and Genetics Group, Wageningen Institute of Animal Sciences, Wageningen University, Wageningen, The Netherlands

The broiler breeding industry has been primarily shaped by the desire to reduce costs. Considering the biological maximum for growth of broiler, the worldwide improvement of human welfare, and the public awareness of animal products, broiler breeding organizations should turn their emphasis on quality, versatility and ethical considerations.

NEW TASK FOR BROILER BREEDING

Since 1940s, the art of broiler breeding has made dramatic progress resulting in large-scale commercial exploitation of genetic selection by breeding organizations (Ewart, 1993). For the last two decades, the body weight of broiler at the age of 42 days has increased by 130%, and the age to 2.0 kg body weight has decreased from 63 to 37 days with the feed conversion rate improving from 2.7:1 to 1.6:1. At the same time, carcass and meat yields have also been improved. The increase in broiler performance has played a major role in the expansion of broiler production, and contributed to food security as a resource for protein. The per capita consumption of broiler meat has risen from 4.0 kg in 1950 (Havenstein *et al.*, 1994) to 36.4 kg in 1996 (Watt Publishing Co., 1997) in the United States, and the per capita consumption of poultry meat has increased from 1.2 kg in 1984 to 7.8 kg in 1995 in China (Huang, 1997). The improvement of broiler performance, according to the comparison studies using 1957 vs 1991 broiler strains, is largely (about 80%) due to the efficient genetic selection by breeding organizations (Havenstein *et al.*, 1994). Progress in breeding and selection techniques has played an essential role in improving performance of broiler (Albers, 1998). Four major driving forces, including cost reduction, quality improvement, versatility and ethical considerations, have been shaping the breeding industry (Ewart, 1993). The balance of these driving forces has been changing from time to time. Before 1960s, cost reduction was much more stressed than the others. Then, the importance of the other three forces was getting closer to that of cost reducing, and in 1990s the importance of quality improvement even excelled that of cost reducing. It is predicted that in the future, all these four driving forces will play a more equivalently important role in broiler breeding industry. Broiler breeding in the future will be challenged by a more complicated task than ever before.

ISSUES CONCERNING BROILER BREEDING PROGRAMS

A comprehensive and sound breeding program is the basis of broiler breeding practice. A broiler breeding program, like those of other classes of animals, includes definition of breeding goals, choice of selection criteria, design of matings for selected animals, and design of systems for expansion of genetic superiority (Harris *et al.*, 1984). Definition of breeding goals and design of selection schemes are primary steps in optimizing breeding programs.

Definition of Breeding Goals

The general goal of animal breeding is: obtaining a new generation of animals that will produce the desired products more efficiently under future farm economic and social circumstances than the present generation of animals (Politiek, 1962, cited by Groen, 1989). To optimize levels of genetic improvement of breeding goal traits, traits are weighed by their predicted contribution to increased economic revenue (Hazel, 1943), which is determined by the multiplication of economic value and cumulative discounted expression (*cde*) of a trait (McClintock and Cunningham, 1974; Brascamp, 1978), the so called discounted economic value (Groen, 1989). The economic value of a trait expresses to what extent economic efficiency of production is improved at the moment of expression of one unit genetic superiority of that trait. The *cde* of a trait reflects time and frequency of future expression of a superior genotype originating from the use of a selected individual in a breeding program. Theoretical aspects of derivation of economic values in animal breeding were recently summarized by Groen *et al.* (1997). Elsen and Mocquot (1974) and Hill (1974) proposed discounted gene flow method for deriving *cde*. Both economic values and *cde* are dependent on production circumstances, for example, economic values strongly depend on market price ratios, and *cde* are influenced by the structure of the production system. Studies in these aspects have been carried out by, e.g., Hirooka and Groen (1999). Besides, the definition of breeding goals is influenced by environmental factors (Brascamp *et al.*, 1998) and should meet the requirements of sustainable production systems (Olesen *et al.*, 1999). For broiler breeding, only few sets of economic values have been presented in scientific literature (see Harris and Newman, 1994), while no attention is paid to the derivation of *cde*.

Design of Selection Schemes

In broiler production systems, production and reproduction traits are expressed at different stages. Production traits are expressed only at commercial grower stage, while reproduction traits are expressed at both pure line stage and multiplier stage. In broiler breeding, selection is carried out at pure line stage (purebred), while the aim of breeding is to increase the (crossbred) performance at both commercial grower and multiplier stages. Wei *et al.* (1991) and Baumung *et al.* (1997) studied the genetic correlation between purebred and crossbred performance under a two-locus model and concluded that in most cases the genetic correlation for a trait between these two populations is not unity, that is, a certain trait in different populations is not genetically the same.

To maximize the response of selection, approaches to make use of both purebred and crossbred information were derived, namely, combined crossbred and purebred selection (CCPS, Wei, 1992). Harvey (1992, cited by Hartmann, 1992) compared the accuracy of estimating breeding values of purebred for crossbred combining ability from different source of information, in which purebred and crossbred records were equally weighed. Wei and Van der Werf (1994) suggested the weighing factors to be derived by the discounted gene flow methodology.

In broiler breeding, in sire lines (originating from, e.g., White Cornish) selection is on production traits only; in some cases fertility is also included. In dam lines (from, e.g., White Plymouth Rock) both production and reproduction traits are selected for. Thus, different selection schemes are required for sire and dam lines. Smith (1964) concluded that selection in specialized sire and dam line is at least as efficient as selection within a single (dual purpose) line, and that the relative efficiency of the former increases if there is an unfavorable correlation between the two sets of traits under selection. The selection scheme for a given line, say, a specialized dam line, should be optimized to meet the requirements of consumers, processors, commercial growers, multipliers and primary breeders. The last four sectors may be in an integrated, partly integrated or non-integrated operation. Different enterprise operations have different implications for genetic improvement for a given trait, depending on perspective taken, either maximizing profitability or minimizing costs (Brascamp *et al.*, 1985; Hirooka and Groen, 1999).

CHOICES OFFERED BY LOCAL CHICKEN BREEDS IN CHINA

Chicken raising in China has a long history. There is a large number of local chicken breeds that developed in different circumstances of various regions of the country. In some parts of China, local consumers prefer chicken meat with high sensory quality, a driving force for the breeding for high (sensory) quality meat of broiler. Although the last decade has seen tremendous increase in chicken production in China as a result of the equivalent increase in gross national product (GNP) per capita (Watt Publishing Co., 1997), there is still large potential demand for chicken meat.

The commercial crossbred (white) broilers from breeding organizations in western countries have a worldwide dissemination. The number of independent breeding programs has been reduced sharply, and only a few breeds are used in these programs. In the way that breeding and selection took place, the modern commercial stock of laying hens has lost important genes, which led populations being unable to perform well when returned to the old floor/free range systems (Sørensen, 1997). While the modern commercial meat-type and egg-type stocks are gradually losing their ability of fitness and adaptability, the local and un-industrialized breeds will appear more and more important in future production with their characteristics. The formation and existence of local breeds are closely connected to the ecological, economic and social conditions of the regions. The value of these breeds and their genes is versatile: they can be used in modern breeding programs but they also have historical importance and ethnographic significance (Alderson and Bodó, 1992). For the fact that a considerable proportion of world animal genetic resources is at high risk of being lost, FAO organized the Global Strategy for the Management of Farm Animal Genetic Resources (Hammond, 1998). The large number of local chicken breeds in China provides choices for broiler breeding in future. Therefore, both conserving the local breeds and breeding with these breeds will come to be more important for future China, and for the world.

OUTLINE OF THIS THESIS

This dissertation considers some aspects of broiler breeding, including: definition of the breeding goals in broiler production systems, selection schemes for specialized lines, and the usefulness of local chicken breeds for China. Firstly, Chapter 2 describes a deterministic model for economic analysis of broiler production systems and the derivation of economic values in integrated and non-integrated systems. Four stages of the production system are considered: multiplier breeder, hatchery, commercial grower, and processor. The model is tested by using simulated economic parameters.

Then, in Chapter 3, economic values in broiler breeding are derived with the model of Chapter 2, considering a fixed amount of broiler meat output of the production system. Resulting levels of economic values are illustrated by showing underlying cost or profit changes in the production system. Sensitivity analysis is made for changing levels of production performance, product prices and feed prices.

The marginal economic values derived in the previous chapter should be weighed by the number of discounted expressions for each trait. Therefore, in Chapter 4, a systematic design for the application of discounted gene flow methodology to derive *cde* for production and reproduction traits in broiler breeding is proposed. The *cde* are calculated for different alternatives regarding crossbreeding system, selection scheme, selection path, trait, interest rate, and time horizon for evaluation. Application of *cde* in broiler breeding is also discussed.

In order to investigate whether or not CCPS improves the genetic response when the aim is to increase the performance at both crossbred and purebred stages of the crossbreeding system, this study constructs a breeding goal and a realistic scheme for the application of CCPS in a specialized dam line of broiler and appraises the relative value of purebred and crossbred performance information in such a realistic scheme. A three-way crossbreeding system is assumed. The breeding goal is defined based on economic values and cumulative discounted expression of hatching egg number. Two selection procedures are proposed, one with shortened generation and the other with normal generation interval. The effects of family structures and genetic parameters on the efficiency of CCPS are also evaluated. The results from this study are in Chapter 5.

After the above results have been obtained, this thesis finally goes to a more specific situation. Chapter 6 discusses the past, present and future of local chicken breeds in China. It illustrates the origin and formation of the local breeds in relation to ecological, economic and social circumstances. A general description is given for local chicken breeds. The present status of the chicken production and the market in China, in comparison with the western countries, are reviewed. Also, the present status of broiler breeding with the local breeds is illustrated, including breeding goals and the existing breeding programs. The potential role of local breeds in breeding programs in China is discussed in relation to both providing chicken meat of higher quality (than white broilers) for the local market and meeting the objectives of genetic resource conservation.

REFERENCES

Albers, G. A. A., 1998. Future trends in poultry breeding. Pages 16–20 *in*: Proceedings of the 10th European Poultry Conference. Jerusalem, Israel.

Alderson, L., and I. Bodó, 1992. Genetic conservation of domestic livestock. Vol. 2. C.A.B International, Wallingford, UK.

Baumung, R., J. Sölkner, and A. Essl, 1997. Correlation between purebred and crossbred performance under a two-locus model with additive by additive interaction. J. Anim. Breed. Genet. 114:89–98.

Brascamp, E. W., 1978. Methods on economic optimization of animal breeding plans. Report B-134, Research Institute for Animal husbandry "Schoonoord", Zeist, The Netherlands.

Brascamp, E. W., C. Smith, and D. R. Guy, 1985. Derivation of economic weights from profit equations. Anim. Prod. 40:175–180.

Brascamp, E. W., A. F. Groen, I. J. M. de Boer, and H. Udo, 1998. The effect of environmental factors on breeding goals. Vol. 27, Pages 129-136 *in*: Proceedings of the Sixth World Congress on Genetics Applied to Livestock Production. Armidale, NSW, Australia.

Elsen, J. M., and J. C. Mocquot, 1974. Récherches pour une rationalisation technique et économique des schémas de sélection des bovins et ovins. Inst. Nat. Réch. Agronomique. Bull. Technique Dept. Génétique Anim. No.17.

Ewart, J., 1993. Evolution of genetic selection techniques and their application in the next decade. Br. Poult. Sci. 34:3-10.

Groen, A. F., 1989. Cattle breeding goals and production circumstances. Ph.D. Thesis. Department of Animal Breeding, Wageningen Agricultural University, Wageningen, The Netherlands.

Groen, A. F., T. Steine, J. J. Colleau, J. Petersen, J. Pribyl, and N. Reinsch, 1997. Economic values in dairy cattle breeding, with special reference to functional traits. Report of an EAAP-working group. Livest. Prod. Sci. 49:1-21.

Hammond, K., 1998. Development of the global strategy for the management of farm animal genetic resources. Vol. 28, Pages 43-50 *in*: Proceedings of the Sixth World Congress on Genetics Applied to Livestock Production. Armidale, NSW, Australia.

Harris, D. L., and S. Newman, 1994. Breeding for profit: synergism between genetic improvement and livestock production (a review). J. Anim. Sci. 72: 2178-2200.

Harris, D. L., T. S. Stewart, and C. R. Arboleda, 1984. Animal breeding programs: a systematic approach to their design. Advances in Agricultural Technology, Agricultural Research Service, U.S.D.A.

Hartmann, W., 1992. Evaluation of the potential of new scientific developments for commercial poultry breeding. World's Poult. Sci. J. 48:17-27.

Havenstein, G. B., P. R. Ferket, S. E. Scheideler, and B. T. Larson, 1994. Growth, livability, and feed conversion of 1957 vs 1991 broilers when fed "typical" 1957 and 1991 broiler diets. Poultry Sci. 73:1785-1794.

Hazel, L. N., 1943. The genetic basis for constructing selection indexes. Genetics 28: 576-490.

Hill, W. G., 1974. Prediction and evaluation of response to selection with overlapping generations. Anim. Prod. 18:117-139.

Hirooka, H., and A. F. Groen, 1999. Effects of production circumstances on expected responses for growth and carcass traits to selection of bulls in Japan. J. Anim. Sci. 77:1135-1143.

Huang, S., 1997. The past, present and future of poultry industry in China. Poultry Industry Science and Technology 13(10):4-8 (in Chinese).

McClintock, A. E., and E. P. Cunningham, 1974. Selection in dual-purpose cattle population: defining the breeding objective. Anim. Prod. 18:237-247.

Olesen, I., A. F. Groen, and B. Gjerde, 1999. Definition of animal breeding goals for sustainable production systems. J. Anim. Sci. (accepted).

Smith, C., 1964. The use of specialised sire and dam lines in selection for meat production. Anim. Prod. 6:337-344.

Sørensen, P., 1997. The population of laying hens loses important genes: a case history. Animal Genetic Resources Information. Vol. 22:71-78. FAO, Rome, Italy.

Watt Publishing Co., 1997. Watt poultry statistics yearbook 1997. Poultry International, Mt Morris, IL, USA.

Wei, M., 1992. Combined crossbred and purebred selection in animal breeding. Ph.D. Thesis, Department of Animal Breeding, Wageningen Agricultural University, Wageningen, The Netherlands.

Wei, M., and J. H. J. Van der Werf, 1994. Maximizing genetic response in crossbred using both purebred and crossbred information. Anim. Prod. 59:401-413.

Wei, M., J. H. J. Van der Werf, and E. W. Brascamp, 1991. Relationship between purebred and crossbred parameters. II. Genetic correlation between purebred and crossbred performance under the model with two loci. J. Anim. Breed. Genet. 108:262-269.

Chapter 2

A Deterministic Model for the Economic Evaluation of Broiler Production Systems

A. F. GROEN*, X. JIANG*, D. A. EMMERSON†, and A. VEREIJKEN‡

**Animal Breeding and Genetics Group, Wageningen Institute of Animal Sciences, Wageningen University, Wageningen, The Netherlands, †Hybrid Turkeys Inc., Kitchener, Ontario, Canada, and ‡Euribrid B.V., Boxmeer, The Netherlands*

Published in ***Poultry Science***, 77 (1998): 925–933.

Model: A set of mathematical expressions representing the behaviour of a system. The model developed in this chapter can be used for the economic evaluation of poultry meat production systems and the derivation of economic values in breeding goals for these systems.

ABSTRACT A deterministic model for the economic evaluation of broiler production and the derivation of economic values in broiler breeding was developed and tested. The model distinguishes four production stages: multiplier breeder, hatchery, commercial grower, and processor. The processor is included to determine relationships for the price per kilogram of live weight and the quality of the carcass, either on "whole sale" or "further processed" base. Quantity of product output for the system is fixed by a predetermined amount of kilogram carcass of final product broilers finished by the commercial grower. Profitability of production and cost prices per unit product for subsequent stages can be calculated. Exogenous parameters are easily changeable in order to calculate profitability and cost prices for different production levels or production circumstances. Economic values can be derived considering influences of changes in genetic merit for performance traits on profitability or costs price, for integrated and nonintegrated production systems. By changing exogenous parameters, the model can also be used to analyze profitability or derive economic values for other meat-type poultry, such as turkey.

Key words: broiler, economics, modeling, production system.

INTRODUCTION

Management of enterprises can be considered a cyclic process including three primary functions (Boehlje and Eidman, 1984): planning, implementation, and control. Planning is the process of selecting among various alternative actions that can be implemented. Normative modeling of the enterprise can be used to evaluate alternative actions in order to support decision-making.

Animal breeding is a part of strategic (long-term) planning of production (Groen, 1989). The breeding goal defines the direction of a technological development — relative improvement of genetic merit for different performance traits. Economic values are major factors in defining the breeding goal (Harris, 1970). The economic value of a trait expresses the extent to which improvement of genetic merit of a trait can contribute to an improvement of economic efficiency of animal production systems. Normative bioeconomic multi-equation simulation models offer good opportunities to derive economic values, for example, by allowing sensitivity analysis for alternative prices and production levels (Groen, 1989). Bioeconomic models have been used to derive economic values in swine (Tess *et al.*, 1983; De Vries, 1989), dairy cattle (Groen, 1988) and beef cattle (Hirooka *et al.*, 1998).

Broiler production is a system with several actors, e.g., multiplier breeders, commercial growers, and processors. Strain and Nordskog (1962) developed a model to analyze profits of multiplier breeders and commercial growers (integrated and nonintegrated) using a function of several performance traits of the parent flocks and the final products. Moav and Moav (1966) described net profit per unit weight of broiler meat as a function of market age and the total number of eggs per hen in the parental stock (PS). Harris (1970) and Dickerson (1970) proposed general functions to evaluate the profitability of meat-type animal. Subsequently, different models were derived and used in broiler breeding (Pasternak and Shalev, 1983; Shalev and Pasternak, 1983; Akbar *et al.*, 1986; Shultz, 1986; Timmons and Aho, 1987; Lance, 1990; Fattori *et al.*, 1991). These studies did not deal with the broiler production as a complete system and traits considered focused on one or some elements of broiler production.

This paper describes a deterministic model for the economic analysis of broiler production systems and the derivation of economic values in integrated and nonintegrated systems. In order to test the model, simulated economic parameters are presented.

MODEL

General Aspects

In producing broilers, many actors are involved, starting with the primary breeder and finally, of course, the consumer. This deterministic model focuses at multiplier breeder, hatchery, commercial grower, and processor stage (Figure 1). In practice, different stages may be fully or partly integrated. The primary breeder is not modeled in detail — exogenous parameters are used to define production costs of PS eggs. The hatchery is included to define specific costs associated with hatching eggs. The processor is included to determine relationships for the price per kilogram of live weight and the quality of the carcass. The consumer stage is represented by exogenous parameters for market prices of broiler meat products (e.g., breast). Eggs will be transferred between multiplier breeder and hatchery; chicks (aged 0 wk) will be transferred between hatchery and commercial grower (Figure 1). The model calculates the profit margin (profitability, total revenues minus total costs) of production per system stage, using market prices for products transferred between stages. Cost prices (total costs per unit product) are calculated for an integrated production system. The economic value of a performance trait can be derived by comparing profitability or cost price for a defined base situation with profitability or cost price after a marginal change in genetic merit for that particular performance trait.

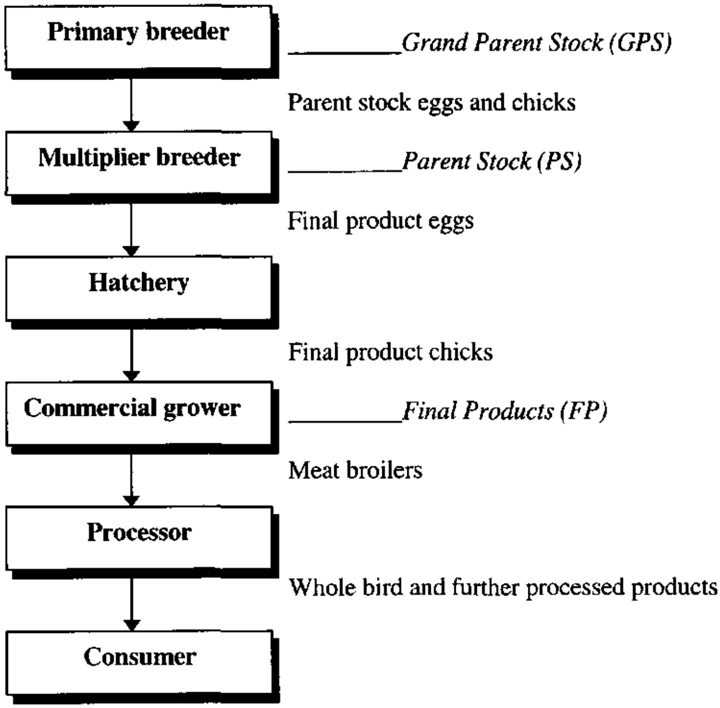


FIGURE 1. The structure of the broiler production system.

The following description defines, per stage, how to compute the dependent variables from the independent variables. The independent variables are the exogenous parameters of the system. Both dependent and independent variables are divided into three categories: price variables, production variables and scale variables. The total of the price variables defines the economic environment of the system. The total of the production variables gives the performance level of the broiler stock. Scale variables define the size of the system and are of particular importance when including fixed costs per enterprise in derivation of both profit margin and cost price.

At different system stages, production is by chickens of different lines with different genetic background. At the multiplier breeder, egg production is by a (crossbred) female PS. Female parental stock is usually mated to males from another (crossbred) parental stock line. So, animals producing at the commercial grower (final products, FP) are also crossbred, having 50% of their genetic background in common with each PS line. Although genetic links exist, in this model no direct relationships between performance traits of different lines (or categories, e.g., male vs female) are considered. These links, however, can be introduced by an appropriate choice of the exogenous parameters for PS and final products (Akbar *et al.*, 1986).

The model is described here in general terms; relevant equations are summarized in Appendix A.

System Scaling

The base scale exogenous parameter is "kilograms of carcass of FP of broilers finished by the commercial grower" (FPCARCASS). In other words, the size of the system is defined on the basis of the consumer market output, ignoring market output from the multiplier breeder (laying hens, breeder males). The number of FP chicks is derived as a function of carcass yield per finished chick. The number of PS female chicks required to give a certain market output (as defined by FPCARCASS) depends on production characteristics of the PS (i.e., hen housed egg production) and the final products (i.e., live weight and carcass yield), as well as on rates of involuntary culling of eggs (infertility, inhatchability) and chickens (mortality rate in PS, early and late mortality in final products).

Multiplier Breeder

The multiplier breeder purchases chicks from primary breeders: female chicks from a grandparent dam (crossbred) line and male chicks from a grandparent sire (crossbred) line, and sells FP eggs. The profit margin of the multiplier breeder is calculated as the total revenues minus the total costs at this system stage. The cost price per FP egg is calculated as the total costs at this system stage divided by the number of FP eggs produced. As an additional parameter, variable costs of parental stock males can be calculated as the sum of costs of purchasing male chick, and costs of feeding males, minus the salvage values of males at the end of the laying period. An alternative way to derive the profit margin of the multiplier breeder is to compare market price and cost price per FP egg hatched. When considering an integrated production system, the market price and cost price are equalized, in other words, profit will be zero.

The revenues of the multiplier breeder are calculated as the multiplication of number of FP eggs produced and the market price per FP egg. The costs of the multiplier breeder consist of costs of purchasing the female and male chicks, feed costs, and other variable and fixed costs. Salvage values of culled male, females and eggs are considered as negative costs components; this way, costs better reflect the "added values" from input of primary production factors. When starting rearing, numbers of males and female chicks are set at a certain ratio. Both breeder females and males are housed at an age of about 20 wk, again at a (different) fixed ratio. Possibly, a significant number of males is marketed at the end of the rearing period. Marketing males at the end of the rearing period is not practised in Dutch broiler production, but it is usually done in (e.g., Northern American) turkey production. Revenues from marketing parental stock males are not considered in the model as described, but can easily be included.

The model distinguishes mortality rates of PS for the early period of rearing (0 to 2 wk of age), late rearing period (2 wk of age until being housed) and for the laying period. Also, separate mortality rates for male and female PS are assumed, as male mortality usually exceeds female mortality. Feed costs associated with early mortality are negligible. Feed costs associated with mortality during other periods are proportional to live weight of the animals at half time of this period. Mortality disposition costs are not considered. Feed costs for hens during the laying period include requirements for growth and egg production. Different feeds are assumed for rearing females and males, for breeder males, and for laying females. Salvage values are calculated from the number of animals or eggs involved, and market prices per kilogram of live weight. Variable costs of the multiplier breeder are assumed to be related to the number of PS females housed only, including costs of rearing males and breeder males.

Hatchery

The hatchery is the enterprise in which FP eggs are hatched to become FP chicks (Figure 1). Part of the FP eggs will not be fertilized (determined by the percentage of fertile FP eggs), and part of the fertilized eggs will not yield living FP chicks (determined by the percentage hatch of fertile eggs). Variable costs of hatching are assumed to be associated with the number of eggs hatched rather than the number of living chicks.

The profit margin of the hatchery is calculated as revenues of the hatchery minus the costs of the hatchery, where the revenues of the hatchery are determined by the number of FP chicks sold, and the costs of the hatchery are determined by the number of FP eggs bought, plus the variable costs and fixed costs at this stage. The cost price per FP chick is given by the total costs of the hatchery divided by the number of FP chicks produced. Again, an alternative way to derive the profit margin is to compare market price and cost price per FP egg hatched, and profit will be zero when market price and cost price are equalized in an integrated system.

Commercial Grower

The commercial grower purchases FP chicks from the hatchery at a uniform price per chick. Assumed sex ratio female:male chicks is 1:1. There are differences between males and females with respect to (early and late) mortality, as well as feed consumption, finishing weight, and prices per kilogram of live weight at finishing.

Revenues of the commercial grower arise from selling FP animals. The commercial grower is paid per kilogram of FP finishing weight. As finishing weight is set as an exogenous production parameter, length of the growing period (about 7 wk) and growth rate are dependent performance variables. The exogenous performance parameter is feed consumption. Feed consumption is set for a given finishing weight, growing period and growth rate.

Costs components for the commercial grower are feed cost, purchased FP starting birds and possibly other costs fixed per bird or fixed per farm. Feed requirements are per kilogram feed, assuming one standard feed for the growing period. Early (0 to 1 wk of age) and late (1 onwards) mortality are distinguished during the growing period. Feed costs associated with early mortality are ignored; feed costs of late mortality are related to 50% of the finishing weight of the animals.

By combining revenue and cost components, the profit of the commercial grower, the cost price per FP finished male, and the cost price per FP finished female are calculated. In an integrated approach, cost prices per finished FP are set equal to revenues for the commercial grower.

Processor

The Processor is included in the model to define relationships between FP quality and price per kilogram of live weight. Commercial growers usually are paid on a per kilogram of live weight base, without a explicit payment for quality of the FP. However, one might determine the (long term) relationship between FP quality and price per kilogram of live weight by considering product revenues of the processor. For the consumer market, products are either the whole carcass ("whole bird" base) or breast, wings and legs ("further processed" base). For the "whole bird" base, quality is defined in terms of percentage of the carcass in grade A; for the "further processed" base, quality is determined by the relative percentages of the carcass for breast, wings and legs. Yields of breast, wings and legs are often denoted as percentage white meat and percentage dark meat, where white meat and dark meat are breast + wings and legs, respectively. As

TABLE 1. Price data for broiler production.

Variable	Abbreviation[*]	Value
Market price PS female chicks (Dfl.bird^{-1})	$PM_{Dfl/PSfemale\ chick}$[†]	5.000
Market price PS male chicks (Dfl.bird^{-1})	$PM_{Dfl/PSmale\ chick}$	0.000
Salvage value PS female at end laying period (Dfl.kg^{-1})	$P_{Dfl/kg\ live\ weight\ PSfemale\ at\ end\ laying}$	1.500
Salvage value PS male at end laying period (Dfl.kg^{-1})	$P_{Dfl/kg\ live\ weight\ PSmale\ at\ end\ laying}$	1.500
Price carcass grade A FPfemale 'whole bird' base (Dfl.kg^{-1})	$P_{Dfl/kg\ carcass\ grade\ A\ Fpfemale}$	3.500
Price carcass grade A FPmale 'whole bird' base (Dfl.kg^{-1})	$P_{Dfl/kg\ carcass\ grade\ A\ FPmale}$	3.500
Price breast yield FP (Dfl.kg^{-1})	$P_{Dfl/kg\ breast}$	10.000
Price wings yield FP (Dfl.kg^{-1})	$P_{Dfl/kg\ wings}$	3.500
Price legs yield FP (Dfl.kg^{-1})	$P_{Dfl/kg\ legs}$	5.000
Price remainder yield FP (Dfl.kg^{-1})	$P_{Dfl/kg\ remainder}$	0.500
Price feed rearing period PS (Dfl.kg^{-1})	$P_{Dfl/kg\ PSfeed\ rearing}$	0.550
Price feed PS breeder males (Dfl.kg^{-1})	$P_{Dfl/kg\ PSfeed\ breeder\ males}$	0.550
Price feed PS laying females (Dfl.kg^{-1})	$P_{Dfl/kg\ PSfeed\ laying}$	0.550
Price feed FP (Dfl.kg^{-1})	$P_{Dfl/kg\ FPfeed}$	0.630
Market price FP egg hatched (Dfl.egg^{-1})	$PM_{Dfl/FPegg\ hatched}$	0.360
Market price FP starting bird (chick) (Dfl.bird^{-1})	$PM_{Dfl/FPchick}$	0.550
Price FP egg culled (Dfl.egg^{-1})	$P_{Dfl/cull\ egg}$	0.050
Market price FP female at finishing weight (Dfl.kg^{-1})	$PMFPFE_{Dfl/kg\ live\ weight}$	2.000
Market price FP male at finishing weight (Dfl.kg^{-1})	$PMFPMA_{Dfl/kg\ live\ weight}$	2.000
Var. costs MULTIPLIER BREEDER PS female housed (Dfl.bird^{-1})	$VARCOSTPSFE_{Dfl/PSfemalehoused}$	21.500
Variable costs HATCHERY per FPegg (Dfl.egg^{-1})	$VARCOSTHA_{Dfl/FPegg\ hatched}$	0.070
Var. costs COMMERCIAL GROWER per FP finished (Dfl.bird^{-1})	$VARCOSTFP_{Dfl/FP\ bird\ finished}$	0.510
Fixed costs MULTIPLIER BREEDER (Dfl)	$FIXCOSTPS_{Dfl}$	1,000 [‡]
Fixed costs HATCHERY (Dfl)	$FIXCOSTHA_{Dfl}$	5,000 [‡]
Fixed costs COMMERCIAL GROWER (Dfl)	$FIXCOSTFP_{Dfl}$	150,000 [‡]
Processing costs (corrected for revenues from non-carcass components; Dfl.bird^{-1}) whole bird base	$PROCCOST_{Dfl/FPbird}$	0.650
further processed base		1.800

[*] For abbreviation key, see Appendix A.
[†] Dfl: Dutch Guilder. 1.00 Dfl = 0.51 \$US = 0.74 \$Can, approx.
[‡] Based on a 2,000,000 kg broiler enterprise.

prices of breast, wings and legs in fact can be determined separately, this subdivision is preferred above a subdivision in white and dark meat only. These prices for breast, wings and legs, as well as prices per kilogram of carcass grade A and nongrade A are considered exogenous price parameters. Percentage yields are considered exogenous production parameters.

Processing costs per FP bird are included in the prices, again distinguishing between processing costs on the whole bird and on the further processed base. It is assumed that

TABLE 2. Performance data for broiler production.

Variable	Abbreviation*	Value
Number of FP eggs per PS female housed	$\#_{FP\ eggs/PS\ female\ housed}$	150.00
Feed consumption laying period PS female (kg.bird^{-1})	LAYINGFEED/HH	45.00
Number of cull eggs per laying PS female	$\#_{cull\ egg}$	10.00
Body weight PS female when housed (kg.bird^{-1})	$PSFEHOUWEI_{kg/PSfemale}$	2.10
Body weight PS female at end of laying period (kg.bird^{-1})	PSFEFINWEIkg/$_{PSfemale}$	3.60
Body weight PS breeder male at end of laying period (kg.bird^{-1})	$PSMAFINWEI_{kg/PSmale}$	4.80
Feed consumption rearing period PS females (kg.bird^{-1})	$PSFEREAFE_{kg\ feed}$	10.00
Feed consumption rearing period PS males (kg.bird^{-1})	$PSMAREAFE_{kg\ feed}$	8.00
Feed consumption PS breeder males	$PSMABREEFE_{kg\ feed}$	50.00
Ratio of PS males to PS females at start rearing period	male/female-startrearing	0.15
Ratio of PS breeder males selected to PS females housed	male/female-housed	0.10
# PS females died during early rearing (wk 0-2), % # PS female chicks	%PSFEEARLYMORTREA	1.00
# PS females died during late rearing (> wk 2), % # PS female chicks	%PSFELATEMORTREA	5.00
# PS males died during early rearing (wk 0-2), % # PS male chicks	%PSMAEARLYMORTREA	2.00
# PS males died during late rearing (> wk 2), % # PS male chicks	%PSMALATEMORTREA	10.00
# PS females died during laying, % # PS females housed	%PSFEMORTLAY	8.10
# PS breeder males died, % # PS breeder males selected	%PSMABREEMORT	20.00
# fertile FP eggs as a percentage of total FP eggs	%FERTILEFPEGGS	90.00
# chicks (alive) as a percentage of # fertile FP eggs	%HATCHOFFERTILEFPEGGS	90.00
Finishing weight FP female (kg.bird^{-1})	$FPFEFINWEI_{kg/FPbird}$	1.90
Finishing weight FP male (kg.bird^{-1})	$FPMAFINWEI_{kg/FPbird}$	2.30
Feed consumption growing period FP females (kg.bird^{-1})	$FPFEFE_{kg\ feed}$	3.80
Feed consumption growing period FP males (kg.bird^{-1})	$FPMAFE_{kg\ feed}$	4.46
# FP males died during early growing (wk 0-1), % # FP male chicks	%FPMAEARLYMORT	0.00
# FP males died during late growing (> wk 1), % # FP male chicks	%FPMALATEMORT	4.50
# FP females died during early growing (wk 0-1), % # FP female chicks	%FPFEEARLYMORT	0.00
# FP females died during late growing (> wk 1) % # FP female chicks	%FPFELATEMORT	4.50
Carcass yield FP female, % finishing weight	%FPFECARYI	68.80
Carcass yield FP male, % finishing weight	%FPMACARYI	68.80
Breast yield FP female, % total carcass weight	%FPFEBREAST	21.40
Breast yield FP male, % total carcass weight	%FPMABREAST	21.40
Wings yield FP female, % total carcass weight	%FPFEWINGS	12.40
Wings yield FP male, % total carcass weight	%FPMAWINGS	12.40
Legs yield FP female, % total carcass weight	%FPFELEGS	33.90
Legs yield FP male, % total carcass weight	%FPMALEGS	33.90
Percentage grade A carcasses FP female ("whole bird" base)	%FPFEGRADEA	100.00
Percentage grade A carcasses FP male ("whole bird" base)	%FPMAGRADEA	100.00

* For abbreviation key, see Appendix A.

TABLE 3. Simulated production scales in relation to production levels in a 2,000,000 kg broiler meat enterprise.

Production scale	Basic	Hatching egg number*		Body weight†	
		-20%	+20%	-20%	+20%
$\#_{PSfemale\ chicks}$	12,692	15,864	10,576	15,864	10,576
$\#_{PSfemales\ housed}$	11,930	14,913	9942	14,913	9942
$\#_{PSmale\ chicks}$	1904	2380	1586	2380	1586
$\#_{PSbreeder\ males}$	1193	1491	994	1491	994
$\#_{FPeggs\ hatched}$	1,789,509	1,789,509	1,789,509	2,236,884	1,491,257
$\#_{FPchicks}$	1,449,502	1,449,505	1,449,502	1,811,877	1,207,919
$\#_{FPmales\ finished}$	692,137	692,137	692,137	865,172	576,781
$\#_{FPfemales\ finished}$	692,137	692,137	692,137	865,172	576,781

* Hatching egg number = number of hatching eggs produced per breeder hen housed.

† Body weight = market live weight (kilograms) of commercial broiler for both male and female at 7 wk of age.

these processing costs are adjusted for possible revenues on noncarcass components of the bird when being processed.

Prices per kilogram of live weight are separately defined for FP males and FP females. Prices per kilogram of live weight used to calculate salvage value of PS male breeders and PS females at the end of the laying period are (fixed) exogenous parameters. In situations where the revenues per kilogram of live weight FP at finishing for the processor exceed market prices per kilogram of live weight FP at finishing for grower, the processor is making a profit. Cost prices per kilogram of carcass for males and females are now calculated.

MODEL TESTING

To test the model, actual broiler price and breed performances were obtained from Euribrid B.V. (Table 1 and Table 2). Values are based on a system with PS females laying until 64 wk of age, and a market age of 7 wk for FP birds. Simulated production scales, assuming an annual FP carcass production of 2,000,000 kg, are in Table 3. Changes in performance of the animals do not result in changes in the level (quantity) of output, but lead to changes in production scales: costs per unit of product are reduced or increased (Table 3). As an example, a 20% change in hatching egg number and body weight of commercial broiler are imposed to illustrate changes in production scales. Production scales for commercial growers are influenced by body weight but not by hatching egg number. Production scales for multiplier breeders and hatcheries are influenced by both hatching egg number and body weight. In terms of production scale, improvements in both broiler growth rate and egg production in the PS have the same consequences for the multiplier breeder. Costs and profit margins are in Table 4, including effects of changes in hatching egg number and body weight on these economic parameters. In the basic situation, all costs are lower than assumed market prices (Table 1), as indicated by positive profit margins. Only with a decrease of 20% in hatching egg number, the cost per FP egg hatched becomes higher than the market price (0.4445 vs 0.3600). When ignoring fixed cost, an increase in hatching egg number per PS female decreases all costs as well as increases the profit of the multiplier breeder, but does not downstream change profit of hatchery and commercial grower, as market prices (rather than costs) are used in calculating profits of these stages. A change in body weight directly influences costs and profits at the stages of commercial grower and processor. A change in body weight of FP birds only indirectly influences costs and profits for the multiplier breeder and hatchery upstream when accounting for fixed cost. An increase in body weight of FP birds decreases the number of FP eggs required upstream, without changing fixed costs of the multiplier breeder and hatchery — as a result cost per FP egg increases from 0.3566 to 0.3567. Note, that an increase in body weight increases cost per FP male (with fixed cost, 4.6488 vs 4.0508) but decreases in cost per kg FP male (with fixed cost, 1.6843 vs 1.7612).

DISCUSSION

The model is developed for economic evaluation in broiler breeding. It allows for the computation of the influence of production parameters and values of production factor input and product output on overall profitability. The model calculates costs and revenues for different participants of broiler production system, and can be used to analyze the economic status of broiler enterprise. By alternative data input, the model is suitable for situations of nonintegration, part integration or full integration.

The model can be used to derive economic values in broiler breeding based on profit equations (Jiang *et al.*, 1998). Marginal changes in performance traits will lead to (marginal) changes in profits and costs. Furthermore, the model can be used to quantify to what extent economic values in broiler breeding depend on production circumstances. When analyzing marginal changes in profits and costs from (independently) changing

TABLE 4. Simulated cost prices and profits in a broiler enterprise with and without fixed costs input in relation to production levels.

	Without fixed costs input					With fixed costs input				
		Hatching egg #		Body weight			Hatching egg #		Body weight	
	Basis	+20%	-20%	+20%	-20%	Basis	+20%	-20%	+20%	-20%
Cost prices ($Dfl^{*}.unit^{-1}$) (integrated)										
FP hatching egg (egg)	0.3556	0.2963	0.4445	0.3556	0.3556	0.3566	0.2973	0.4456	0.3567	0.3565
FP chick (chick)	0.5254	0.4522	0.6352	0.5254	0.5254	0.5301	0.4569	0.6400	0.5309	0.5293
FP male finished (bird)	3.9375	3.8608	4.0524	4.5129	3.3620	4.0508	3.9741	4.1658	4.6488	3.4528
FP male finished (kg)	1.7119	1.6786	1.7619	1.6351	1.8272	1.7612	1.7279	1.8112	1.6843	1.8756
FP female finished (bird)	3.5106	3.4340	3.6255	4.0006	3.0205	3.6239	3.5472	3.7390	4.1365	3.1113
FP female finished (kg)	1.8477	1.8073	1.9081	1.7547	1.9872	1.9073	1.8669	1.9679	1.8143	2.0469
Carcass of FP male (kg)	2.4883	2.4398	2.5609	2.3766	2.6558	2.9707	2.9222	3.0434	2.7905	3.2409
Carcass of FP female (kg)	2.6856	2.6270	2.7735	2.5504	2.8883	3.2695	3.2108	3.3575	3.0514	3.5967
Profits ($Dfl.unit^{-1}$) (nonintegrated)										
Multiplier breeder (FP egg hatched)	0.0044	0.0673	-0.0845	0.0044	0.0044	0.0039	0.0631	-0.0850	0.0038	0.0040
Hatchery (FP chick)	0.0191	0.0191	0.0191	0.0191	0.0191	0.0157	0.0157	0.0157	0.0150	0.0164
Commercial grower (FP bird finished)	0.4502	0.4502	0.4502	0.7575	0.1430	0.3419	0.3419	0.3419	0.6274	0.0563

* Dfl: Dutch Guilder. 1.00 Dfl = 0.51 $US = 0.74 $Can, approx.

single performance traits, full recognition of model assumption on relationships between variables is required. For example, this model does not include an optimization of the length of the growth period in dependence of feed consumption. Also, marginal changes in egg production will not change the amount of laying feed for PS females, as the latter variable is an independent exogenous parameter. Accordingly, in deriving economic values, a sensitivity analysis for parameters within the model has to be performed. This model considers feed consumption for PS laying hens, breeder males, and FP birds as exogenous parameters. If adequate performance data are available, feed consumption might be replaced by feed requirement per egg or per kilogram of body weight gain.

In conclusion, the model can be used for the economic evaluation and the derivation of economic values of poultry meat production systems, not only for broiler enterprise but also for turkey, meat-type duck, and the other meat-type poultry as well.

REFERENCES

Akbar, M. K., D. L. Harris, and C. R. Arboleda, 1986. Development of the relative economic weights for linear and quadratic bioeconomic objectives in commercial broilers. Poultry Sci. 65:1834-1846.

Boehlje, M. D., and Eidman, V. R., 1984. Farm Management. John Wiley and Sons, Inc., New York, USA.

De Vries, A. G., 1989. A model to estimate economic values of traits in pig breeding. Livest. Prod. Sci. 21:49-66.

Dickerson, G., 1970. Efficiency of animal production — modelling the biological components. J. Anim. Sci. 30:849-859.

Fattori, T. R., P. E. Hildebrand, and H. R. Wilson, 1991. Response of broiler breeder females to feed restriction below recommended levels. 2. Economic analysis. Poultry Sci. 70:489-498.

Groen, A. F., 1988. Derivation of economic values in cattle breeding. A model at farm level. Agric. Systems 27:195-213.

Groen, A. F., 1989. Cattle breeding goals and production circumstances. Ph.D. Thesis, Department of Animal Breeding, Wageningen Agricultural University, Wageningen, The Netherlands.

Harris, D. L., 1970. Breeding for efficiency in livestock production: defining the economic objectives. J. Anim. Sci. 30:860-865.

Hirooka, H., A. F. Groen, and J. Hillers, 1998. Developing breeding objectives for beef cattle production. I. A bio-economic simulation model. Animal Sci. 66:607-621.

Jiang, X., A. F. Groen, and E. W. Brascamp, 1998. Economic values in broiler breeding. Poultry Sci. 77:934-943.

Lance, G. C., 1990. Economic evaluation of farm efficiency rates for integrated-broiler and contract-grower operations in Georgia, by type of housing system. Poultry Sci. 69:554–562.

Moav, R., and J. Moav, 1966. Profit in a broiler enterprise as a function of egg production of parent stocks and growth rate of their progeny. Br. Poult. Sci. 7:5–15.

Pasternak, H., and B. A. Shalev, 1983. Genetic-economic evaluation of traits in a broiler enterprise: reduction of food intake due to increased growth rate. Br. Poult. Sci. 24:531–536.

Shalev, B. A., and H. Pasternak, 1983. Genetic-economic evaluation of traits in a broiler enterprise: the relative genetic-economic values. Br. Poult. Sci. 24:521–529.

Shultz, F. T., 1986. Formulation of breeding objectives for poultry meat production. Vol. X., Pages 215–227 *in*: Proceedings of the third World Congress on Genetics Applied to Livestock Production. University of Nebraska, Lincoln, NE.

Strain, J. H., and A. W. Nordskog, 1962. Genetic aspects of the profit equation in a broiler enterprise. Poultry Sci. 41:1892–1902.

Tess, M. W., G. L. Bennett, and G. E. Dickerson, 1983. Simulation of genetic changes in life cycle efficiency of pork production. I. A bio-economic model. J. Anim. Sci. 56:336–353.

Timmons, M. B., and P. W. Aho, 1987. A broiler production analysis equation. Poultry Sci. 66: 586–595

APPENDIX A: Modeling Equations

Abbreviation key: FP = final product; PS = parental stock; MORT = mortality (rate); chicks = chicks at 0 wk of age; # = number; P = price (PM = price market); FE = female; MA = male; REA = rearing (period); LAY = laying (period); MARK = marketing; BREE = breeding; VAR = variable; FIX = fixed; PROC = processing; HA = hatchery; CAR = carcass; WEI = weight; YI = yield.

System Scaling

$$\#_{\text{FPchicks}} = \text{FPCARCASS} / [\ \{\ \%\text{FPMACARYI}/100 \times \text{FPMAFINWEI}_{\text{kg/FPbird}} \times 0.50 \times (100 - \%\text{FPMAEARLYMORT} - \%\text{FPMALATEMORT})/100\ \} + \{\ \%\text{FPFECARYI}/100 \times \text{FPFEFINWEI} \times 0.50 \times (100 - \%\text{FPFEEARLYMORT} - \%\text{FPFELATEMORT})/100\ \}\ ]$$

$$\#_{\text{FPmales finished}} = 0.5 \times (100 - \%\text{FPMAEARLYMORT} - \%\text{FPMALATEMORT})/100 \times \#_{\text{FPchicks}}$$

$$\#_{\text{FPfemales finished}} = 0.5 \times (100 - \%\text{FPFEEARLYMORT} - \%\text{FPFELATEMORT})/100 \times \#_{\text{FPchicks}}$$

$$\#_{\text{FPeggs hatched}} = \#_{\text{FPchicks}} \times 100^2/[\%\text{FERTILEFPEGGS} \times \%\text{HATCHOFFERTILEFPEGGS}]$$

$$\#_{\text{PSfemales housed}} = \#_{\text{FPeggs hatched}} / \#_{\text{FPeggs/PSfemale housed}}$$

$$\#_{\text{PSfemale chicks}} = \#_{\text{PSfemales housed}} \times 100/(100 - \%\text{PSFEEARLYMORTREA} - \%\text{PSFELATEMORTREA})$$

$$\#_{\text{PSfemales end laying}} = \#_{\text{PSfemales housed}} \times (100 - \%\text{PSFEMORTLAY})/100$$

$$\#_{\text{PSmale chicks}} = \#_{\text{PSfemaleschicks}} \times \text{male/female-startrearing}$$
$$\#_{\text{PSbreeder males}} = \#_{\text{PSfemales housed}} \times \text{male/female-housed}$$
$$\#_{\text{PSmales end laying}} = \#_{\text{PSbreeder males}} \times (100 - \%\text{PSMABREEMORT})/100$$
$$\#_{\text{PSmales marketed}} = \#_{\text{PSmale chicks}} \times (100 - \%\text{PSMALATEMORTREA} - \%\text{PSMAEARLYMORTREA})/100 - \#_{\text{PSbreeder males}}$$

Multiplier

$$\text{Profit margin multiplier breeder} = \text{Revenues multiplier breeder} - \text{Costs multiplier breeder}$$
$$\text{Cost price per FP egg hatched} = P_{\text{Dfl/FP egg hatched}} = \text{Costs multiplier breeder} / \#_{\text{FP eggs hatched}}$$

$$\text{Costs PSmales multiplier breeder} = \text{Costs purchasing male chicks} + \text{Feed costs males} - \text{Salvage value males end laying period}$$

$$\text{Revenues multiplier breeder} = \#_{\text{FP eggs hatched}} \times PM_{\text{Dfl/FP egg hatched}}$$

$$\text{Costs multiplier breeder} = \text{Costs purchasing male chicks} + \text{Costs purchasing female chicks} + \text{Feed costs males} + \text{Feed costs females growth} + \text{Feed costs females egg production} - \text{Salvage value females} - \text{Salvage value males} - \text{Salvage value cull eggs} + \text{Variable costs multiplier breeder} + \text{Fixed costs multiplier breeder}$$

$$\text{Costs purchasing male chicks} = \#_{\text{PSmale chicks}} \times PM_{\text{Dfl/PSmale chick}}$$
$$\text{Costs purchasing female chicks} = \#_{\text{PSfemale chicks}} \times PM_{\text{Dfl/PSfemale chick}}$$
$$\text{Feed costs males} = [\ \#_{\text{PSbreeder males}} + \#_{\text{PSmale chicks}} \times \%\text{PSMALATEMORTREA}/100 \times \tfrac{1}{2}\ ] \times \text{PSMAREAFE}_{\text{kg feed}} \times P_{\text{Dfl/kg PSfeed rearing}} + [\ \#_{\text{PSmales end laying}} + \#_{\text{PSbreeder males}} \times \%\text{PSMABREEMORT}/100\ \tfrac{1}{2}\ ] \times \text{PSMABREEFC}_{\text{kg feed/kg weight gain}} \times P_{\text{Dfl/kg PSfeed breeder males}}$$
$$\text{Feed costs females growth} = [\ \#_{\text{PSfemales housed}} + \#_{\text{PSfemale chicks}} \times \%\text{PSFELATEMORTREA}/100 \times \tfrac{1}{2}\ ] \times \text{PSFEREAFE}_{\text{kg feed}} \times P_{\text{Dfl/kg PSfeed rearing}}$$
$$\text{Feed costs females egg production} = \#_{\text{FPeggs hatched}} \times \text{FEEDFPEGG}_{\text{kg feed/egg}} \times P_{\text{Dfl/kg PSfeed laying}}$$
$$\text{Salvage value females} = \#_{\text{PSfemales end laying}} \times \text{PSFEFINWEI}_{\text{kg/PSfemale}} \times P_{\text{Dfl/kg live weight PSfemale at end laying}}$$
$$\text{Salvage value males} = \#_{\text{PSmales end laying}} \times \text{PSMAFINWEI}_{\text{kg/PSmale}} \times P_{\text{Dfl/kg live weight PSmale at end laying}}$$
$$\text{Salvage value cull eggs} = \#_{\text{cull eggs}} \times P_{\text{Dfl/cull egg}}$$
$$\text{Variable costs multiplier} = \text{VARCOSTPSFE}_{\text{Dfl/PSfemale housed}} \times \#_{\text{PSfemales housed}}$$

Hatchery

$$\text{Profit margin hatchery} = \text{Revenues hatchery} - \text{Costs hatchery}$$
$$\text{Cost price per FP chick} = P_{\text{Dfl/FPchick}} = \text{Costs hatchery} / \#_{\text{FPchicks}}$$

$$\text{Revenues hatchery} = \#_{\text{FPchick}} \times PM_{\text{Dfl/FPchick}}$$

$$\text{Costs hatchery} = \#_{\text{FPeggs hatched}} \times P_{\text{Dfl/FPegg hatched}} + \#_{\text{FPeggs hatched}} \times VARCOSTHA_{\text{Dfl/FPegg hatched}} + FIXCOSTHA_{\text{Dfl}}$$

Commercial grower

$$\text{Profit margin commercial grower} = \text{Revenue commercial grower} - \text{Cost commercial grower}$$

$$\text{Cost price per FP male finished} = \text{Feed costs males} / \#_{\text{FP males finished}}$$
$$+ P_{\text{Dfl/FP chick}} \times 100/(100 - \%FPMAEARLYMORT - \%FPMALATEMORT)$$
$$+ VARCOSTFP_{\text{Dfl/FP bird finished}} + FIXCOSTFP_{\text{Dfl}}/\#_{\text{FP birds finished}}$$

$$\text{Cost price per FP female finished} = \text{Feed costs females} / \#_{\text{FP females finished}}$$
$$+ P_{\text{Dfl/FP chick}} \times 100/(100 - \%FPFEEARLYMORT - \%FPFELATEMORT)$$
$$+ VARCOSTFP_{\text{Dfl/fp bird finished}} + FIXCOSTFP_{\text{Dfl}}/\#_{\text{FP birds finished}}$$

$$\text{Revenues commercial grower} = \#_{\text{FPmales finished}} \times FPMAFINWEI_{\text{kg/FPmale}} \times PMFPMA_{\text{Dfl/kg live weight male}}$$
$$+ \#_{\text{FPfemales finished}} \times FPFEFINWEI_{\text{kg/FPfemale}} \times PMFPFE_{\text{Dfl/kg live weight}}$$

$$\text{Costs commercial grower} = \text{Costs purchasing chicks} + \text{Feed costs males} + \text{Feed costs females}$$
$$+ VARCOSTFP_{\text{Dfl/FP bird finished}} \times (\#_{\text{FPmales finished}} + \#_{\text{FPfemales finished}}) + FIXCOSTFP_{\text{farm}}$$

$$\text{Costs purchasing chicks} = \#_{\text{FPchicks}} \times P_{\text{Dfl/FPchick}}$$

$$\text{Feed costs males} = [\, \#_{\text{FPmales finished}} + 0.5 \times \#_{\text{FPchicks}} \times \%FPMALATEMORT/100 \times ½ \,]$$
$$\times FPMAFE_{\text{kg feed}} \times P_{\text{Dfl/kg FPfeed}}$$

$$\text{Feed costs females} = [\, \#_{\text{FPfemales finished}} + 0.5 \times \#_{\text{FPchicks}} \times \%FPFELATEMORT/100 \times ½ \,]$$
$$\times FPFEFE_{\text{kg feed}} \times P_{\text{Dfl/kg FPfeed}}$$

Processor

$$\text{Cost price per kg male carcass} = (\text{Cost price per FP male finished} + PROCCOST_{\text{Dfl/bird}}) /$$
$$(FPMAFINWEI \times \%FPMACARYI/100)$$

$$\text{Cost price per kg female carcass} = (\text{Cost price per FP female finished} + PROCCOST_{\text{Dfl/bird}}) /$$
$$(FPFEFINWEI \times \%FPFECARYI/100)$$

"Whole bird" base

$$PFPFE_{\text{Dfl/kg liveweight}} = \%FPFECARYI/100 \times [\%FPFEGRADEA/100 \times P_{\text{Dfl/kg carcass grade A FPfemale}}$$
$$+ (1 - \%FPFEGRADEA/100) \times P_{\text{Dfl/kg carcass non-grade A FPfemale}} \,]$$
$$- PROCCOSTwb_{\text{Dfl/bird}}/FPFEFINWEI_{\text{kg/bird}}$$

$$PFPMA_{\text{Dfl/kg live weight}} = \%FPMACARYI/100 \times [\%FPMAGRADEA/100 \times P_{\text{Dfl/kg carcass grade A FPmale}}$$
$$+ (1 - \%FPMAGRADEA/100) \times P_{\text{Dfl/kg carcass non-grade A FPmale}} \,]$$
$$- PROCCOSTwb_{\text{Dfl/bird}}/FPMAFINWEI_{\text{kg/bird}}$$

"Further processed" base

$$PFPFE_{Dfl/kg\ live\ weight} = \%FPFECARYI/100 \times [\%FPFPBREAST/100 \times P_{Dfl/kg\ breast} + \%FPFEWINGS/100 \times P_{Dfl/kg\ wings} + \%FPFELEGS/100 \times P_{Dfl/kg\ legs} + \%FPFEREMAINDER/100 \times P_{Dfl/kg\ remainder}] - PROCCOSTfp_{Dfl/bird}/FPFEFINWEI_{kg/bird}$$

$$FPMA_{Dfl/kg\ live\ weight} = \%FPMACARYI/100 \times [\%FPFPBREAST/100 \times P_{Dfl/kg\ breast} + \%FPMAWINGS/100 \times P_{Dfl/kg\ wings} + \%FPMALEGS/100 \times P_{Dfl/kg\ legs} + \%FPMAREMAINDER/100 \times P_{Dfl/kg\ remainder}] - PROCCOSTfp_{Dfl/bird}/FPMAFINWEI_{kg/bird}$$

$$\text{Cost price per kilogram male carcass} = (\text{Cost price per FP male finished} + PROCCOST.._{Dfl/bird}) / (FPMAFINWEIGHT_{kg/bird} \times \%FPMACARCASSYIELD/100)$$

$$\text{Cost price per kilogram female carcass} = (\text{Cost price per FP female finished} + PROCCOST_{Dfl/bird}) / (FPFEFINWEIGHT_{kg/bird} \times \%FPFECARCASSYIELD/100)$$

Chapter 3

Economic Values in Broiler Breeding

X. JIANG, A. F. GROEN, and E. W. BRASCAMP

Animal Breeding and Genetics Group, Wageningen Institute of Animal Sciences, Wageningen University, Wageningen, The Netherlands

Published in ***Poultry Science***, 77 (1998): 934–943.

Economic value: The change in efficiency of a production system as a result of one unit genetic improvement of a trait, without changing for other traits in the breeding goal. Economic values are sensitive to production levels, product prices and feed prices; there are both linear and nonlinear relationships between economic values and production circumstances.

ABSTRACT The objectives of this study were to derive economic values in broiler breeding and to determine their relationship with production circumstances. Economic values were derived using a deterministic economic model based on profit equations with a fixed amount of broiler meat output of the production system. Nonintegrated and the integrated broiler production systems were studied. The difference between these originates from different definitions of cost components and scaling aspects. For each stage of a nonintegrated system, the model calculated the profit margin; for an integrated system, (total) cost prices per unit of product at each stage were calculated. The Dutch broiler performance data and prices were input into the model as the representative situation. For all traits, in the nonintegrated system, economic values were derived, expressed as Dutch guilders (Dfl) per unit of product, where the unit of product depends on the stage of the production system and equals an egg for the multiplier breeder, a day-old chick for the hatchery, and a marketable broiler for both commercial grower and the processor. Resulting levels of economic values were illustrated by showing underlying cost or profit changes in the production system. For the integrated system, economic values were expressed as Dfl.marketable broiler^{-1}.unit^{-1}. Economic values of traits in the integrated system were also derived for situations where technical parameters or prices of production factors were changed (20% increase or decrease). A general conclusion from these sensitivity analyses is that the economic values are sensitive to production levels, product prices and feed prices; there are both linear and nonlinear relationships between economic values and production circumstances.

Key words: economic values, economic model, broiler breeding, production systems, production circumstances.

INTRODUCTION

A breeding goal provides the basis for each breeding program. To optimize levels of genetic improvement of breeding goal traits, traits are weighed by their predicted contribution to increased economic revenue (Hazel, 1943). The contribution of a trait to increased economic revenue is determined by 1) time and frequency of future expression of genetic superiority for the trait, and 2) economic benefit at the moment of expression of genetic superiority for the trait (McClintock and Cunningham, 1974; Brascamp, 1978). This latter aspect is generally referred to as the economic value of a trait.

Only few sets of economic values in poultry breeding have been presented in the scientific literature (see Harris and Newman, 1994). Using simple marginal cost and marginal revenue functions (per bird), Hogsett and Nordskog (1958) obtained economic values in layer chicken breeding. Akbar *et al.* (1986) developed profit functions to describe bio-economic objectives in an integrated (three-way cross) broiler production system. They derived economic values considering maximization of the profitability per broiler as the objective. Shalev and Pasternak (1983) derived economic values using a single profit function describing production cost per unit of marketable broiler body weight in a fully integrated broiler enterprise. Economic values may differ for integrated and nonintegrated systems and Strain and Nordskog (1962) studied this using profit equations for the evaluation of both a nonintegrated broiler enterprise and an integrated enterprise with parent flocks and broiler progeny.

As pointed out by Dickerson (1970), it is important to consider the whole production-marketing system, rather than only part of it. For this reason we modeled a broiler production system including multiplier breeder, hatchery, commercial grower, and processor. The aim of the present study is to derive economic values of traits in broiler breeding, for both integrated and nonintegrated production systems, and to determine the influence of production circumstances (price and performance data) on economic values.

MATERIALS AND METHOD

Model

The deterministic model by Groen *et al.* (1998) was used. The model was developed for the economic analysis of broiler production. The general structure of broiler production is as described in Groen *et al.* (1998: Figure 1). The model focuses on multiplier breeder, hatchery, commercial grower, and processor stages. Major elements and their relationships in the model are outlined briefly; detailed information is given by Groen *et al.* (1998). Price and performance data are summarized in Table 1.

The size of the system is defined by a fixed output of carcass of final product (FP) broilers, ignoring market output from the multiplier breeder (laying hens, breeder males). Sizes of subsequent system stages are derived from this fixed output. The number (#) of parental stock (PS) female chicks required to produce the fixed output depends on performance levels of PS (i.e., hen housed egg production) and FP (i.e., live weight and carcass yield), as well as on rates of involuntary culling of chickens and eggs.

TABLE 1. Representative price and performance data for broiler production (Groen *et al.*, 1998).

Variable	Value
Price input data	
Market price PS female chicks (Dfl*.bird^{-1})	5.00
Market price PS male chicks (Dfl.bird^{-1})	0.00
Salvage value PS female or male at end laying period (Dfl.kg^{-1})	1.50
Price carcass grade A FPfemale or FPmale 'whole bird' base (Dfl.kg^{-1})	3.50
Price breast yield FP (Dfl.kg^{-1})	10.00
Price wings yield FP (Dfl.kg^{-1})	3.50
Price legs yield FP (Dfl.kg^{-1})	5.00
Price remainder yield FP (Dfl.kg^{-1})	0.50
Price feed PS rearing period or PS breeder male or PS laying female (Dfl.kg^{-1})	0.55
Price feed FP (Dfl.kg^{-1})	0.63
Market price FP egg hatched (Dfl.egg^{-1})	0.36
Market price FP starting bird (chick) (Dfl.bird^{-1})	0.55
Price FP egg culled (Dfl.egg^{-1})	0.05
Market price FP female or male at finishing weight (Dfl.kg^{-1})	2.00
Variable cost MULTIPLIER BREEDER PS female housed (Dfl.bird^{-1})	21.50
Variable cost HATCHERY per FPegg (Dfl.egg^{-1})	0.07
Variable cost COMMERCIAL GROWER per FP finished (Dfl.bird^{-1})	0.51
Processing cost corrected for revenue from noncarcass components	
whole bird base (Dfl.bird^{-1})	0.65
further processed base (Dfl.bird^{-1})	1.80
Performance input data	
Number of FP eggs per PS female housed	150.00
Feed consumption laying period PS female (kg.bird^{-1})	45.00
Number of cull eggs per laying PS female	10.00
Body weight PS female when housed (kg.bird^{-1})	2.10
Body weight PS female at end of laying period (kg.bird^{-1})	3.60
Body weight PS breeder male at end of laying period (kg.bird^{-1})	4.80
Feed consumption rearing period PS females (kg.bird^{-1})	10.00
Feed consumption rearing period PS males (kg.bird^{-1})	8.00
Feed consumption PS breeder males (kg.bird^{-1})	50.00
Ratio of PS males to PS females at starting rearing period	0.15
Ratio of PS breeder males selected to PS females housed	0.10
# PS females died during early rearing (week 0–2), % # PS female chicks	1.00
# PS females died during late rearing (> week 2), % # PS female chicks	5.00
# PS males died during early rearing (week 0–2), % # PS male chicks	2.00
# PS males died during late rearing (> week 2), % # PS male chicks	10.00
# PS females died during laying, % # PS females housed	8.10
# PS breeder males died, % # PS breeder males selected	20.00
# fertile FP eggs as a percentage of total FP eggs	90.00
# chicks (alive) as a percentage of # fertile FP eggs	90.00
Finishing weight FP female (kg.bird^{-1})	1.90
Finishing weight FP male (kg.bird^{-1})	2.30
Feed consumption FP females growing period (kg.bird^{-1})	3.80

TABLE 1. (continued) Representative price and performance data for broiler production (Groen *et al.*, 1998).

Feed consumption FP males growing period ($kg.bird^{-1}$)	4.46
# FP females died during early growing (week 0 to1), % # FP female chicks	0.00
# FP females died during late growing (> week 1) % # FP female chicks	4.50
Carcass yield FP female or male, % finishing weight	68.80
Breast yield FP female or male, % total carcass weight	21.40
Wings yield FP female or male, % total carcass weight	12.40
Legs yield FP bird, % total carcass weight	33.90
Percentage grade A carcass FP female or male ('whole bird' base)	100.00
Simulated economic performance (without fixed cost)	
Profit multiplier breeder ($Dfl.FP\ egg\ hatched^{-1}$)	0.0044
Profit hatchery ($Dfl.FP\ chick^{-1}$)	0.0191
Profit commercial grower ($Dfl.FP\ bird\ finished^{-1}$)	0.4502
Cost price FP egg hatched ($Dfl.egg^{-1}$)	0.3556
Cost price FP chick ($Dfl.chick^{-1}$)	0.5254
Cost price FP male finished ($Dfl.bird^{-1}$)	3.9375
Cost price FP male finished ($Dfl.kg^{-1}$)	1.7119
Cost price FP female finished ($Dfl.bird^{-1}$)	3.5106
Cost price FP female finished ($Dfl.kg^{-1}$)	1.8477
Cost price carcass FP male ($Dfl.kg^{-1}$)	2.8994
Cost price carcass FP female ($Dfl.kg^{-1}$)	3.1832

* Dfl: Dutch Guilder. 1.00 Dfl = 0.51 $US = 0.74 $Can, approx. # = number; FP = final product; PS = parental stock.

Revenues of the multiplier breeder originate from selling FP eggs to the hatchery, whereas costs include purchasing PS chicks, feed costs of PS (breeder) males, feed costs of PS females (growth and egg production), and other variable and fixed costs (e.g., housing, and labor). Salvage values of PS females, PS males, and cull eggs are considered to be negative cost components. Separate mortality rates for male and female PS are assumed. Feed costs associated with early mortality are ignored. Feed costs associated with mortality during other periods are proportional to live weight of animals at the midpoint of this period.

At the hatchery, some of the FP eggs will not be fertilized (determined by the percentage of fertile FP eggs), and some of the fertilized eggs will not yield a living FP chick (determined by the percentage hatch of fertile eggs). Variable and fixed costs of the hatchery are included, with variable costs assumed proportional to the number of eggs hatched.

The commercial grower purchases FP chicks from the hatchery at a uniform price per chick. A 1:1 sex ratio in chicks at hatch is assumed. Males and females differ with respect to (early and late) mortality, feed intake, finishing weight, and prices per kilogram live weight at finishing. Feed costs associated with early mortality are ignored; feed costs of late mortality are related to 50% of finishing weight. Revenues of the commercial grower arise from selling FP animals. The commercial grower is paid per kilogram FP finishing weight.

The processor is included in the model to define relationships between FP quality and price per kilogram live weight. On the consumer market, products are either the whole carcass ("whole bird" base) or breast, wings and legs ("further processed" base). On the "whole bird" base, quality is defined in terms of percentage of the carcass in grade A. On the "further processed" base, quality is determined by breast, wings, and legs yields. Processing costs per FP bird are included, again distinguishing between processing costs on "whole bird" and on "further processed" base.

Performance data and prices are equal for nonintegrated and integrated systems. In nonintegrated systems, however, products transferred from one stage to another are assigned costs according to market price, whereas in the integrated system costs are assigned according to cost price in the preceding stage. For each stage of the production system the model computes total revenues and total costs, in which fixed costs include reward for labor and ownership. In the case of the nonintegrated system, prices for inputs and outputs are their market prices. In the case of the integrated system, as prices of inputs for a stage that are the output of the preceding stage, the cost prices at the preceding are taken. The base for the derivation of economic values differs between nonintegrated and integrated systems. In nonintegrated systems the basis is profit margin (i.e., the difference between revenue and cost). In the integrated system the basis is the cost price per unit of product. For both of the two situations, the economic values are derived from savings on cost for system or subsystems, rather than from an increase in output.

Derivation of Economic Values

In general, the economic value of a trait is defined as "the change in profitability of an enterprise expressed per unit product output as a consequence of one unit of change in performance of the trait considered, without changing performance of other traits". In an integrated broiler enterprise, the unit product output is a marketable FP bird. In a nonintegrated enterprise, the unit product output is a FP egg for the multiplier breeder, a FP chick for the hatchery, and a marketable FP bird for the commercial grower and processor. The unit of change in performance is defined per trait, e.g., kilogram per marketable bird when considering body weight, percentage when considering mortality trait, or egg per female when considering hatching egg production (Table 2).

TABLE 2. Economic values in a nonintegrated broiler enterprise for all traits (Dfl per product output unit specified per system stage, per unit change in performance trait).

System stage	Performance trait	Unit	Economic value
Multiplier Breeder*	Hatching egg number	egg.hen housed^{-1}	0.0024
Dfl‡.egg^{-1}.unit^{-1}	Feed consumption laying hen	kg.hen housed^{-1}	-0.0037
	Body weight PSfemale end laying	kg.hen^{-1}	0.0092
	Feed consumption rearing PSfemales	kg.hen^{-1}	-0.0038
	Early mortality PSfemales	%	-0.0004
	Late mortality PSfemales	%	-0.0006
	Laying mortality PSfemales	%	-0.0004
Hatchery*	Fertility	%	0.0058
Dfl.chick^{-1}.unit^{-1}	Hatchability of fertiles	%	0.0058
Commercial Grower[1]	Finishing weight FPfemales	kg.female^{-1}	0.3552
Dfl.bird^{-1}.unit^{-1}	Finishing weight FPmales	kg.male^{-1}	0.3745
	Feed consumption FPfemales	kg.female^{-1}	-0.3224
	Feed consumption FPmales	kg.male^{-1}	-0.3224
	Late mortality FPmales	%	-0.0118
	Late mortality FPfemales	%	-0.0086
Processor*,†	Carcass yield FPfemale	%	0.0665
Dfl.bird^{-1}.unit^{-1}	Breast meat FPfemale	%	0.1242
	Wings yield FPfemale	%	0.0392
	Legs yield FPfemale	%	0.0588
	Carcass yield FPmale	%	0.0805
	Breast meat yield FPmale	%	0.1503
	Wings yield FPmale	%	0.0475
	Legs yield FPmale	%	0.0712

* The base of evaluation in different system stages is defined as per egg for Multiplier Breeder, per chick for Hatchery, per (marketable) bird for Commercial Grower and Processor. According to "performance input data" in Table 1, there exists a fixed relationship among different bases of evaluation. Equivalent are 1 hen housed, 150 hatching egg, 121.50 chicks, 116.03 finishing birds and 167.64 kg of meat. The equivalence can be used to change the base of evaluation from one to another.

† In Processor, the economic value only denotes birds of single sex (see text in RESULTS). The economic value of carcass is based on "whole bird" and of breast meat, wings or legs is based on "further processed".

‡ Dfl: Dutch Guilder. 1.00 Dfl = 0.51 \$US = 0.74 \$Can, approx. FP = final product. PS = parental stock.

Economic values in principle are derived by computing profit margin (nonintegrated) or cost price (integrated) for the base level of the trait concerned and for a level that is marginally higher. It has been shown by Groen (1989b) that in case of fixed product output, which is the case here, economic values equal the average variable cost minus the marginal costs. That is, the economic value of an increase in egg number per parent stock female will be positive when the marginal cost of an additional egg per female is lower than the average variable cost per egg before genetic improvement. An exception is that the economic values of breast meat, legs, and wings are determined by marginal revenues, as they are affected by market price.

The defined representative market prices and performance levels influence average variable cost in the representative situation, and will therefore, influence economic values. These influences are illustrated by giving underlying aspects of quantification and valuation of changes in cost or profit of the system. Moreover, the sensitivity of economic values is illustrated by results from alternative performance levels and price elements (product prices and feed prices).

RESULTS

Representative Reference Situation

Economic values for a nonintegrated broiler enterprise, assuming representative parameters (Table 1), are in Table 2. For illustration purposes, economic values are worked out, assuming an arbitrarily chosen scale of 1,000,000 kg FP carcass output at the processor stage. To obtain this output, 1,000,000.00/0.688 = 1,453,488.37 kg live weight of FP finished birds is required, corresponding to 1,453,488.37/[(1.9 + 2.3)/2] = 692,137.32 FP birds finished, 692,137.32/0.955 = 724,751.12 FP chicks started by the commercial grower. To produce 724,751.12 FP chicks, 724,751.12/(0.9 × 0.9) = 894,754.47 FP eggs are hatched, 894,754.47/150 = 5,965.03 PS hens are housed, and 5,965.03/0.94 = 6,345.78 PS female chicks are purchased at the multiplier breeder stage.

At the multiplier breeder stage, seven traits are considered. The base of evaluation is per unit of product, i.e., per hatching egg. The economic value of hatching egg numbers originates from decreases in cost of purchasing PS chicks and feed cost. As hatching egg number per hen housed increases from 150 (Table 1) to 151, for getting the same output, i.e., 894,754.47 FP eggs, the numbers of PS female in every production period are reduced. The reduction in PS female number also decreases the number of PS males, as they are set proportional to those of females. Thus, costs for purchasing PS chicks are decreased by

(6,345.20 − 6,303.88) × 5.0 = 206.60 Dfl[1], for feed in females by 1,200.91 Dfl (calculated from feed saved in both growth and laying periods as number of hens is reduced), for feed in males by 67.40 Dfl; variable cost is decreased by (5,965.03−5,925.57) × 21.5 = 848.39 Dfl. As the number of hens and cocks at the end of laying decreases, salvage value for females and males is decreased by 218.87 Dfl. So, the economic value of an additional hatching egg is (206.6 + 1200.91 + 67.41 + 848.39 − 218.87)/894,754.47 = 0.0024 Dfl.

The economic value of feed consumption in the laying period is worked out thus: an additional 1 kg feed consumption does not change the number of animals in the system, but increases feed cost directly. Thus, the economic value for feed consumption in the laying period is −(5,965.03 hens housed × 1 kg feed per hen housed × 0.55 Dfl per kg feed) / 894,754.47 eggs = −0.0037 Dfl. The economic values of mortality of PS females in different periods originate from increase in cost of purchasing PS chicks and feed cost in both in PS females and males because an additional percentage of mortality leads to increasing the numbers of females and males in different periods. In the same way, it can be illustrated that the economic value of the body weights of PS females at the end of lay originates from a decrease in cost of multiplier breeder. This decrease in cost originates from an increase in the salvage value of females, as the salvage value is considered negative cost components.

At the hatchery stage, the base of evaluation is per unit of product, i.e., per day-old chick. Fertility and hatchability of fertiles have the same economic value. With an additional percentage in fertility or in hatchability, the number of hatching eggs needed to produce the constant output (724,751.12 FP chicks) is reduced from 894,754.47 to 724,751.12/(0.91 × 0.90) = 884,922.00. Thus, cost of hatching eggs is decreased by (894,754.47 − 884,922.00) × 0.36 Dfl per egg = 3,539.69 Dfl, the variable cost of the hatchery is reduced by (894,754.47 −884,922.00) × 0.07 Dfl per egg = 688.27 Dfl. Thus, the economic value of fertility or hatchablity is (3,539.69 + 688.27)/724,751.12 = 0.0058 Dfl per percentage per chick.

At the commercial grower stage, the base of evaluation is per individual, i.e., per marketable broiler bird. Three important traits (body weight, feed consumption, and mortality) are subdivided into six traits by sex, as a male produces more efficiently than a female. In the representative situation, revenue and cost of the commercial grower are: revenue = 1,453,488.37 kg × 2 Dfl/kg = 2,906,976.74 Dfl; cost of purchasing chicks is 724,751.12 chicks × 0.55 Dfl per chick = 398,613.12 Dfl, cost of feed for females is (692,137.32/2 birds + 724,751.12 × 0.0225 birds/2) × 3.80 kg feed per bird × 0.63 Dfl per

[1] Dfl: Dutch Guilder. 1.00 Dfl = 0.51 $US = 0.74 $Can, approx.

kg feed = 848,007.73 Dfl. Cost of feed for males is 995,739.51 Dfl; the variable cost is 692,137.32 birds × 0.51 Dfl per bird = 352,990.03 Dfl. Total profit is 2,906,976.74 - 398,613.12 - 848,007.73 - 995,739.51 - 352,990.03 = 311,626.35 Dfl; profit per bird finished is 311,626.35/692,137.32 = 0.4502 Dfl. Now the economic value of finishing weight of FP females is derived: as females increase from 1.9 to 2.9 kg, maintaining the fixed output, i.e., 1,453,488.37 kg live weight of FP finished, the number of FP birds finished is reduced from 692,137.32 to 1,453,488.37/(2.3 + 2.9)/2 = 559,033.99. The feed conversion ratio (from Table 1: 3.80/1.9 = 2 for females and 4.462/2.3 = 1.94 for males) does not change with the change in body weight, based on the definition of the economic values of a trait. Thus, the cost of feed for females is (559,033.99/2 birds + 13,170.91 birds /2) × 2.9 kg body weight × 2.000 kg feed/kg body weight × 0.63 Dfl/kg feed = 1,045,418.35 Dfl, of feed for males is 804,250.52 Dfl; the cost of purchasing chicks is 321,956.92 Dfl; the variable cost is 559,033.99 birds × 0.51 Dfl per bird = 285,107.33 Dfl. Therefore, total profit is 450,243.62 Dfl, and profit per bird finished is 450,243.62/559,033.99 = 0.8054 Dfl. The economic value of an additional 1 kg body weight of female broiler is derived by 0.8054 - 0.4502 = 0.3552 Dfl. This computation illustrates that the economic value of body weight originates from a decrease in the number of animals per fixed output of FP finished, leading to a decrease in cost of purchasing day-old chicks and in variable cost. As males and females are different in feed efficiency, the repartition of output between males and females also contributes to the profit, either positively or negatively. The economic value of an additional 1 kg feed consumed is the same for both male and female, because increasing feed consumption only increases feed cost by (692,137.32/2 birds + 724,751.12 × 0.0225 birds/2) × 1 kg feed × 0.63 Dfl/kg feed = 223,159.93 Dfl; thus, the economic value is - 223,159.93/692,137.32 = -0.3224 Dfl. The economic value of mortality originates from increase in cost of purchasing day-old chicks and feed, and variable cost.

At the processor stage, the base of evaluation is per individual, i.e., per marketable male or female bird. The economic value of carcass yield of a FP male is derived as follows. In the representative situation, the profit of a male bird is 2.3 kg live weight × 68.8% × 3.5 Dfl/kg carcass - 2.3 × 2 Dfl/kg live weight - 0.65 Dfl per bird = 0.2884 Dfl. When the carcass yield of FP male increases from 68.8 to 69.8%, the number of birds needed for 1,000,000 kg FP meat output decreases from 692,137.32 to 685,947.22. Profit per male bird is 2.3 × 69.8% × 3.5 - 2.3 × 2 - 0.65 = 0.3689 Dfl. The economic value per additional percent of carcass yield is 0.3689 - 0.2884 = 0.0805 Dfl. Economic values of breast meat yield, wings yield, and legs yield originate from the repartition of different parts of carcass and this leads to changes in revenue, as the product prices for them are higher than that for the remainder. As an example, the economic value of an additional percent of breast meat yield in male birds is 1% × 2.3 kg per bird × 68.8% × (10.00 Dfl per kg breast meat - 0.5 Dfl/kg remainder) = 0.1503 Dfl. In the same way, economic values of carcass traits of FP female are derived.

In an integrated broiler enterprise, two factors are taken into consideration. First, traits considered are only those generally important in broiler breeding. Three dam traits, three broiler traits and two carcass traits are considered (Table 3; defined in the footnote of the table). The definition for each broiler trait and carcass trait is a combination of male and female, which is different from that in the situation of nonintegration. Secondly, only for integration level, are the effects of production levels, product prices and feed prices on economic values of traits studied.

In an integrated broiler enterprise, the base of evaluation of economic values is per individual, i.e., per marketable broiler bird. The prices of products for the multiplier breeder and hatchery are set to be equal to their costs, and the costs for the processor are set to be equal to their market prices of products; thus, in the production system, all of the profits from a subsystem are expressed at the commercial grower stage. Economic values of traits are in Table 3. For broiler traits, the economic values are equal to those in the situation of nonintegration, because the base of evaluation is the same for these traits, except that here these traits are expressed based on a combined improvement in males and females. For example, the economic value of finishing weight is the sum of 0.3552 Dfl (for females only) and 0.3745 Dfl (for males only). For carcass traits and dam traits, the base of evaluation is different from the one in the situation of nonintegration.

Alternative Production Levels

Influences of alternative production levels on the economic values in an integrated broiler enterprise are calculated (Table 3). It is worth noting that changes in hatching egg number do not influence the economic values of traits at the commercial grower and the processor stage downstream, but only change those at the multiplier breeder and the hatchery stage. Changes in traits at the commercial grower influence economic values of traits at both the commercial grower and processor stage, but do not upstream change those of the multiplier breeder and hatchery stage.

Table 3 shows that economic values of feed consumption, mortality, carcass yield, and breast meat are sensitive to changes in finishing weight; higher finishing weight gives

TABLE 3. Economic values of important traits in relation to production levels in an integrated broiler enterprise (Dfl.marketable bird^{-1}.unit^{-1})*.

	Dam traits			Broiler traits			Carcass traits	
Base and alternative production level	Hatching egg no. (egg)	Laying feed (kg)	Hatchability /fertility (%)	Finishing weight (kg)	Feed consn. (kg)	Broiler mortality (%)	Carcass yield† (%)	Breast meat‡ (%)
Representative	0.0030	-0.0047	0.0060	0.7297	-0.6448	-0.0205	0.0735	0.1373
Finishing weight								
-20%	0.0030	-0.0047	0.0060	0.7297	-0.5159	-0.0176	0.0588	0.1098
+20%	0.0030	-0.0047	0.0060	0.7297	-0.7738	-0.0234	0.0882	0.1647
Feed consumption								
-20%	0.0030	-0.0047	0.0060	0.9837	-0.6448	-0.0176	0.0735	0.1373
+20%	0.0030	-0.0047	0.0060	0.4756	-0.6448	-0.0234	0.0735	0.1373
Mortality								
-20%	0.0030	-0.0047	0.0060	0.7357	-0.6418	-0.0205	0.0735	0.1373
+20%	0.0030	-0.0047	0.0060	0.7235	-0.6480	-0.0205	0.0735	0.1273
Hatching egg								
-20%	0.0047	-0.0059	0.0073	0.7297	-0.6448	-0.0205	0.0735	0.1373
+20%	0.0021	-0.0040	0.0052	0.7297	-0.6448	-0.0205	0.0735	0.1373

* The base of evaluation is per individual, i.e., per finished broiler bird. The meanings of the traits are: Finishing weight = Market weight of commercial broiler for both male and female at 7 weeks of age (kg). Feed consumption (feed consn.) = Feed in kg for both male and female commercial broiler from day-old to market weight. Mortality = number of commercial broilers died during the late growing period (week 2 onwards) as a percentage of number of day-old chick for both sexes. Hatching egg = number of hatching eggs per hen housed for breeders. Laying feed = Feed consumption in kg for per hen housed in laying period for PS. Fertility = Number of fertile eggs as a percentage of total eggs for breeders. Hatchability = Number of chicks (alive) as a percentage of number of fertile eggs for breeders. Carcass yield = Percentage carcass yield of commercial broilers of both sexes. Breast meat = Breast yield as a percentage of total carcass weight in both male and female commercial broilers.

† Based on "whole bird".

‡ Based on "further processed".

higher economic values of carcass yield and breast meat, but leads to lower economic values of feed consumption and mortality. For example, a 20% change in finishing weight leads to 0.1290 Dfl change in economic value of feed consumption. Changes in feed consumption only result in changes in the economic values of finishing weight and mortality. Changes in mortality result in slight changes in the economic values of finishing weight and feed consumption.

A 20% decrease of hatching egg production results in increases of the economic values of hatching egg by 57% (from 0.0030 Dfl to 0.0047 Dfl) and hatchability/fertility by 22% (from 0.0060 Dfl to 0.0073 Dfl), and a decrease of economic value of laying feed by 26% (from -0.0047 Dfl to -0.0059 Dfl). Figure 1 gives economic values of dam traits (hatching egg, hatchability/fertility and laying feed) at different hatching egg production levels. Model calculations show that with increasing hatching egg production per hen housed, hatching egg cost decrease from 1.778 Dfl for 30 hatching eggs to 0.213 Dfl for 250 hatching eggs, day-old chick cost decrease from 2.281 to 0.350 Dfl, and laying feed consumption per egg decrease from 1.500 to 0.180 kg, respectively. The value of an additional hatching egg expressed as per broiler per year decreases from 0.0740 to 0.0011 Dfl; the value of an additional 1% of hatchability/fertility decreases from 0.0263 to 0.0040 Dfl; and the value of an additional kilogram of laying feed increases from -0.0237 to -0.0028 Dfl. Figure 1 shows that the relationships between economic values of the concerned traits and hatching egg production levels are nonlinear. Shultz (1986) presented similar results, although the economic curve for a trait followed a stairstep pattern in that study.

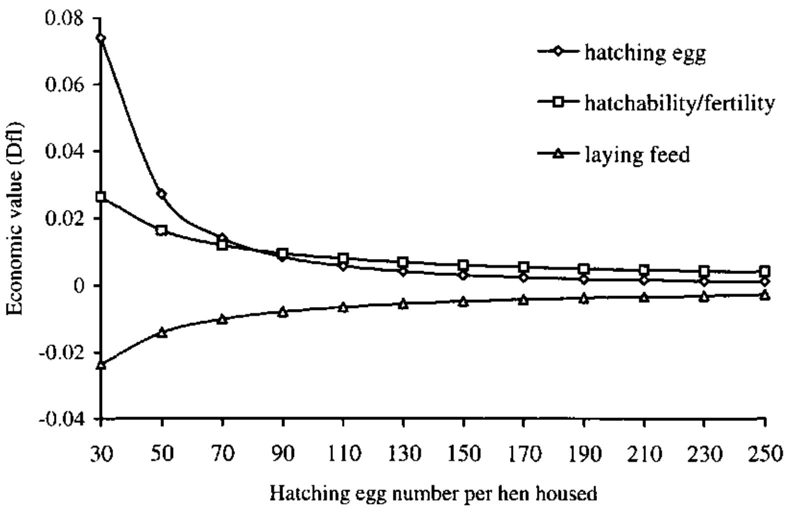


FIGURE 1. Economic values of dam traits at different egg production levels in an integrated broiler enterprise. The economic values are expressed as Dfl per unit per marketable bird. The unit is per egg for hatching egg number, per percent for hatchability/fertility and per kilogram for laying feed.

TABLE 4. Economic values of production traits in relation to product prices in an integrated broiler enterprise (Dfl.marketable bird^{-1}.unit^{-1})*.

		Deviation from representative product price				
Alternative price	Trait	-20%	-10%	0	+10%	+20%
Price of broiler at finishing weight	Finishing weight	0.3297	0.5297	0.7297	0.9297	1.1297
Price of carcass grade A	Carcass yield†	0.0588	0.0662	0.0735	0.0809	0.0882
Price of breast meat	Breast meat‡	0.1084	0.1228	0.1373	0.1517	0.1662

* The production unit is set as marketable commercial broiler. The meanings of the traits are: Finishing weight = Market weight of commercial broiler for both male and female at 7 weeks of age (kg). Feed consumption (feed consn.) = Feed in kg for both male and female commercial broiler from day-old to market weight. Mortality = number of commercial broilers died during the late growing period (week 2 onwards) as a percentage of number of day-old chick for both sexes. Hatching egg = number of hatching eggs per hen housed for breeders. Laying feed = Feed consumption in kg for per hen housed in laying period for PS. Fertility = Number of fertile eggs as a percentage of total eggs for breeders. Hatchability = Number of chicks (alive) as a percentage of number of fertile eggs for breeders. Carcass yield = Percentage carcass yield of commercial broilers of both sexes. Breast meat = Breast yield as a percentage of total carcass weight in both male and female commercial broilers.

† Based on "whole bird".

‡ Based on "further processed".

Alternative Product Prices

Economic values of production traits in relation to product prices in an integrated broiler enterprise are given in Table 4. Groen (1989a) stated that changes in product prices would only change economic values of those traits that influence output of corresponding products. Increases in product price will lead to linear increases in the economic values of the traits considered (Table 4). As the product price increases, the increase in the economic values is faster for finishing weight than for carcass yield and breast meat, implying that at different product price levels, relative values of traits would change.

Alternative Feed Prices

Influences of feed prices on economic values in an integrated broiler enterprise are shown in Table 5. Changes in the price of feed for the commercial grower only change

TABLE 5. Economic values of important traits in dependence on feed prices in an integrated broiler enterprise (Dfl.marketable bird^{-1}.unit^{-1})*.

Alternative Price	Trait†	Deviation from representative feed price						
		−30%	−20%	−10%	0	+10%	+20%	+30%
Price A‡	Finishing weight	1.1108	0.9837	0.8567	0.7297	0.6026	0.4756	0.3486
	Feed consumption	−0.4514	−0.5159	−0.5804	−0.6448	−0.7093	−0.7738	−0.8383
	Mortality	−0.0159	−0.0174	−0.0188	−0.0202	−0.0217	−0.0231	−0.0246
Price B§	Hatching egg	0.0025	0.0027	0.0028	0.0030	0.0032	0.0034	0.0035
	Laying feed	−0.0033	−0.0038	−0.0043	−0.0047	−0.0052	−0.0056	−0.0061
	Hatchability/fertility	0.0051	0.0054	0.0057	0.0060	0.0063	0.0066	0.0068

* The production unit is set as marketable commercial broiler.

† The meanings of the traits are: Finishing weight = Market weight of commercial broiler for both male and female at 7 weeks of age (kg). Feed consumption (feed consn.) = Feed in kg for both male and female commercial broiler from day-old to market weight. Mortality = number of commercial broilers died during the late growing period (week 2 onwards) as a percentage of number of day-old chick for both sexes. Hatching egg = number of hatching eggs per hen housed for breeders. Laying feed = Feed consumption in kg for per hen housed in laying period for PS. Fertility = Number of fertile eggs as a percentage of total eggs for breeders. Hatchability = Number of chicks (alive) as a percentage of number of fertile eggs for breeders. Carcass yield = Percentage carcass yield of commercial broilers of both sexes. Breast meat = Breast yield as a percentage of total carcass weight in both male and female commercial broilers.

‡ Price A denotes the price of feed for commercial broilers in whole growing period.

§ Price B denotes the prices of three kinds of feed for parent stock in rearing period, male breeders in laying period and hens in laying period.

economic values of traits for the commercial grower; changes in the price of feed for the multiplier breeder only result in changes in economic values of traits for the multiplier breeder and the hatchery. As feed price for commercial broilers increases, economic values of finishing weight and feed consumption are decreased, and the economic cost of mortality is increased. As feed price for breeders increases, economic values of hatching egg and hatchability/fertility are increased, while the economic value of laying feed is decreased. If absolute values of the economic values are considered, only those of finishing weight and mortality are decreased and those of the other four traits among the aforementioned six traits are increased as the prices of feed increase.

DISCUSSION

The deterministic model by Groen *et al.* (1998) is flexible. Economic values can be derived with different bases of evaluation, i.e., per female, per individual and per unit of product. It is also suitable for different kinds of broiler enterprise, either nonintegration, full integration or part integration. In every situation, the model assumes a fixed consumer market demand, i.e., fixed product output. In deriving economic values in the case of the integrated system, taking per unit of product as the base of evaluation already implies that product output is fixed. The assumption of output limitation is more acceptable in developed countries than in some developing ones where there are potentials to increase the average consumption of poultry meat. The model is written as a spreadsheet program. The model and the method of deriving economic values in this study can be extended, without changing the computer program, to apply in other meat-type poultry, e.g., turkeys and ducks, as the breeding method and production system are similar to that of broiler (Hunton, 1990). The model can also be extended to apply to the situation without output limitation just by changing a few lines in the computer program.

In the present study, the basic scale that establishes size of the broiler production system is a fixed amount of broiler carcass output. Any change in phenotypic trait does not change the gross revenue of the integrated enterprise. Moreover, any change in trait of a subsystem does not change the revenue of the same subsystem in the nonintegrated enterprise. The economic value of genetic improvement originates from reducing cost per unit of product value, rather than increasing revenue. Thus, in this study the difference between integrated and nonintegrated enterprises lies in two aspects, the definition of the cost components and the production scale.

The size of a subsystem may change as a result of change in performance in other subsystems. Both input and output production scales in commercial grower (number of animals) are influenced by finishing weight but not by hatching egg production; multiplier breeder and hatchery subsystems (number of animals and FP eggs) are influenced by both hatching egg number and finishing weight, in situations of both integration and nonintegration (Groen *et al.*, 1998). The genetic improvement of traits in one stage of subsystem will upstream force the other stages of subsystem to change size of output, and thus changes the revenue and total profit. For example, in the situation of nonintegration, the hatchery may not expect genetic improvement in finishing weight of the FP broiler, which means that the commercial grower will need a smaller number of FP chicks. A probable compensation for the hatchery is that the commercial grower will pay the hatchery according to genetic quality of FP chicks, e.g., a higher price for chicks with higher potential of growth. Therefore, based on the same consumer market demand and fixed market prices, the implications of genetic improvement are different between nonintegrated and integrated broiler enterprises.

Strain and Nordskog (1962) suggested that the breeder hen be used as the profit unit in an integrated enterprise; but it may provide a highly exaggerated estimate of relative economic worth of reproductive traits, as shown by Moav and Moav (1966). Moav and Moav (1966) suggested 1 lb (or 1 kg) broiler meat be used as a production unit. Harris (1970) indicated that the animal breeder's primary unit of selection is usually the individual animal. In this study, both per unit of product and per individual are used as the bases of evaluation. As in both nonintegration and integration, the output of the production system is at a given scale, there exists a fixed relationship among different bases of evaluation, e.g., in the representative situation as defined in Table 3, per FP finished bird is equivalent to 894,754.47 egg /692,137.32 birds = 1.2927 eggs. This relationship can be used to change the expression of economic values from one base of evaluation to another directly, e.g., the economic value of laying feed in an integrated enterprise (-0.0047 Dfl, Table 3) is derived from the one in the nonintegrated situation (-0.0037 Dfl, Table 2) multiplied by 1.2927. Thus, different choices may be made by breeders, as different perspectives of breeding goals may exist.

This study shows that, in an integrated broiler enterprise, the economic return of selection for dam traits (reproduction traits) are much smaller than those of broiler traits (production traits). Figure 1 illustrates that while the initial reproductive levels are higher, the economic values of the reproductive traits are correspondingly lower. This results agree with the conclusion of Moav and Moav (1966). Moav and Hill (1966) stated that in broilers the average commercial standard of reproductive performance was sufficiently high that selection on production traits alone was almost as efficient as selection on the optimum index. In broiler breeding practice, selection is carried out differently in dam lines and sire lines by using a different selection index; some reproductive traits, such as egg production, are only required in the dam line (Hunton, 1990). However, greater attention should be paid to reproductive traits at least for two reasons (Hunton, 1990): 1) improvement in production trait, especially growth rate is appreciable, but the associated deterioration in reproductive performance is not welcomed by the broiler industry; 2) although most broilers are grown by integrated operations, broiler hatcheries may not be part of integrated corporations, and they are concerned with the cost of producing a broiler chick. Moreover, as commercial broilers are crossbreds, the number of times traits are expressed in a population and the interval between selection and expression of these traits should be considered. The marginal economic values should be weighted by the number of discounted expressions for each trait (McClintock and Cunningham, 1974; Brascamp, 1978). These items leave room for further study.

Different sets of economic weights may exist between groups of producers, although these depend on the perspective in investment (e.g., from a national viewpoint or a competitive viewpoint) and on the different breeds or areas or production system, rather on the base of evaluation (Brascamp *et al.*, 1985). Similar phenomena were mentioned by Hazel (1943), Pearson (1982), Smith (1985) and Groen (1990). As shown in this study, the economic values of performance traits in broilers are sensitive to production levels, product prices and feed prices; and there are both linear (Tables 3, 4 and 5) and nonlinear (Table 3 and Figure 1) relationships between economic values and production circumstances. This sensitivity shows that relative values might change in future. Smith (1985) studied the cost and revenue of selecting many breeding stocks of a species and concluded that, from national viewpoint, the costs of developing alternative selection stocks are small relative to the possible returns. However, as indicated by Groen (1990), assumptions made by Smith (1985), especially on the level of the risk factor and the marginal cost of additional stocks, possibly were an overestimation of benefits of having a large number of stocks. Groen (1990) showed that losses in revenue due to incorrect prediction of production circumstances seemed too low to justify complete diversification of cattle breeding goals within a breeding organization, except for different types of output limitations. Groen (1990) made assumptions only by changing price parameters by 10%. As the rate of prices may change by more than 10% under future production circumstances, losses in revenue may be higher. Therefore, influences of production circumstances on the economic revenue of broiler breeding programs are worthy of further study.

ACKNOWLEDGMENT

The first author wishes to thank the State Education Commission of China for financial support for the stay at Wageningen Institute of Animal Sciences, Wageningen Agricultural University, The Netherlands.

REFERENCES

Akbar, M. K., D. L. Harris, and C. R. Arboleda, 1986. Development of the relative economic weights for linear and quadratic bioeconomic objectives in commercial broilers. Poultry Sci. 65:1834-1846.

Brascamp, E. W., 1978. Methods on economic optimization of animal breeding plans. Report B-134, Research Institute for Animal husbandry "Schoonoord", Zeist, The Netherlands.

Brascamp, E. W., C. Smith, and D. R. Guy, 1985. Derivation of economic weights from profit equations. Anim. Prod. 40:175-180.

Dickerson, G., 1970. Efficiency of animal production — modeling the biological components. J. Anim. Sci. 30:849-859.

Groen, A. F., 1989a. Economic values in cattle breeding. I. Influence of production circumstances in situation without output limitations. Livest. Prod. Sci. 22:1-16.

Groen, A. F., 1989b. Cattle breeding goals and production circumstances. Ph.D. Thesis, Department of Animal Breeding, Wageningen Agricultural University, Wageningen, The Netherlands.

Groen, A. F., 1990. Influences of production circumstances on the economic revenue of cattle breeding programs. Anim. Prod. 51:469-480.

Groen, A. F., X. Jiang, D. A. Emmerson, and A. Verijken, 1998. A deterministic model for the economic evaluation of broiler production systems. Poultry Sci. 77 :925-933.

Harris, D. L., 1970. Breeding for efficiency in livestock production: defining the economic objectives. J. Anim. Sci. 30:860-865.

Harris, D. L., and S. Newman, 1994. Breeding for profit: synergism between genetic improvement and livestock production (a review). J. Anim. Sci. 72: 2178-2200.

Hazel, L. N., 1943. The genetic basis for constructing selection indexes. Genetics 28: 576-490.

Hogsett, M. L., and A. W. Nordskog, 1958. Genetic-economic value in selecting for egg production rate, body weight and egg weight. Poultry Sci. 37:1404-1419.

Hunton, P., 1990. Industrial breeding and selection. Pages 985-1028 *in*: Poultry Breeding and Genetics. R. D. Crawford, ed. Elsevier, Amsterdam, The Netherlands.

McClintock, A. E., and E. P. Cunningham, 1974. Selection in dual-purpose cattle population: defining the breeding objective. Anim. Prod. 18:237-247.

Moav, R., and W. G. Hill, 1966. Specialised sire and dam lines. IV. selection within lines. Anim. Prod. 8:375-390.

Moav, R., and J. Moav, 1966. Profit in a broiler enterprise as a function of egg production of parent stocks and growth rate of their progeny. Br. Poult. Sci. 7:5-15.

Pearson, R. E., 1982. Economic aspects of the choice of a breeding objective. Vol. VI, Pages 50-59 *in*: Proceedings of the Second World Congress on Genetics Applied to Livestock Production. Madrid, Spain.

Shalev, B. A., and H. Pasternak, 1983. Genetic-economic evaluation of traits in a broiler enterprise: the relative genetic-economic values. Br. Poult. Sci. 24:521-529.

Shultz, F. T., 1986. Formulation of breeding objectives for poultry meat production. Vol. X, Pages 215-227 *in*: Proceedings of the Third World Congress on Genetics Applied to Livestock Production. University of Nebraska, Lincoln, NE.

Smith, C., 1985. Scope for selecting many breeding stocks of possible economic value in the future. Anim. Prod. 41:403-412.

Strain, J. H., and A. W. Nordskog, 1962. Genetic aspects of the profit equation in a broiler enterprise. Poultry Sci. 41:1892-1902.

Chapter 4

Discounted Expressions of Traits in Broiler Breeding Programs

X. JIANG, A. F. GROEN, and E. W. BRASCAMP

Animal Breeding and Genetics Group, Wageningen Institute of Animal Sciences, Wageningen University, Wageningen, The Netherlands

Published in ***Poultry Science***, 78 (1999): 307–316.

CDE: The number of cumulative discounted expressions of a parent's genotype in the progeny as a consequence of one mating, over a time horizon. It is suggested that in broiler breeding practice, cde resulting from discounted gene flow methodology should be taken into consideration.

ABSTRACT The commercially grown broiler usually is a crossbred from specialized purebred sire and dam lines. The position of a purebred line in the crossbreeding system influences its genetic contribution to expression of productive and reproductive performance at different stages of the production column and, thus, influences the breeding goal for a given line. In broiler breeding, cumulative discounted expressions (*cde*) should be considered to define breeding goals for multi-trait selection. In the present study, a systematic design for the application of discounted gene flow methodology to derive *cde* for production and reproduction traits in broiler breeding was developed. Factors considered as influencing the magnitude of *cde* were: crossbreeding system (two-way, three-way and four-way cross), selection scheme (with and without progeny testing and intensity of selection), selection path, trait (production at commercial stage and reproduction at either nucleus or multiplier stage), interest rate, and time horizon for evaluation. Performance data from a commercial breeding stock were applied in the analysis. Results indicated that levels of *cde* were significantly affected by all factors studied. The more pure lines were included in the crossbreeding system, the lower the *cde* for a particular selection path. However, the summation of all selection paths did not differ much among crossbreeding systems. Progeny testing decreased *cde* by increasing generation intervals. *cde* for reproduction traits were higher than those for production traits mainly as a result of earlier expression of the reproduction traits.

Key words: broilers, crossbreeding systems, cumulative discounted expressions, gene flow, selection schemes.

INTRODUCTION

The theory of simultaneous selection for various traits requires a weighing of the relative importance for these traits (Hazel, 1943). McClintock and Cunningham (1974) showed that the usual way of weighing by marginal return per unit is not appropriate when traits or groups of traits are unequally expressed (different frequencies and times of future expression). The weighing factors should include both the rate of expression and the marginal return per unit of improvement in each trait. McClintock and Cunningham (1974) proposed the use of a "standard discounted expression" of an individual's genotype being one expression of a parent's genotype in the progeny in the year in which the mating took place. To deal with more complex design of mating systems in breeding programs, the discounted gene flow method was proposed by Elsen and Mocquot (1974) and Hill (1974).

The discounted gene flow is expressed as a number of cumulative discounted expressions (*cde*), as a consequence of one mating; "cumulative" refers to an accumulation of expressions over generations or years; and "discounted" implies to the fact that future return is discounted to today's values by a discounting factor (Brascamp, 1978). It has been applied in dairy cattle (e.g., Brascamp, 1975) and beef cattle (e.g., Wilton and Danell, 1981). Danell *et al.* (1976) extended the approach by McClintock and Cunningham (1974) to pig breeding, considering the genetic consequences in different types of population according to the replacement of breeding animals. It is relevant to consider *cde* in poultry breeding because different groups of traits, e.g., production and reproduction traits, are expressed by different numbers of birds at different stages of the production column (nucleus, multiplier, and commercial grower).

The commercial grower bird usually is a crossbred from pure lines, in which specialized sire and dam lines are used (Fairfull, 1990; Hunton, 1990). The crossbreeding system may involve two, three or four purebred lines. Birds producing at different stages of the production column have different (although related) genetic origins. The position of a purebred line in the crossbreeding system influences the relative contribution of genes of the line to expression of reproductive (especially the crossbred grandparent) and productive (especially the commercial end product) performance (Moav, 1966), and therefore, should be considered when defining the breeding goal for a given line (Smith, 1964). Jiang *et al.* (1998) derived economic values in broiler breeding, and these economic values should be weighed by the number of discounted expressions for each trait when defining breeding goals.

In the present study, a systematic design for the application of discounted gene flow methodology to derive *cde* for production and reproduction traits in broiler breeding is proposed. The *cde* are calculated for different alternatives regarding crossbreeding system (two-way, three-way, and four-way cross), selection scheme (with and without progeny testing and intensity of selection), selection path, trait (production at commercial stage, and reproduction at either nucleus or multiplier stage), interest rate, and time horizon for evaluation.

TABLE 1. Crossbreeding systems for broilers.

	Genotypes				
Crossbreeding system	Purebred sire lines	Purebred dam lines	Multiplier sire	Multiplier dam	Commercial grower
Two-way cross	A	D	–	–	A×D
Three-way cross	A	C, D	–	C×D	A×(C×D)
Four-way cross	A, B	C, D	A×B	C×D	(A×B)×(C×D)

MATERIALS AND METHODS

General Description

The *cde* are calculated using the computer program Gflow (Brascamp, 1978). The factors influencing *cde* as considered in the present study are schematically presented in Figure 1. The cumulative discounted expression c_{lt} is:

$$c_{lt} = \sum_{i=0}^{t} \mathbf{h}'\mathbf{m}_{li}\delta^{i} \tag{1}$$

where t is the time horizon; l is selection path; **h** is the incidence vector that specifies frequencies by which age-classes contribute to (phenotypic) expression of traits; $\mathbf{m}_{li}$ specifies the relative contribution of the initial set of genes in the selected animals to the genes of animals in this age-class at time i; δ^{i} is the discounting factor that discounts future revenue to a base year (i=0). The total number of rows in both **h** and **m** is equal to the total number of age-classes over tiers and sexes within tiers considered in the gene flow. Two lengths of age-classes are considered: the longer age-class (0.5 yr) is used to compare breeding systems, and the shorter one (7 wk) to quantify the importance for *cde* of factors other than crossbreeding system. Tiers include all stages of the crossbreeding system (commercial grower, multiplier breeders, and pure lines). Four pure lines denoted as A, B, C, and D are assumed, in which A and B are specialized sire lines and C and D are specialized dam lines. Crossbreeding systems are shown in Table 1.

The time horizon defines the period over which future expression of genes by offspring of an initial set of selected individuals is evaluated. A 20-yr time horizon for evaluation of revenue of the breeding programs is used, which reflects 40 age-classes when one age-class is 0.5 yr, and $(365/49) \times 20 = 149$ age-classes when one age-class is 7 wk, respectively.

The incidence vector is defined according to reproduction levels and replacement times of birds. As expression of genes is not exactly at the end of the age-classes, the additional time adjustment discounts revenue from the last day of the age-class to the average moment of expression (in an age-class). As an example, in situation of 0.5 yr of age-class, production traits for commercial broiler are expressed at the moment of 7 wk old; resulting additional time adjustment is (49 days − 182.5 days)/182.5 days = −0.7315.

The *cde* differ according to the selection path l where the initial matings of the selected individuals are performed: selected individuals are sires to breed sires, dams to breed dams, dams to breed sires, or dams to breed dams (path ss, sd, ds and dd, respectively). In

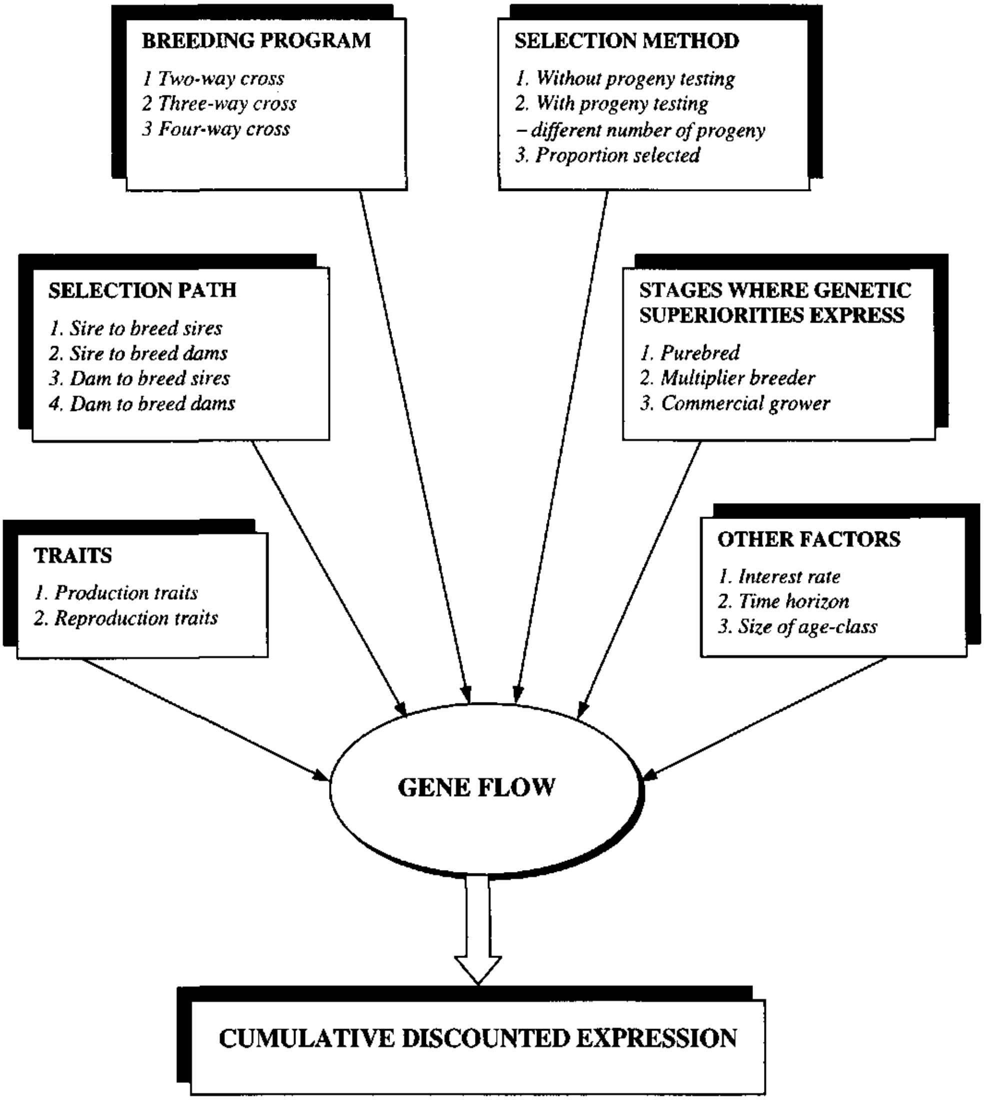


FIGURE 1. Schematic representation of factors that are considered in the present study.

calculating $\mathbf{m}_{li}$, first an initial $\mathbf{n}_{l0}$ vector is defined, with one non-zero element equal to 1, indicating that the initial matings are performed with selected individuals in that age-class (in a certain tier and sex) and that these selected individuals represent 100 % of their own genes.

$$\mathbf{n}_{li} = \mathbf{Q}\ \mathbf{n}_{l(i-1)} \tag{2}$$

$$\mathbf{m}_{li} = \mathbf{R}_l\,\mathbf{n}_{l(i-1)} + \mathbf{P}\ \mathbf{m}_{l(i-1)} \tag{3}$$

$$\mathbf{R} = \sum_{l=1}^{s} \mathbf{R}_l \tag{4}$$

$$\mathbf{P} = \mathbf{Q} + \mathbf{R} \tag{5}$$

R describes the process of reproduction. Elements in **R** denote the relative contribution of parents to the genes of the youngest animals (per sex per tier) one time period later. **Q** describes aging: elements are either zero or one, where the ones denote the aging (per sex per tier) up to the eldest age-class. Equation (2) describes the aging of the initial set of genes of selected individuals (the initial set of genes will be lost after selected individuals reached the eldest age-class), and equation (3) describes the flow of (offspring) genes through the population age-classes by reproduction and aging.

The discounting factor is calculated according to Smith (1978),

$$\delta^i = \left(\frac{1}{1+q}\right)^i \tag{6}$$

$$q = \frac{r-k}{1+k} \tag{7}$$

where q is the inflation free interest rate; r is the (uncorrected) interest rate; and k is the inflation rate. Average q for the period of 1985 to 1995 in the Netherlands is 0.0451 (Statistical Office of the European Communities, 1996). This base value of q is used throughout this study, unless other alternatives are indicated. A total of eight alternatives is studied in the present study. Each alternative includes consideration of age-class length, selection scheme, and calculated replacement times (Table 2).

Selection Schemes and Traits

The selection scheme applied and the traits considered in selection not only affect the transmission of genes in populations, but also the generation interval. Two types of selection scheme applied are defined:

- NO-PROTEST = Selection not including progeny testing; selection is based on individual and sib performance;
- PROTEST = Selection based on progeny testing; selection is based on the performance of pure line or crossbred offspring.

TABLE 2. Alternatives considered with respect to selection scheme, age-class length and replacement times.

Alter-native*	Age-class length	Fertility considered in sire line	Number of progeny per female for testing (Pro/Repro)† Sire line	Number of progeny per female for testing (Pro/Repro)† Dam line	Proportion selected in female	Replacement time in wk of age Sire line	Replacement time in wk of age Dam line	Applied to cross
1	7 wk	No	0/0	0/0	0.10	28 to 35	46 to 52	Two-way
2	7 wk	Yes	0/0	0/0	0.10	46 to 53	46 to 52	Two-way
3	7 wk	No	10/0	10/5	0.10	39 to 46	82 to 89	Two-way
4	7 wk	No	20/0	20/10	0.10	42 to 49	91 to 100	Two-way
5	7 wk	Yes	10/5	10/5	0.10	84 to 92	82 to 89	Two-way
6	7 wk	Yes	20/10	20/10	0.10	93 to 103	91 to 100	Two-way
7	0.5 yr	No	0/0	0/0	0.10	28 to 35	46 to 52	Two-, three- and four-way
8	0.5 yr	Yes	10/5	10/5	0.10	84 to 92	82 to 89	Two-, three- and four-way

* Alternatives 1, 2 and 7 = selection not-including progeny testing; Alternatives 3, 4, 5, 6 and 8 = selection based on progeny testing.

† Pro = Production traits; Repro = Reproduction traits.

Two groups of traits are distinguished, i.e. production (e.g., body weight for age, feed consumption, and meat yield) and reproduction (e.g., hatching egg production per hen housed and fertility/hatchability). Production traits are measured at 7 wk of age (for both sire lines and dam lines); reproduction traits are measured up to 45 wk of age. For specialized sire lines, two situations are considered: only production traits are measured and included in the selection, or measurement and selection is for both production and reproduction. In specialized dam lines, production traits are always measured along with reproduction traits.

In calculating the *cde*, expression of genetic superiority (as defined in vector **h**) for production is considered to be in growers only. For reproduction, expression is considered to be in pure lines (A, B, C, and D) and in the multipliers (A×B and C×D).

Definition of Matrix P

The matrix **P** defines average gene transmission from parent to offspring by reproduction and aging. The definition of age-classes (7 wk, 0.5 yr) and tiers (i.e., crossbreeding system) define the size of matrix **P**: $\mathbf{P}_{2w}$, $\mathbf{P}_{3w}$ and $\mathbf{P}_{4w}$ for two-, three- and four-way crossbreeding, respectively:

$$\mathbf{P}_{2W}=\begin{bmatrix}\mathbf{P}_A & \mathbf{0} & 0\\ \mathbf{0} & \mathbf{P}_D & 0\\ \mathbf{P}_{GA} & \mathbf{P}_{GD} & 0\end{bmatrix},\ \mathbf{P}_{3W}=\begin{bmatrix}\mathbf{P}_A & \mathbf{0} & \mathbf{0} & \mathbf{0} & 0\\ \mathbf{0} & \mathbf{P}_C & \mathbf{0} & \mathbf{0} & 0\\ \mathbf{0} & \mathbf{0} & \mathbf{P}_D & \mathbf{0} & 0\\ \mathbf{0} & \mathbf{P}_{MC} & \mathbf{P}_{MD} & \mathbf{0} & 0\\ \mathbf{P}_{GA} & \mathbf{0} & \mathbf{0} & \mathbf{P}_{GCD} & 0\end{bmatrix}$$

$$\text{and } \mathbf{P}_{4W}=\begin{bmatrix}\mathbf{P}_A & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & 0\\ \mathbf{0} & \mathbf{P}_B & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & 0\\ \mathbf{0} & \mathbf{0} & \mathbf{P}_C & \mathbf{0} & \mathbf{0} & \mathbf{0} & 0\\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{P}_D & \mathbf{0} & \mathbf{0} & 0\\ \mathbf{P}_{MA} & \mathbf{P}_{MB} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & 0\\ \mathbf{0} & \mathbf{0} & \mathbf{P}_{MC} & \mathbf{P}_{MD} & \mathbf{0} & \mathbf{0} & 0\\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{P}_{GAB} & \mathbf{P}_{GCD} & 0\end{bmatrix}$$

The $\mathbf{P}_A$, $\mathbf{P}_B$, $\mathbf{P}_C$, and $\mathbf{P}_D$ are sub-matrices defining the tiers for pure lines A, B, C, and D (reproduction and aging), respectively. The rank of a sub-matrix for pure lines is equal to the number of age-class defined for the pure line. The $\mathbf{P}_{MA}$, $\mathbf{P}_{MB}$, $\mathbf{P}_{MC}$ and $\mathbf{P}_{MD}$ are sub-matrices defining the tier for multiplier, where the subscript MA, MB, MC and MD denote that the multiplier obtains genes from pure line A, B, C and D, respectively. The $\mathbf{P}_{GA}$, $\mathbf{P}_{GD}$, $\mathbf{P}_{GAB}$ and $\mathbf{P}_{GCD}$ are sub-matrices defining the tiers for growers: the grower obtains genes from pure line A, pure line D, multiplier A×B and multiplier C×D, respectively.

The commercial grower tier always has one age-class, combined for males and females. The multiplier tiers always have 3 age-classes and only for the relevant sex. The number of age-classes in the nucleus tiers differs according to the selection scheme and position of the pure line in the crossbreeding system.

With the PROTEST selection schemes and an age-class of 0.5 yr, eight age-classes for a pure line are defined (four male and four female age-classes), without differentiating between pure lines. So, in situations of two-, three- and four-way crosses, the total number of age-classes is considered 17, 28 and 39, respectively. With the PROTEST selection schemes and an age-class of 7 wk (only considered for a two-way cross), 32 age-classes for a pure line are defined (16 for each sex). This results in a total rank of $\mathbf{P}_{2w}$ equal to 65 age-classes.

With the NO-PROTEST selection scheme and an age-class of 7 wk (also only two-way cross), 18 age-classes for a pure line are defined (nine for each sex); a total rank of $\mathbf{P}_{2w}$ equals 37 age-classes. With the NO-PROTEST selection schemes and an age-class of 0.5 yr, five age-classes for a pure line are defined. Within these five age-classes, three are for the sex contributing to crossbreeding and two are for the sex not contributing to crossbreeding. For example in a situation of a two-way cross, there are three male age-classes in A, two female age-classes in A, two male age-classes in D, three female age-classes in D and one (male+female) age-class in A×D (a total of three tiers and 11 age-classes). In a situation of three-way and four-way crosses, five and seven tiers and 19 and 27 age-classes are included. When males are used for crossbreeding, the sub-matrix for pure lines (A and C) is defined as $\mathbf{P}_i$; when females contribute to crossing, the sub-matrix for pure lines (B and D) is defined as $\mathbf{P}_j$, and

$$\mathbf{P}_i = \left[\begin{array}{ccc|cc} a & b & c & d & e \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ \hline a & b & c & d & e \\ 0 & 0 & 0 & 1 & 0 \end{array}\right] \quad \text{and} \quad \mathbf{P}_j = \left[\begin{array}{cc|ccc} d & e & a & b & c \\ 1 & 0 & 0 & 0 & 0 \\ \hline d & e & a & b & c \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{array}\right]$$

In these matrices, a, b, c, d, and *e* denote proportions for each age-class of the pure line producing its replacement. In both $\mathbf{P}_i$ and $\mathbf{P}_j$, $a + b + c = d + e = 0.5$. The proportions for each age-class of pure lines to produce crossbreds, and the proportion for each age-class of the multiplier to produce (crossbred) growers, are defined in the same way. All of these proportions are calculated from the reproduction levels for pure lines and multipliers and the replacement times for pure lines.

Reproduction Levels and Replacement Times

Assumed reproduction levels in terms of the (cumulative) numbers of chicks born alive produced by a hen in a pure line or a multiplier are given in Table 3. Assumed performance of multiplier C×D originates from recommendations by Euribrid (Euribrid, 1995). For purebred dam lines, a 10% lower performance level is assumed, considering 10% of

TABLE 3. Distribution of number of chicks produced by a hen from pure lines and multiplier*.

	Multiplier		Lines C and D		Lines A and B	
Age in wk	Chicks/wk	Cumulative	Chicks/wk	Cumulative	Chicks/wk	Cumulative
27	0.0	0.0	0.0	0.0	0.0	0.0
28	0.6	0.6	0.5	0.5	0.5	0.5
29	2.1	2.7	1.9	2.5	1.7	2.2
30	3.7	6.4	3.4	5.8	3.1	5.3
31	4.2	10.6	3.8	9.6	3.5	8.8
32	4.5	15.1	4.1	13.7	3.7	12.5
33	4.7	19.8	4.3	18.0	3.9	16.4
34	4.8	24.6	4.4	22.4	4.0	20.3
35	4.8	29.4	4.4	26.7	4.0	24.3
36	4.7	34.1	4.3	31.0	3.9	28.2
37	4.7	38.8	4.3	35.3	3.9	32.1
38	4.6	43.4	4.2	39.5	3.8	35.9
39	4.6	48.0	4.2	43.6	3.8	39.7
40	4.4	52.4	4.0	47.6	3.6	43.3
41	4.4	56.8	4.0	51.6	3.6	46.9
42	4.3	61.1	3.9	55.5	3.6	50.5
43	4.2	65.3	3.8	59.4	3.5	54.0
44	4.1	69.4	3.7	63.1	3.4	57.4
45	4.1	73.5	3.7	66.8	3.4	60.7
46	4.0	77.5	3.6	70.5	3.3	64.0
47	3.9	81.4	3.5	74.0	3.2	67.3
48	3.8	85.2	3.5	77.5	3.1	70.4
49	3.7	88.9	3.4	80.8	3.1	73.5
50	3.6	92.5	3.3	84.1	3.0	76.4
51	3.5	96.0	3.2	87.3	2.9	79.3
52	3.5	99.5	3.2	90.5	2.9	82.2
53	3.4	102.9	3.1	93.5	2.8	85.0
54	3.3	106.2	3.0	96.5	2.7	87.8
55	3.2	109.4	2.9	99.5	2.6	90.4
56	3.1	112.5	2.8	102.3	2.6	93.0
57	3.1	115.6	2.8	105.1	2.6	95.5
58	3.0	118.6	2.7	107.8	2.5	98.0
59	2.9	121.5	2.6	110.5	2.4	100.4
60	2.8	124.3	2.5	113.0	2.3	102.7
61	2.7	127.0	2.5	115.5	2.2	105.0
62	2.6	129.6	2.4	117.8	2.1	107.1
63	2.5	132.1	2.3	120.1	2.1	109.2

* Data for multiplier are adapted from "Euribrid technical information on Hybro N breeders"; data for Lines C and D are calculated by assuming 10% of heterosis; and data for Lines A and B are calculated by assuming that egg production of sire lines is 10% lower than that of dam lines. The second round of reproduction begins at 75 wk of age and the number of chicks produced by a dam is 20% lower than the first round (figures are not listed in the table).

heterosis for chick production (Fairfull, 1990). Also a 10 % lower reproduction level for purebred sire lines relative to purebred dam lines was assumed. In the alternatives with progeny testing, a second round of reproduction starts at 75 wk of age (equivalent to 28 wk of age in first round). The pattern of production of chicks in the second round is similar to the number of chicks produced in the first round, but only at a 20% lower level. Figures in Table 3 exclude mortality in chicks; for calculation of replacement times, mortality is 4.5% during the period of 0 to 7 wk of age, 5% for the period of 7 wk of age up to beginning of reproduction, and 8% for the laying period (total mortality up to end laying period is 16.5%).

Replacement time represents the age period when a breeding animal produces its purebred offspring. In fact, the average ages during the replacement times reflect generation intervals of pure lines. The distribution of reproductive performance during replacement times defines relative contributions of age-classes to replacement (e.g., $\mathbf{P}_i$ and $\mathbf{P}_j$-elements) and the contributions of age-classes to (phenotypic) performances in the incidence vector **h**. Replacement times for different selection schemes are calculated from reproduction levels times define relative contributions of age-classes to replacement (e.g., $\mathbf{P}_i$ and $\mathbf{P}_j$-elements) and the contributions of age-classes to (phenotypic) performances in the incidence vector **h**. Replacement times for different selection schemes are calculated from reproduction levels assumed (Table 3) and are listed in Table 2. For example, alternative 1, using specialized sire lines with NO-PROTEST (i.e., only production traits are considered), selection and measurement of traits are at 7 wk of age. When proportion selected is 0.10 in females, i.e., 10 female progeny per dam up to reproduction age are required. In other words, 10 / (0.95 × 0.955) = 11.02 female chicks or total of 11.02 × 2 = 22.04 day-old chicks are needed. According to Table 3, a female can produce 22.04 chicks from 28 wk old to 35 wk of age.

As a next step, proportions for (purebred) nucleus age-classes contributing to replacement (e.g., in matrix $\mathbf{P}_i$ and $\mathbf{P}_j$ the values of a, b, c, d, and e) are calculated from the replacement times. Reproduction levels and replacement times were translated into contributions for alternatives with age-class lengths of 7 wk and 0.5 yr. For example, in alternative 1 with an age-class of 7 wk and a dam line in a two-way cross, the number of age-classes is nine. The replacement time is 46 to 52 wk of age (Table 2). Weeks 46 to 49 are in the 7th age-class, and Weeks 50 to 52 are in the 8th age-class. Based on the number of chicks (pure line D) produced per week (Table 3), the relative contribution of age-classes to replacement is (3.6 + 3.5 + 3.5 + 3.4)/22.04 = 0.635 in the 7th age-class, and 1 - 0.635 = 0.365 in the 8th age-class. Then, in the column of chicks per week for pure line D, take away the number of chicks for replacement, and sum up the remaining number of chicks for per age-class. Thus, the number of chicks for per age-class divided by the remaining total

TABLE 4. Cumulative discounted expressions of production and reproduction traits for different selection paths arising from two-way, three-way and four-way crossbreeding in broilers.

		NO-PROTEST*		PROTEST†	
Crossbreeding system	Selection path‡	Production trait	Reproduction trait	Production trait	Reproduction trait
Two-way	Sire to A (ss)	4.89c§	9.03p	1.89c	2.90p
cross	Dam to A (ds)	4.41c	9.03p	1.42c	2.90p
A×D	Sire to D (sd)	2.94c	6.06p	1.41c	2.87p
	Dam to D (dd)	3.42c	6.06p	1.88c	2.87p
Three-way	Sire to A (ss)	4.89c	9.03p	1.89c	2.90p
cross	Dam to A (ds)	4.41c	9.03p	1.42c	2.90p
A×(C×D)	Sire to C (ss)	1.60c	3.27m	0.87c	1.79m
	Dam to C (ds)	1.37c	2.81m	0.65c	1.34m
	Sire to D (sd)	1.37c	2.81m	0.65c	1.34m
	Dam to D (dd)	1.60c	3.27m	0.87c	1.79m
Four-way	Sire to A (ss)	2.28c	4.66m	0.88c	1.80m
cross	Dam to A (ds)	2.05c	4.20m	0.66c	1.35m
(A×B)×(C×D)	Sire to B (sd)	2.05c	4.20m	0.66c	1.35m
	Dam to B (dd)	2.28c	4.66m	0.88c	1.80m
	Sire to C (ss)	1.60c	3.27m	0.87c	1.79m
	Dam to C (ds)	1.37c	2.81m	0.65c	1.34m
	Sire to D (sd)	1.37c	2.81m	0.65c	1.34m
	Dam to D (dd)	1.60c	3.27m	0.87c	1.79m

* NO-PROTEST = alternative 7 in Table 2.

† PROTEST = alternative 8 in Table 2.

‡ Selection path *sire to A* means sire to breed offspring of pure line A, which is equivalent to path *sire to breed sires* (ss) in general. ds = *dam to breed sires*, sd = *sire to breed dams*, dd = *dam to breed dams*.

§ Letters (c, m and p) denote the stages where genetic superiorities are expressed. c = commercial grower stage, m = multiplier breeder stage, p = purebred stage.

number of chicks for 0 to 63 wk of age, is the relative contribution of every age-class to the crossbred.

RESULTS

Comparison of Different Crossbreeding Systems

Table 4 gives *cde* for production and reproduction traits for all selection paths arising from different crossbreeding systems. The *cde* are per commercial bird when genetic superiority is expressed in commercial grower stage (here only production traits) and per female when it is expressed in multiplier and/or purebred stage (here only reproduction traits).

The *cde* for a certain path differ between breeding systems (Table 4). For example, for selection path sire to A, *cde* for production traits in two-way, three-way and four-way crosses and selection without progeny test (NO-PROTEST) are 4.89, 4.89 and 2.28, respectively. The values of *cde* for different pure lines depend on the relative contribution to the grower; *cde* for sire/dam to A in two-way and three-way cross are the same, and *cde* for sire/dam to D in two-way and three-way cross are different. Generally, the more pure lines included in crossbreeding, the less important for a certain selection path, i.e, the relative contribution of a line to future expression of the genotypic superiority in offspring is lower. However, if *cde* for all paths in a crossbreeding system are added, the differences of total *cde* among crossbreeding systems are much smaller. For example, for production traits, total values of *cde* for two-way, three-way and four-way cross are 15.66, 15.24, and 14.60 for NO-PROTEST, 6.60, 6.35, and 6.12 for PROTEST, respectively. The differences in total *cde* are due to a lengthening of generation intervals with increasing number of pure lines in the crossbreeding system. The *cde* for reproduction traits are always higher than those for production traits. This difference originates from the fact that reproduction

TABLE 5. Cumulative discounted expressions for production and reproduction traits expressed in commercial grower in two-way crossbreeding for different alternatives.

		Selection path			
Alternative	Traits	Sire to A	Dam to A	Sire to D	Dam to D
	NO-PROTEST				
1	Production traits	4.90	4.43	2.97	3.45
	Reproduction traits	9.15	9.15	5.93	5.93
2	Production traits	3.43	2.95	2.97	3.45
	Reproduction traits	5.92	5.92	5.97	5.97
	PROTEST				
3	Production traits	3.72	3.25	1.63	2.10
	Reproduction traits	6.84	6.84	3.13	3.13
4	Production traits	3.49	3.03	1.46	1.93
	Reproduction traits	6.34	6.34	2.77	2.77
5	Production traits	2.04	1.57	1.63	2.10
	Reproduction traits	3.08	3.08	3.13	3.13
6	production traits	1.88	1.41	1.46	1.93
	Reproduction traits	2.74	2.74	2.77	2.77

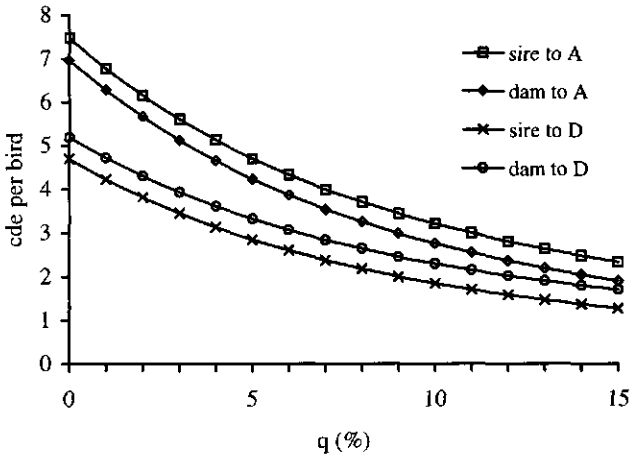


FIGURE 2. Cumulative discounted expressions (*cde*) for production traits expressed in commercial grower, in relation to inflation free interest rates (q), for all selection paths in alternative 1 for two-way cross, when time horizon is 20 yr. *cde* is plotted for each 1% increase from 0% to 15% of q.

performance is always influenced by a lower number of pure lines. A comparison of *cde* for production sire to pure line A in a two-way cross with *cde* for reproduction sire to pure line A in a four-way cross would be more fair: 4.89 vs 4.66 (NO-PROTEST). Remember that these *cde* are for different animal units.

Comparison of Selection Schemes and Selection Paths

For a two-way cross and 7 wk of age-classes, the *cde* for six alternatives of selection operation are presented in Table 5 (for production and reproduction traits). The differences in *cde* for selection without (NO-PROTEST) and with (PROTEST) progeny test are revealed in detail. Again, *cde* for NO-PROTEST are always higher than those for PROTEST, comparing among alternative-groups of same property. For example, *cde* for Alternative 1, which represents NO-PROTEST without fertility considered in sire line, are higher than *cde* for Alternatives 3 and 4, which represent PROTEST without fertility considered in sire line. Similarly, Alternative 2 is comparable with Alternatives 5 and 6, where fertility is considered in the sire line. Again, *cde* for Alternative 2 is higher than *cde* for Alternatives 5 and 6.

The *cde* for different paths are quite different (Table 5, Figure 2). The differences are caused by the time a trait is expressed after initial selection in different paths and the generation intervals for pure lines. Taking an example from Table 5, in the row for Alternative 1, *cde* for selection path sire to pure line A (4.90) is larger than that for selection path dam to pure line A (4.43); *cde* for selection path dam to pure line D is bigger than that for selection path sire to pure line D. This effect is because in case of two-way cross, commercial growers get their genes directly from sire of pure line A and dam of pure line D; they do not get their genes directly from dam of pure line A and sire of pure line D. This is well represented by vector **n** in gene flow methodology as described previously. The difference in *cde* for pure line A (4.90 + 4.43) and pure line D (2.97 + 3.45) originates from generation intervals as described in Table 2.

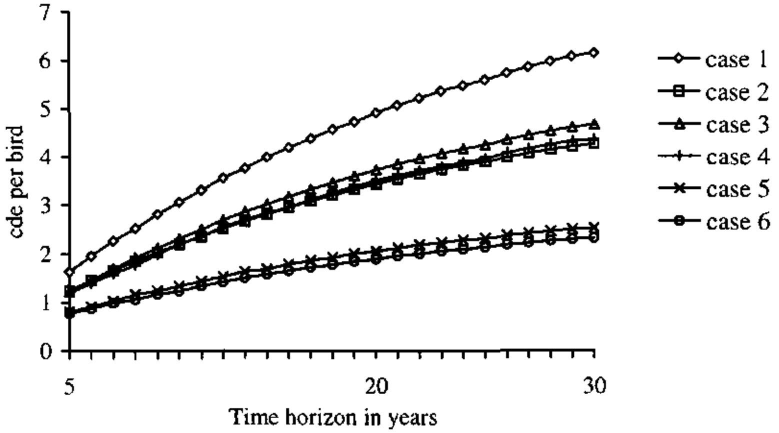


FIGURE 3. Cumulative discounted expressions (*cde*) for production traits expressed in commercial grower, in relation to time horizon, for different alternatives for two-way cross from sire to A path, where inflation free interest rate (q) is 0.0451.

Effect of Varying Interest Rate and Time Horizon

Figures 2 and 3 give the effect of changing interest rate and time horizon on *cde*. As an example, inflation interest rate (q) is changed from 0 to 15 %, and applied to Alternative 1 for all paths for production traits. Results (Figure 2) show that as q value increases, *cde* decreases. As q value increases from 0 to 8%, *cde* for sire to pure line A decreases by 50.5%, for sire to pure line D by 53.6%; as q value is changed from 8 to 15%, the decreases are 37.2% and 41.6%, respectively.

The effect of time horizon on *cde* is shown in Figures 3 (for different alternatives of path sire to pure line A), again for production traits. Generally, as time horizon increases, *cde* increase. Percentage increases for Alternative 6 of path sire to pure line A are 59.3, 53.1 and 23.4 (Figure 3), respectively.

DISCUSSION

In the present study, *cde* for traits in broiler breeding are derived. The influences of different factors on *cde* are quantified and their importance in a broiler crossbreeding structure is revealed. Meanwhile, a systematic method is described in detail to the use of discounted gene flow methodology in broiler breeding. Based on the method in the present study, discounted gene flow can also be applied in other classes of poultry.

Factors Relevant to cde in Broiler Breeding

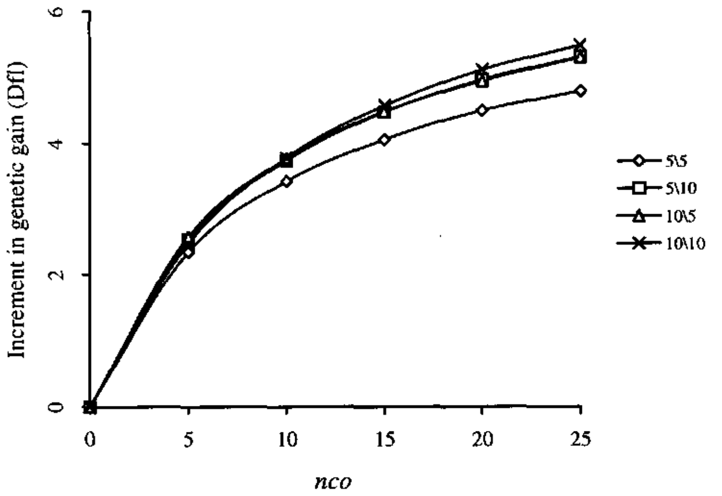
The present study indicates, that *cde* vary with different crossbreeding systems, selection schemes (with or without progeny testing), selection paths, traits (production and reproduction traits) and stages in the production column. The results agree to Brascamp (1975) using dairy cattle, Danell *et al.* (1976) using pig, and Wilton and Danell (1981) using beef cattle, although not all of these factors were considered by any of these authors in one study because of different breeding structure. Brascamp (1975) studied four selection paths for dairy cattle and found different relative contributions of the path to genetic gain and financial return. Danell *et al.* (1976) concluded that different definitions of the breeding goals might be necessary for the two sexes when some traits are shown by the selected animals themselves; the aggregate genotype may differ in nucleus, sub-nucleus and commercial populations in pig breeding. Considering beef crossbreeding programs, Wilton and Danell (1981) revealed the difference in relative rates of expressions between crossbreeding systems.

Crossbreeding systems affect the time at which genes are expressed for a certain selection path. Both absolute and relative values of *cde* are influenced by crossbreeding structure. When more pure lines take part in crossbreeding, selection in a certain pure line is less important. The selection scheme strongly influences *cde*, favoring selection without progeny testing. This means that the larger return on investment is with the simplest of schemes as described by Harris and Stewart (1986). However, Harris and Stewart (1986) indicated that this is not likely the optimum scheme. The optimum scheme is that where the recognized value of response is greater than the recognized costs of achieving that response just enough to yield acceptable return of investment. De Vries (1989) studied effects of alternative distributions of nucleus places for dams and testing capacity for sires on total selection response in pig breeding and concluded that crossbreeding system (3-way vs 4-

TABLE 5. Genetic gains (ΔG, Dfl.crossbred female^{-1}) in an integrated operation with alternative family structures*, with selection schemes with shortened (SGI) and normal (NGI) generation intervals and with alternative genetic correlations between purebred and crossbred performance (r_{pc}) (fixed heritabilities for purebred and crossbred performance ($h_p^2 = 0.23, h_c^2 = 0.25$), fixed genetic standard deviation ($\sigma_G = 16$)).

Family structure			$r_{pc} = 0.3$		$r_{pc} = 0.7$		$r_{pc} = 0.9$	
npd	*npo*	*nco*	SGI	NGI	SGI	NGI	SGI	NGI
5	5	0	4.56	2.97	9.24	6.06	11.58	7.61
5	5	1	5.24	3.42	9.53	6.25	11.76	7.72
5	5	5	6.90	4.52	10.33	6.78	12.18	8.06
5	5	10	7.98	5.23	10.94	7.19	12.71	8.34
5	5	15	8.62	5.66	11.36	7.45	13.02	8.54
5	5	20	9.07	5.95	11.63	7.63	13.23	8.67
5	5	25	9.38	6.15	11.86	7.78	13.39	8.78
5	10	0	5.91	3.90	11.98	7.93	15.02	9.94
5	10	1	6.64	4.38	12.23	8.09	15.15	10.03
5	10	5	8.44	5.57	12.99	8.58	15.58	10.31
5	10	10	9.65	6.38	13.60	8.99	15.95	10.55
5	10	15	10.39	6.87	14.02	9.27	16.21	10.72
5	10	20	10.89	7.20	14.31	9.46	16.41	10.86
5	10	25	11.24	7.43	14.52	9.61	16.55	10.95
10	5	0	5.18	3.37	10.49	6.88	13.15	8.61
10	5	1	5.93	3.87	10.81	7.07	13.36	8.75
10	5	5	7.75	5.07	11.72	7.66	13.96	9.16
10	5	10	8.95	5.85	12.42	8.13	14.47	9.47
10	5	15	9.67	6.32	12.88	8.27	14.80	9.70
10	5	20	10.14	6.64	13.20	8.65	15.07	9.86
10	5	25	10.50	6.87	13.44	8.80	15.24	9.98
10	10	0	6.43	4.22	13.01	8.59	16.30	10.77
10	10	1	7.20	4.74	13.30	8.77	16.46	10.88
10	10	5	9.15	6.03	14.14	9.33	16.97	11.21
10	10	10	10.46	6.90	14.81	9.77	17.39	11.48
10	10	15	11.26	7.43	15.28	10.08	17.74	11.69
10	10	20	11.81	7.78	15.61	10.30	17.93	11.83
10	10	25	12.18	8.04	15.87	10.47	18.11	11.96

* *npd*, number of dams mated to a sire within pure line D; *npo*, number of testing/selection candidate female offspring produced by a dam within pure line D up to end of performance testing; *nco*, number of testing female offspring produced by a dam of pure line D mated to sire of pure line C up to end of performance testing.



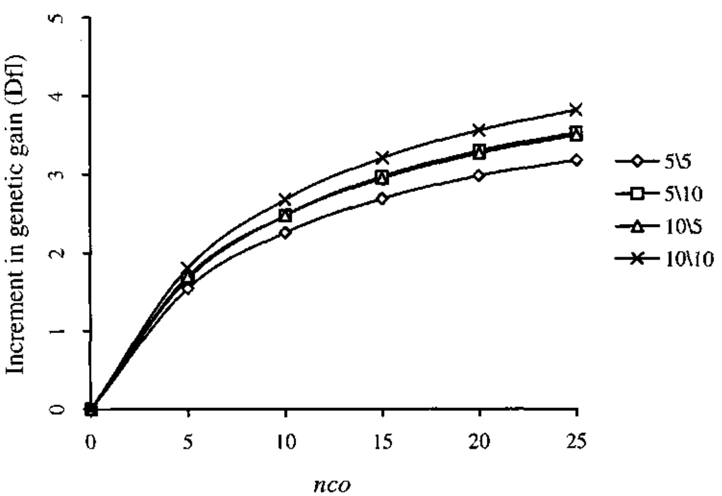


FIGURE 3. Absolute increment in genetic gain (Dfl.crossbred female^{-1}) when the number of testing female crossbred C×D offspring per D dam (*nco*) increases, with alternative family structures (*npd*/*npo* denoted as legends; where *npo* is the number of purebred testing female offspring per dam, and *npd* is the number of dams mated to a sire within pure line D) in case of integration operation for selection procedure with shortened generation interval (SGI, Fig.3a) and normal generation interval (NGI, Fig.3b), with the correlation between purebred and crossbred performance (r_{pc}) = 0.3.

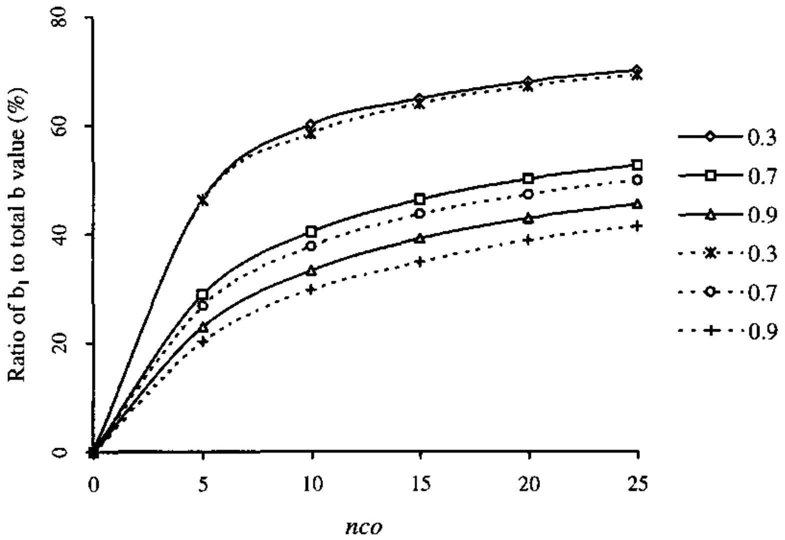


FIGURE 4. Ratio (%) of information index value b_1 for crossbred performance (x_1) to the sum of all b-value in the index, in relation to alternative the number of testing female crossbred C×D offspring per D dam (*nco*) and the genetic correlation between purebred and crossbred performance (r_{pc}), with family structure fixed as *npd* = *npo*= 5 (*npo* = number of purebred testing female offspring per dam, and *npd* = number of dams mated to a sire within pure line D), for sire index (solid lines) and dam index (dotted lines), in case of integration operation.

However, the absolute *b*-values for purebred information (b_2, b_3 and b_4) did not change much with changing *nco*.

The genetic correlation between purebred and crossbred performance (r_{pc}) had an important influence on genetic gain. Higher r_{pc} was associated with higher genetic gain (Table 6). Again SGI showed a higher genetic gain relative to NGI. The increase in genetic gain for higher r_{pc}, was mainly due to an increase in standard deviation of aggregate genotype and accuracy of the index; accuracy of index for r_{pc} = 1.0 was almost double that for r_{pc}= 0.1 (0.60 vs 0.33 for sire index, 0.68 vs 0.33 for dam index). Figure 5 (Figure 5a for SGI and Figure 5b for NGI) shows the relative increment in genetic gains for alternative *nco*, with different r_{pc}. The lower r_{pc} resulted in a higher relative increment: r_{pc} = 0.30 resulted in a genetic gain for *nco* = 25 that was 107% (sire index) and 105% (dam index) higher than those of *nco* = 0.

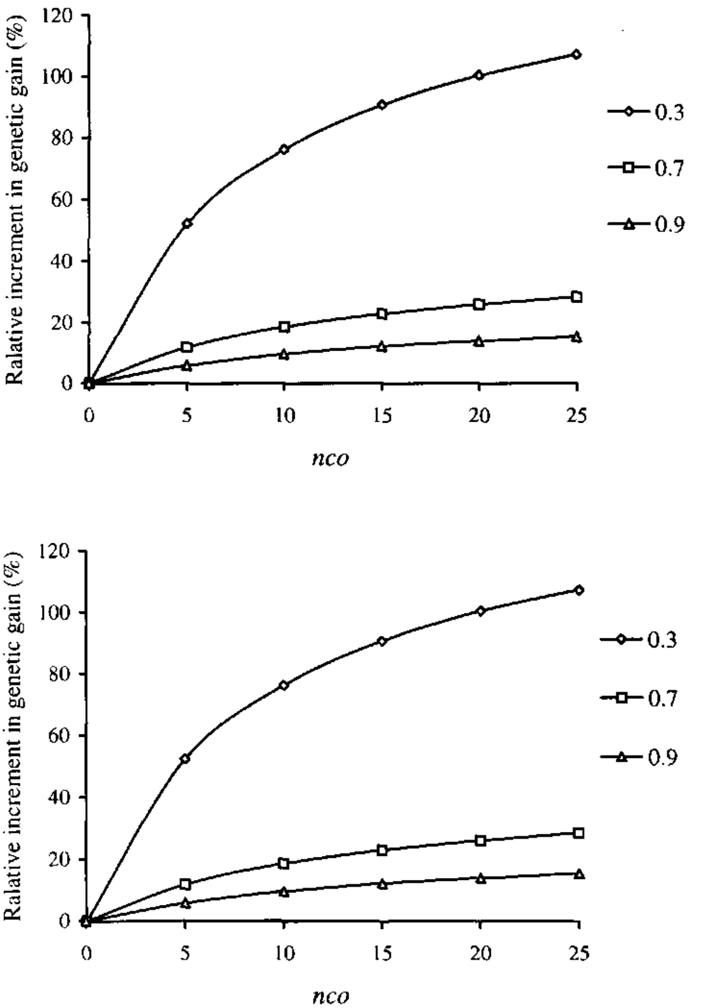


FIGURE 5. Relative increment (%) in genetic gain as the number of testing female crossbred C×D offspring per D dam (*nco*) increases, with alternative genetic correlations between purebred and crossbred performance (r_{pc} denoted as legends) in case of integration operations for selection procedures with shortened (SGI, Fig.5a) and normal generation interval (NGI, Fig.5b). Family structure fixed as *npd* = *npo* = 5 (*npo* is the number of purebred testing female offspring per dam, and *npd* is the number of dams mated to a sire within pure line D).

TABLE 6. Standard deviation of aggregate genotype in selection paths for sires and dams (σ_{Hs} and σ_{Hd}, Dfl.crossbred female^{-1}) and genetic gain (ΔG, Dfl.crossbred female^{-1}) in an integration operation with selection schemes with shortened (SGI) and normal (NGI) generation intervals and with alternative heritabilities for purebred and crossbred performance (h_p^2, h_c^2) and genetic correlations between purebred and crossbred performance (r_{pc}) (fixed genetic standard deviation ($\sigma_G = 16$) and family structure*).

Genetic parameters			SGI			NGI		
h_p^2	h_c^2	r_{pc}	σ_{Hs}	σ_{Hd}	ΔG	σ_{Hs}	σ_{Hd}	ΔG
0.23	0.25	0.1	13.22	14.52	8.26	8.51	9.87	5.47
0.23	0.25	0.2	13.34	14.64	8.96	8.59	9.95	5.94
0.23	0.25	0.3	13.46	14.76	9.68	8.66	10.03	6.41
0.23	0.25	0.4	13.58	14.88	10.53	8.74	10.10	6.97
0.23	0.25	0.5	13.70	15.00	11.53	8.81	10.18	7.63
0.23	0.25	0.6	13.81	15.11	12.53	8.89	10.25	8.30
0.23	0.25	0.7	13.93	15.23	13.56	8.96	10.33	8.97
0.23	0.25	0.8	14.04	15.34	14.85	9.04	10.40	9.84
0.23	0.25	0.9	14.16	15.46	15.91	9.11	10.48	10.53
0.23	0.25	1.0	14.27	15.57	17.24	9.18	10.55	11.41
0.23	0.15	0.5	10.77	11.77	8.55	6.93	7.98	5.66
0.23	0.20	0.5	12.32	13.49	10.13	7.93	9.15	6.71
0.23	0.25	0.5	13.70	15.00	11.53	8.81	10.18	7.63
0.23	0.30	0.5	14.94	16.36	12.85	9.61	10.11	8.10
0.23	0.35	0.5	16.08	17.62	13.84	10.35	11.96	9.16
0.23	0.40	0.5	17.14	18.79	15.08	11.03	12.76	9.99
0.23	0.45	0.5	18.14	19.98	16.34	11.67	13.51	10.68
0.15	0.25	0.5	13.56	14.86	10.77	8.73	10.09	7.13
0.20	0.25	0.5	13.65	14.95	11.23	8.78	10.15	7.43
0.25	0.25	0.5	13.72	15.02	11.54	8.83	10.20	7.64
0.30	0.25	0.5	13.79	15.09	11.99	8.88	10.24	7.94
0.35	0.25	0.5	13.86	15.16	12.18	8.92	10.28	8.07
0.40	0.25	0.5	13.92	15.22	12.50	8.96	10.32	8.27
0.45	0.25	0.5	13.98	15.28	12.68	9.00	10.36	8.40

* Family structure is fixed as *npd* = 5, *npo* = *nco* = 10; *npo* is the number of testing/selection candidate female offspring produced by a dam within pure line D up to end of performance testing; *nco* is the number of testing female offspring produced by a dam of pure line D mated to sire of pure line C up to end of performance testing.

An increase in crossbred and purebred heritabilities had the same impact on genetic gains as an increase in genetic correlation on genetic gains. The increase in genetic gain for higher heritabilities came mainly from an increase in standard deviation of aggregate genotype, while the accuracy of the index only slightly increased with higher heritabilities (not more than 3%). However, crossbred heritability had a stronger influence on the genetic gains than purebred heritability (Table 6). In fact, the trait with a higher economic weight tended to be more sensitive to the change of its heritability than the trait with a lower economic weight.

DISCUSSION

The present study showed that with selection for a combined increase in purebred and crossbred performance (CCPS) including information on crossbred animals always gave additional selection response. However, in different alternatives, the magnitude of the additional response varied much, depending on the genetic background of the population and the perspective taken by the breeders. In previous studies on CCPS (Wei and Van der Werf, 1994, for chicken; Bijma and Van Arendonk, 1998, for pigs), the breeding goals were defined only as improved crossbred performance. This holds for some traits in crossbreeding system of meat-type animals, e.g., growth and carcass traits, and thus, fits the specialized sire lines. The present study focused on a specialized dam line and assumed a combined selection for both improved purebred and crossbred performance. In specialized dam lines, the importance of reproduction traits at purebred stage could not be offset by the fact that the number of animals at purebred stage is much smaller than that of crossbred.

Family structures with regard to CCPS

In the present study, family structure refers to the sizes and combinations of *npd*, *npo* and *nco*. For all cases, the higher *nco* would result in higher genetic gains. In practice, *nco* will be limited in dependence on the reproduction rate of dams, and the period to produce progeny from a given mating will also be limited because of organizational reasons (vaccination schedules, utilization of testing facilities etc.).

In selection for a sire line of chicken with CCPS, Wei and Van der Werf (1994) found that a higher number of dams mated to a sire favored CCPS over pure line selection (PLS); although it also favored crossbred selection (CS), responses of CS were always lower than CCPS under given conditions. Bijma and Van Arendonk (1998) also obtained higher response with a higher number of crossbred offspring included in the selection index. However, the efficiency of *nco* in the role of increasing genetic gains was dependent on the purebred-crossbred genetic correlation r_{pc}: when r_{pc} was lower, the increment in genetic gain was higher. This is also the case in the study by Wei and Van der Werf (1994). In the present study, it was found that economic weights for breeding values of purebred and crossbred also had a major influence on the efficiency of increasing *nco* under CCPS. In the situation of integration, that is, with higher economic weight for crossbred relative to purebred performance, increase in *nco* gave an appreciate increment in genetic gain. When purebred performance gets a higher economic value relative to crossbred performance (for example, in situations of nonintegrated enterprise operation or when the performance level of purebreds is much lower than average performance level of other breeding organizations; De Vries, 1989), calculations showed that increasing *nco* only gave a marginal increase in genetic gain.

Effects of selection procedures

The selection procedure with the shortened generation interval (SGI; 30.5 to 32.1 wk of age) always resulted in higher genetic gains than the selection procedure with the normal generation interval (NGI; 47.3 to 49.1 wk of age). Apart from differences in revenues from SGI and NGI, also differences in costs, for example, in testing capacity, should be considered. With SGI, tested animals produce "pre-testing" offspring before selection. This pre-testing offspring had to be housed up to the time of selection of parents, that is, the identification of offspring to be tested (at 14 wk of age for D×D pre-testing offspring and 8 wk of age for C×D pre-testing offspring). Therefore, the testing capacity required for SNI and NGI will differ. When selection proportion was 10% in dams, the resulted testing capacity of D×D before 14 wk of age and for C×D before 8 wk of age, was 10 times for SGI more than for NGI. After that time, the testing capacity was the same for the two selection procedures.

Another practical difference between SGI and NGI not considered in this study is the difference in information available on persistency of production at the end of laying period. SGI assumes records to 45 wk of age and NGI assumes records to 51 wk of age. A higher economic value of persistency of production combined with a higher (genetic) variation in this trait would favor the NGI selection procedure.

This study focused on maximizing returns (in term of genetic gain) in dependence on selection procedures with varying testing capacities. In practice, commercial breeding organizations aim at maximizing returns on investment rather than maximizing returns. Moreover, testing capacity may be fixed or limited, and optimization should aim at maximizing returns per testing unit, in other words, an optimum ratio of testing purebred and crossbred offspring given the testing capacity.

Effects of genetic parameters on the efficiency of CCPS

The advantage of CCPS over PLS, and the effect of r_{pc} on the efficiency of CCPS in this study were somewhat different from Wei and Van der Werf (1994) and Baumung *et al.* (1997a). Wei and Van der Werf (1994) suggested that CCPS should replace the commonly used PLS for lower values of r_{pc}. Baumung *et al.* (1997a) concluded that in case with a genetic correlation between purebred and crossbred performance close to unity the use of crossbred information additional to purebred information had a marginal benefit only. Both of them addressed 0.6 to 0.7 as low r_{pc}, and both defined breeding goal only for crossbred performance. Recent studies showed, that r_{pc} was higher than 0.7, even very close to 1.0 (Besbes and Gibson, 1998; Merks and Hanenberg, 1998). In the present study, the breeding goals were defined as combined increase in purebred and crossbred performance, and varying r_{pc} showed an influence on genetic gains. It is likely that with r_{pc} higher than 0.7, there is no significant increment in genetic gain from an increase in *nco*. Calculations showed that with a higher economic value for purebred than for crossbred, varying r_{pc} (from 0.3 to 0.9) only had a very small influence on genetic gain.

REFERENCES

Baumung, R., J. Sölkner, and A. Essl, 1997a. Selection response according the use of pure- and/or crossbred information in crossbred animals with varying levels of dominance and additive by additive effects. *in*: 48th Ann. Meeting Eur. Assoc. Anim. Prod. (EAAP), August 25-28, Vienna, Austria.

Baumung, R., J. Sölkner, and A. Essl, 1997b. Correlation between purebred and crossbred performance under a two-locus model with additive by additive interaction. J. Anim. Breed. Genet. 114:89-98.

Besbes, B., and J. Gibson, 1998. Genetic variability of egg production traits in purebred and crossbred laying hens., Vol. 25, Pages 459-462 *in*: Proceedings of the 6th World's Congress on Genetics Applied to Livestock Production. Armidale, NSW, Australia.

Bijma, P., and J. A. M. Van Arendonk, 1998. Maximising genetic gain for the sire line of a crossbreeding scheme utilising both pure-bred and crossbred information. Anim. Sci. 66:529-542.

De Vries, A. G., 1989. A method to incorporate competitive position in the breeding goal. Anim. Prod. 48:221-227.

Elsen, J. M., and J. C. Mocquot, 1974. Récherches pour une rationalisation technique et économique des schémas de sélection des bovins et ovins. Inst. Nat. Réch. Agronomique. Bull. Technique Dept. Génétique Anim. No.17. Jouy-en-Josas, France.

Euribrid, 1995. Brochure Euribrid technical information on HYBRO N breeders. Euribrid, Boxmeer, The Netherlands.

Fairfull, R. W., and R. S. Gowe, 1990. Genetics of egg production in chickens. Pages 705-759 *in*: Poultry Breeding and Genetics. R. D. Crawford, ed. Elsivier, Amsterdam, The Netherlands.

Groen, A. F., X. Jiang, D. A. Emmerson, and A. Vereijken, 1998. A deterministic model for the evaluation of broiler production systems. Poultry Sci. 77: 925-933.

Hartmann, W., 1992. Evaluation of the potential of new scientific developments for commercial poultry breeding. World's Poult. Sci. J. 48:17-27.

Hazel, L. N., 1943. The genetic basis for constructing selection indexes. Genetics, 28: 576-490.

Hill, W. G., 1974. Prediction and evaluation of response to selection with overlapping generations. Anim. Prod. 18:117-139.

Jiang, X., A. F. Groen, and E. W. Brascamp, 1998. Economic values in broiler breeding. Poultry Sci. 77: 934-943.

Jiang, X., A. F. Groen, and E. W. Brascamp, 1999. Discounted expressions of traits in broiler breeding programs. Poultry Sci. 78: 307-316.

Merks, J. W. M., and E. H. A. T. Hanenberg, 1998. Optimal selection startegy for crossbred performance in commercial pig breeding programmes. Vol. 23, Pages 575-578 *in*: Proceedings of the 6th World's Congress on Genetics Applied to Livestock Production. Armidale, NSW, Australia.

Orozco, F., and J. L. Campo, 1975. A comparison of purebred and crossbred genetic parameters in layers. World's Poultry Sci. 31:149-153.

Shalev, B. A., and H. K. Pasterna, 1983. Genetic-economic evaluation of traits in a broiler enterprise: the relative genetic-economic values. Br. Poult. Sci. 24:521-529.

Smith, C., 1964. The use of specialised sire and dam lines in selection for meat production. Anim. Prod. 6:337-344.

Uimari, P., and J. Gibson, 1998. Combined crossbred and purebred selection versus pureline selection for a sex limited trait in poultry. Vol. 25, Pages 455-458 *in*: Proceedings of the 6th World's Congress on Genetics Applied to Livestock Production. Armidale, NSW, Australia.

Wei, M., 1992. Combined crossbred and purebred selection in animal breeding. Ph.D. Thesis, Department of Animal Breeding, Wageningen Agricultural University, Wageningen, The Netherlands.

Wei, M., and J. H. J. Van der Werf, 1994. Maximizing genetic response in crossbred using both purebred and crossbred information. Anim. Prod. 59:401-413.

Wei, M., H. A. M. Van der Steen, J. H. J. Van der Werf, and E. W. Brascamp, 1991a. Relationship between purebred and crossbred parameters. I. Variances and covariances under one-locus model. J. Anim. Breed. Genet. 108:253-261.

Wei, M., J. H. J. Van der Werf, and E. W. Brascamp, 1991b. Relationship between purebred and crossbred parameters. II. Genetic correlation between purebred and crossbred performance under the model with two loci. J. Anim. Breed. Genet. 108:262-269.

Chapter 6

The Usefulness of Local Chicken Breeds for China

X. JIANG and A. F. GROEN

Animal Breeding and Genetics Group, Wageningen Institute of Animal Sciences,
Wageningen University, Wageningen, The Netherlands

Given the fast changing markets in and outside of China, and the rapid shrink of animal genetic diversity of the world, the local chicken breeds in China can make considerable contributions to human food security and food quality.

ABSTRACT This paper focuses on the past, present and future of local chicken breeds in China. It first illustrates the origin and formation of the local breeds in relation to ecological, economic and social circumstances. Then, a general description is given for more than 30 local chicken breeds. Economically important characteristics, e.g., three-yellow and black-boned, are described. The quality chickens are defined as purebred final products of local breeds, and semi-quality chickens as crossbreds of local breeds with specialized broiler (sire or dam) lines from western breeding organizations. The present status of the chicken production and the market in China, in comparison with the western countries, is reviewed, indicating that there is large market demand for (semi-) quality chickens in the present and future China. Breeding for (semi-) quality chickens emphasizes the sensory quality of chicken meat. The present status of breeding for (semi-) quality chickens with the local breeds is illustrated, including breeding goals and the existing breeding programs. The potential role of local breeds in breeding programs in China is discussed in relation to both providing higher quality (than commercial hybrid broilers) of chicken meat for the local market and meeting the objectives of genetic resource conservation. Besides, further research topics on breeding for (semi-) quality chickens are suggested. Finally, it is concluded that, given the fast change in markets in and outside of China, and the rapid shrink of animal genetic diversity in the world, the local chicken breeds can make considerable contributions to food security and food quality in China and in the rest of the world as well.

Key words: local breeds, quality chickens, genetic diversity, broiler breeding, China.

INTRODUCTION

Poultry production in China has a long history. Based on the findings of archaeologists, the origin of domesticated chickens in China goes back to 6000 BC (West and Zhou, 1989). At least 3,500 years ago, domestic fowls were very popular in China (Qiu, 1996). There are now huge varieties of breeds and types of poultry. The different types of poultry originated from the different circumstances of various regions of the country. The traditional consumption pattern, including people's attitude and the cooking style, was also related to the formation of the local breeds. Different from the situation in some western countries (see Stromberg, 1996), the local breeds in China are not mainly for the fancier and the exhibitions, they are used for economic reasons: both for providing protein food and for meeting the requirements of meat quality.

According to Qiu (1989) and Wu (1998), in China broiler (in this paper broiler means all types of meat-type chicken) is classified into three types with various degrees in meat quality. 1) The highest quality chickens are those from local breeds; they are also called "quality chicken". 2) The second are crossbreds between local breed chickens and imported broiler lines; they are also called "semi-quality chicken", which maintain the appearance of most Chinese local breeds. 3) The last are broiler-type chickens developed in western countries, which is also called "white broiler". Within China, consumers in different regions have different attitude towards chicken meat; some have much preference for local breeds and some others do not have preference.

The last decade witnessed a marked increase in poultry production in China, as a result of the equivalent increase in gross national product (GNP) per capita (Watt Publishing Co., 1997). In 1998 per capita poultry consumption in China reached close to 9.0 kg (Ma, 1999). Projection showed that in the year 2010, poultry meat consumption per capita in China will reach as much as 18 to 20 kg (Ma, 1998).

In the DAD-IS database of FAO (FAO, 1999a), currently only six local chicken breeds from China are listed, and among them four originate from Gansu province (a region with few breeds only), and four are already extinct as described there. No duck and goose breeds are listed. Comparing that there are 118 Chinese local pig breeds included in the same data source, it is obvious that there is a data shortage for local Chinese poultry breeds.

In the way that breeding and selection took place, the modern commercial stock of laying hens has lost important genes, which led populations being unable to perform well when returned to the old floor/free range systems (Sørensen, 1997). While the modern commercial egg-type and meat-type stocks are gradually losing their ability of fitness and adaptability, the local and un-industrialized breeds will appear more important in future. With advances in genetic engineering, it will be feasible to use the wild ancestors or primitive relatives of modern stocks (Crawford, 1990). The large variety of local chicken breeds in China provides choices for world's meat production in future.

The aim of this paper is to: 1) review the local chicken breeds and their origin and formation in relation to ecological, economic and social circumstances; 2) review the present status of the chicken production and the market in China, in comparison with the western countries; 3) review the present status of broiler breeding for the local breeds; 4) discuss the potential role of local breeds in breeding programs in China.

THE FORMATION AND DISTRIBUTION OF CHINESE POULTRY BREEDS IN RELATION TO ECOLOGICAL, ECONOMIC AND SOCIAL CONDITIONS

China is the home of chicken breeds. It is generally believed that the ancestor of domestic fowls is the red jungle fowl (*Gallus gallus*) (West and Zhou, 1989; Crawford, 1990). The red jungle fowl can still be found now in some parts of south and southwest China. Extensive raising of domestic chicken could be dated back to 2,700-2,650 BC; about 3,500 years ago, during the Yin-Dynasty, chickens were very popular in China (Qiu *et al.*, 1989).

A breed is defined as either a subspecific group of domestic livestock with definable and identifiable external characteristics that enable it to be separated by visual appraisal from other similarly defined groups within the same species; or a group for which geographical and/or cultural separation from phenotypically similar groups has led to acceptance of its separate identity. A huge variety of poultry breeds was developed given ecological, economic and social circumstances in China. China is in a sub-tropical and temperate zone with a complicated geography. The general geological feature of China is that the altitude of land goes from higher in west and north to lower in east and south. From north to south China, there are different climate zones: from frigid-temperate, temperate, warm temperate, sub-tropical to tropical zones. The annual accumulated temperature varies from 2,000-2,500 °C in northern Heilongjiang (northeast China) and Tibet Plateau (west China), to 7,000-8,000 °C in the area of the south of Nanling Mountain (south China). The land condition changes from arid, semi-arid, semi-humid, and humid (annual precipitation from less than 25 mm to 2,000 mm). The geological feature is ladder-shaped, higher in west and lower in east. The topographic feature varies from plateaus (4000 m above the sea level on average) to mountains, then hills, then basin, and then to plains. The human population density follows the geological feature, with the lowest density in the west and northwest areas, and the highest density in south and southeast areas. Human education status also differs among regions. According to statistics, in 1996, the highest proportion of illiterate and semi-literate population relative to regional population size, varies from the regions of west and northwest (e.g., 61% for Tibet and 42% for Qinghai) to 10% in Shanghai (southeast) and 14% in Guangdong (south) (State Statistical Bureau of China, 1997). Economic status follows the same way, with the most developed areas in the south and southeast regions.

In the history, the social environment was a closed one, and it was very few that the regions or provinces contacted and communicated with each other. As early as in 1886, a person by the name of Jensen noted that almost every district in China has its peculiar breed of domestic animals. "Sometimes village only a mile apart will have different kinds of goats, different kinds of pigs, different kinds of chickens." (Poultry, April 16, 1886, p.270). Some breeds have made considerable contributions to the world's poultry breeding, such as Cochin chicken and Langshan chicken, which were exported to UK in 1845 and 1872, respectively (Brumbaugh and Hollander, 1966; Brown, 1985). According to statistics, there are more than 100 local chicken breeds reported in China (Qiu *et al.*, 1989), and even more breeds (or varieties) are being exploited (e.g., Yang and Zeng, 1998).

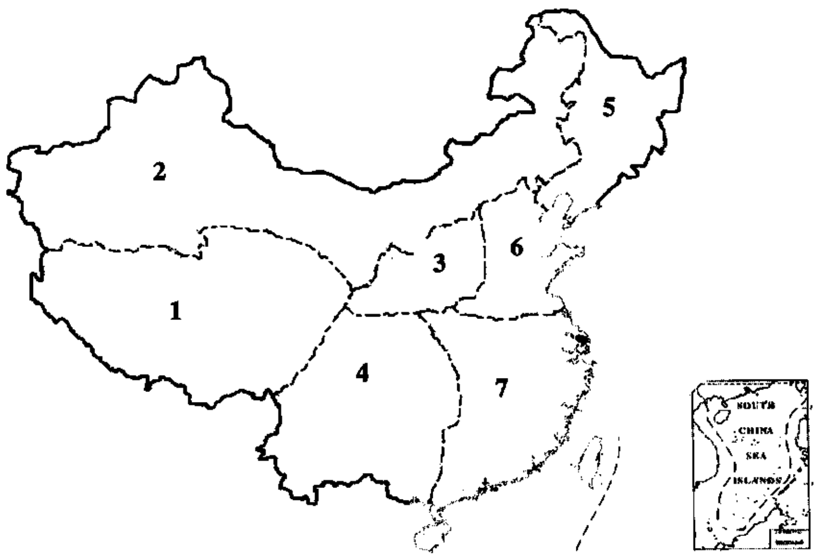


FIGURE 1. The ecological-geological regions for poultry breed distribution in China. 1= Qinghai-Tibet plateau region; 2 = Mongolia-Xinjiang plateau region; 3 = Yellow-land plateau region; 4 = Mountainous region of southwest China; 5 = The region of northeast China; 6 = The region of Huang-huan; 7 = The region of southeast China.

Seven ecological-geological regions are distinguished in relation to the formation and distribution of Chinese local poultry breeds (Qiu *et al.*, 1989, Figure 1). In the Fauna by Qiu *et al.* (1989) (later referred as the Fauna), 52 Chinese local poultry breeds were compiled, including 27 chicken breeds, 12 duck breeds, and 13 goose breeds. These breeds were distributed according to the following ecological-geological regions (Figure 1).

- **Qinghai-Tibet plateau region:** This region accounts for about 22% of the national territory, with climate as cool and dry summers, and cold and dry winters with much wind. The region is on average 4,000 m above sea level. The agriculture production is mainly pasture based, or in the areas below the 3,800 m above sea level there is mixed agriculture-animal production system. There is a specific chicken breed in this region by the name of Tibetan Chicken that is very similar to *Gallus gallus*. Only one breed, i.e., the Tibetan chicken, was compiled in the Fauna.
- **Mongolia-Xinjiang plateau region:** This region accounts for around 32% of the national territory, with the feature of hot and dry summers, and long, cold winters with much wind and dust. It is an arid area in north of China, poor in farming land. Like Qinghai-Tibet plateau region, only few poultry breeds are distributed. Only one goose breed (Yili geese) and one chicken breed (Bian Chicken) are economically important in this region, and these are compiled in the Fauna (Bian chicken is shared with the Yellow-land plateau region).
- **Yellow-land plateau region:** As the name "yellow-land" indicates, non-farming land characterizes this region. This region accounts for about 8% of the country area. Only one chicken breed is noted, but it is shared with the Mongolia-Xinjiang plateau region, i.e., Bian Chicken. Again, only 2 breeds (Jinyuan chicken and Bian chicken) were compiled in the Fauna.
- **Mountainous region of southwest China:** This region accounts for about 12% of the national territory, featured with mild climate and fertile farming land. As the agriculture is advanced in this region, it is also rich in poultry breeds. Seven breeds were compiled in the Fauna, and they are: Chahua chicken, Emei Black chicken, Pengxian Buff chicken, Wuding chicken, Jianchang Duck, Sanshui duck and Sichuan White goose.
- **The region of northeast China:** This region accounts for around 8% of the national territory. Although it has fertile land, agricultural output is not appreciable as a reason of its climate dominated with long, cold and dry winters. Lindian chicken, Dagu

chicken, and one goose breed by the name of Huoyan are found in this region, and they were compiled in the Fauna (Huoyan is shared with the region of Huang-huan).

- **The region of Huang-huan:** This part is only 5% of the national territory. The climatic pattern is hot and wet summers, and cold and dry winters. The farming land in this region amounts to 43%, but the agricultural output per unite of arable land is not high. Breeds including Beijing Fatty chicken, Shouguang chicken, Beijing (Peking) duck, and Huoyan goose were originated from this region and compiled in the Fauna.
- **The region of southeast China:** This region accounts for about 14% of the country's area. Farming land occupies 18% of the region's area. A prominent feature of this region is that there are many rivers, lakes and pools (water area is 7% of the total region area). The climate is with hot, wet summers, and cool to warm winters. This region is the most advanced in agriculture with high output in China. The region has a high population density and social-economic status. The highest number of poultry breeds is found here. As many as 34 breeds were compiled in the Fauna from this region, in which 16 chicken breeds were included. Among these chicken breeds, Putong originating from Shanghai, Buff Baier, Xianju and Xiaoshan from Zhejiang province, Hetian from Fujian province, Huiyang Bearded, Qingyuan Partridge and Xinhua from Guangdong province, Xiayan from Guangxi province, Taoyuan from Hunan province, Taihe Silkies from both Jiangxi and Fujian provinces, Gushi from Henan province, and Langshan, Liyang and Luyuan from Jiangsu province. Chinese game chicken is also from this region. Other poultry breeds, such as Shouxing duck, Jinding duck, and Taihu goose are also included in the Fauna.

An interpretation from the above description is that, the poultry breeds are not distributed evenly among the seven regions. An extreme comparison is between Qinghai-Tibet plateau region and the region of southeast China, with 1 breed vs 34 breeds, although the area of Qinghai-Tibet plateau region is bigger than the region of southeast China. In the mountainous region of southwest China a considerable number of poultry breeds was formed and distributed. The number of breeds in southeast and southwest is 41, which is almost 80% of the total breeds compiled in the Fauna. With milder climate condition, more advanced agriculture, and denser human population, more breeds developed. Other conditions for the formation of more local breeds are those: rich in nature resources (e.g., crop production), backyard husbandry, lack of transportation, and closed market. These conditions eventually resulted in "closed breeding", which is in favor of diversity of variation. The fact that there are many local breeds in Guangdong province (in south China) underlines this statement (Mu *et al.*, 1998). Also, type and characteristics of local breeds are dependent on the culture of the region. For example, in most parts of China white color is regarded as a symbol of un-auspicious and local people do not select these chickens for breeding, so local chicken breed with white plumage is rarely seen in China. Another example of this culture is that in China the yellow color is traditionally a symbolic color of both the empire and gold. This is why local breeds with yellow (buff) plumage are quite popular in China.

The chicken consumption pattern is different among the regions. For example, in south China, especially Guangdong, Guangxi, Fujian, Zhejiang, Jiangsu provinces and Shanghai, consumers favor three-yellow chickens. In some of these regions (Guangdong, Guangxi, Fujian provinces), consumer markets do not accept white broiler (Ma, 1998). In north China, consumers do not have special favor for types of meat-chicken, but white broilers are consumed predominantly (Ma, 1998). The quality of chicken meat is based on its tenderness, richness in juice, intramuscular fat, and yellow delicate skin as well. This meat quality can be quantified (e.g., Yu and He, 1993).

It has to be mentioned here that the Fauna was published in 1989, and the data collection ended in 1984. Since then, investigation and exploitation of local breeds continued. More breeds have been revealed.

DESCRIPTION OF REPRESENTATIVE CHICKEN BREEDS

In this description, only chicken breeds are considered. The description follows two ways. Firstly, a general review of the Chinese local chicken breeds is given, with a summary of characteristics and performances. This general review includes breeds in the Fauna, and breeds not in the Fauna (for reason of revelation after the compilation of the Fauna, or considered not important by compilers of the Fauna). Secondly, some breeds are described in detail, concerning the genetic aspects (genetic distance among breeds, genetic parameters of specific traits).

A brief overview of the Chinese local chicken breeds

Generally, the Chinese local chicken breeds can be categorized into three types, that is, meat type, egg type, and dual-purpose type. However, as Qiu *et al.* (1989) stated, this classification is not as strict as usually applied for modern commercial strains. General feature of the local breeds is slow growth (especially at the early stage of growth) and late maturity, and use of the local breeds is for both table eggs and meat. The local breeds, which have never been crossbred with imported commercial lines, are regarded as quality chickens when they are used for meat. Classification in meat-type or egg-type, only indicates a tendency for the breed to be more likely used for meat or egg, respectively. The following description is mainly based on the Fauna, but data are updated and more breeds are included. Code number (three-number) is given for each breed (or group of breeds). The first number represents type of breed (1: meat type, 2: egg type, 3: general purpose type, and 4: other type); the second number refers to the ecological-geological regions for breed distribution as shown in Figure 1, and when a breed is distributed across regions, all the region numbers are listed, e.g., 4/7 indicating that the breed distributes in regions 4 and 7; the third number is sequence number within breed type.

Meat type

- **Hetian (1.7.01)**: Originating from Fujian province of south China, Hetian chicken has moderate growth performance. Adult male weighs 1.7 kg and female 1.2 kg. Plumage of both male and female is basically in yellow color. A unique character is the husbandry practice. Unlike in other areas in China, local people rear the chickens in a way similar to free range in other countries, e.g., UK. At daytime while farmers working on their land, the chickens were on the land around them. In evenings, farmers bring the chickens back home, and then feed them some grain. While housed, body weights at 90 days of age are 0.6 kg and 0.5 kg for cockerel and pullets, respectively. Annual production is about 100 eggs, with light brown eggshell. The population of Hetian chickens is about 2 millions.
- **Huiyang Bearded (1.7.02)**: Native to Huiyang county of Guangdong province in south China, this breed is famous for its large size of breast muscle, early maturity and super quality of meat. Together with Qingyuan Partridge and Xinghua, they were mainly sold to Hong Kong and Macau markets. The chicken is striking in appearance with well developed beard and three-yellow: yellow plumage, beak and shanks. Body weight is 2.2 kg and 1.6 kg for adult male and female, respectively. At 15 weeks of age under backyard conditions, body weight for cockerel and pullets are 1.4 kg and 1.1 kg, respectively. Before marketing, pullets near to laying are moved to cages for fattening for 12-15 days, weighing 1.3-1.4 kg. The chicken is early sexual mature; cocks at 90 days of age and hens at 150 days. As a heavy brooder, annual production is

only 50 eggs in backyard, and about 110 eggs when housed. Population is more than 15 millions.

- **Liyang (1.7.03)**: With adult weights of about 4.0 kg for males and 2.6 kg for females, Liyang is also called Buff Juijing (means Buff Cochin). It is native to Liyang County of Jiangxi province, south China, where people traditionally selected large size chickens. However, the growth rate at early stage is not high. In moderate nutrition conditions, body weights at 90 days of age are 1.4 kg and 1.2 kg for cockerel and pullets, respectively. Up to 500 days of age, a female can lay 145 eggs with dark brown shell. About 200,000 chickens are in production in the central native area.
- **Normal feathered, black-boned chickens (1.4/7.04)**: This name is used to describe all breeds or varieties that are claimed to have the characteristics of "three black" (black skin, meat and bone) but with normal feather (different from Taihe Silkies). Literature showed that these breeds, although originating from and distributed in different regions, have some common properties apart from "three-black", e.g., black plumage and bigger body size than Taihe Silkies. These breeds or varieties include normal-feathered black-boned chickens in south Sichuan (also named Sichuan Mountain black-boned chickens, Yang and Zeng, 1998), Yugan black-boned with black plumage in Jiangxi province (Li *et al.*, 1995), Chishui black-boned chickens with black plumage in Guizhou province (Liu *et al.*, 1995; Liu *et al.*, 1998). There are other local breeds and varieties in China being claimed with these "three black" characteristics, such as Emei Black chickens, Black Jiuyuan, Miyi Shortened legs chickens, and Chaoke chickens (Zhang and Huang, 1998), although with different proportions of the "three-black" chickens in the population.
- **Qingyuan Partridge (1.7.05)**: Originating from Guangdong province, small in body size, and rich in intramuscular fat, the Qingyuan Partridge chicken is famous for its high quality meat. The cock has single comb, yellow shanks, and yellow plumage with a black tail. The hen has yellow plumage, but on the back the color appears in two types, i.e., yellow-partridge and brown-partridge. The adult live weight for male is 2.2 kg, for female 1.8 kg. The number of eggs per year is about 70-80 eggs, with average egg weight 45-50 g. In its native county, population is more than 4 millions chickens. The breed is now used for commercial production as meat-type chickens (Chen and Chen, 1999).
- **Taihe Silkies (1.7.06)**: Appearing with white silky-feathers and black-colored meat, Taihe Silkies is mainly native to Taihe county of Zhejiang province, and the nearby areas of Fujian province. In the Fauna, this breed is classified into the class of Medical

type, as its meat was traditionally regarded effective to treating women's sickness, enriching the blodd and building up health, based on an ancient Chinese medical book entitled Compendium of Materia Medica (1578) during Ming dynasty. In China, some well recognized Chinese-made medicine are made by using the chicken as one of the ingredients; and also some research showed the medical value of the chicken due to that it contains certain hormones, blue pigment and amino acides which increase the blood cells and hemoglobin of human body (e.g., as stated by Qiu *et al.*, 1989). However, based on the following two reasons, in this description it is classified as meat-type chickens. (1) There is uncertainty about its medical effectiveness (e.g., Huang *et al.*, 1984). (2) The Taihe Silkie is now very popular in China; in some cities, the live Taihe Silkies can be seen at every market (e.g., in Chengdu city). That consumers like the breed nowadays, is mainly because of its flavor, not because of its medical effects. Chinese people believe that food with dark color is nutritive and healthy, but at least some of them do not really trust its medical effectiveness. Another example is that in China the black sesame seeds are more precious than the white ones. Taihe Silkies are held commercial husbandry practice in China with the main product being the marketable live bird of about 1 kg body weight. Population of Taihe Silkies in 1980 was about 200,000 chickens in its native area. As the breed is more used in commercial production than before, the present population size is bigger.

- **Taoyuan (1.7.07)**: Native to Toayuan county and the nearby areas, Hunan province, south China, Taoyuan is characterized by its big body size and height. Adult male weighs 3.3 kg and female 2.9 kg. Male plumage color is golden or red, female yellow or partridge. Growth at early stage is very slow; up to 90 days of age, cockerel weighs 1.1 kg and pullet weighs 0.9 kg on average, hen starts laying at 195 days of age, and lays 86 eggs up to 500 days of age. In Taoyuan country, the population is 180,000 chickens.
- **Tunchong Snow (1.4.08):** A more recently found breed, first reported by Shen and Yun (1999). As a semi-wild breed, Tunchong Snow chickens originate from Tunchong county, Yunnan province. The central native location of the breed is around the east wing of Gaoligong Mountain that is covered by snow all year. As the native county varies very much in altitude (ranging from 300 m to 3,000 m above sea level), the area includes subtropical to temperate, and to frigid zones. Rainfall is on average 1469 mm. The vast variety in ecological conditions and rearing in semi-wild with coarse feeding, resulted in the fact that the breed has good adaptations to climate and ecological conditions. It is said that the origin of the breed is dated back hundreds of years ago,

when the white jungle fowl from the Gaoligong Mountain mated to the local partridge chickens. As some of the offspring of these matings were with dark (black) meat and bone, and good flavor and taste, local people selected them for breeding. Therefore, the breed is with striking appearance of plumage as white as snow (normal plumage, different from Taihe Silkies) and black meat. This is why it was also named Snow Chickens. The breed has middle body size, raising head and tail, active in running and flying, single or rose comb, black beak and shanks. Adult male weighs 1.8 kg and female weighs 1.6 kg. Annual egg production is 100 to 150 eggs, with per egg sized 42 g, light-brown eggshell. Population size in 1997 was about 20,000 chickens.

- **Wuding (1.4.09)**: Originating from Wuding county and the nearby areas in Yunnan province, southwest China, Wuding chickens have large body size. Adult male weighs 3.0 kg and female weighs 2.1 kg. However, it also is a very slow grower. Under backyard conditions, chickens (males and females together) weigh only 0.5 to 0.6 kg at the age of 90 days. In a dam line selected for seven generations, body weight at 90 days of age was improved to 1.1 and 1.0 kg for cockerel and pullet, respectively (Lou *et al.*, 1991). Annual egg production ranged 90 to 130 eggs, with light brown eggshell. Plumage color for male is mainly red, and female yellow, both with black tail. About 900,000 Wuding chickens are in production. The local people have the custom that chickens are allowed to be sold to outside areas, but can not be imported from outside. This custom supported the development of the unique characteristics of Wuding.
- **Xiayan (1.7.10)**: Developed in a village by the name of Xiayan, Rongxian county, Guangxi province, south China, Xiayan chickens are with yellow plumage. Adult male weighs 2.2 kg and female 1.9 kg. When housed, body weight at 90 days of age is 922 g for cockerel and 776 g for pullet. Hens start laying at 170 to 180 days of age. Annual production is 80 eggs, with light brown shells. In the Xianyan county population of Xiayan chickens is 80,000.
- **Xinghua (1.7.11)**: Having small body size, Xinhua has high quality of meat: rich in breast muscle, fine muscle fiber, intramuscular fat, and an evenly distribution of fat under skin. These features, together with its three-yellow, particularly fit the chicken cuisine style in Guangdong province, where the breed originates. Adult male weighs about 2.0 kg and female weighs 1.6 kg on average. Carcass yield at age of 112 days is 74% and 70% for cockerel and pullet, respectively. Annual egg production is 60 to 90 eggs with brown shell. In a new line, body weights at 90 days of age were 1.0 kg for cockerel and 0.9 kg for pullet (Xiao *et al.*, 1998). In the native county, Fengkai, more than one million chickens are produced annually.

Egg type

- **Buff Baier (2.7.01)**: As its name denoted, Buff Baier is with yellow plumage and white ear lobes (Baier). Its native area is Jiangxi province, south China. The chickens have small sizes. Its formation was based on the fact that the local people tended to select the chicken with character of yellow plumage, beak and shanks with white ear lobes as for breeding. The age of first egg is on average 151 days, and annual production is 180 eggs, with average weight 54.23 g per egg, with dark brown egg shell. It was suggested to breed Buff Baier as laying chickens. However, it also seems possible to be developed towards meat type (Tong *et al.*, 1997). Population is more than 1,000,000 chickens.
- **Hebei Caiji (2.2/6.02)**: According to Jiang and Jiang (1995), Hebei Caiji chickens are widely distributed in Hebei province and other parts of north China. Population of the breed is estimated 10 to 20 millions chickens. Caiji chickens have small body size similar to Leghorn, and they are nimble and active. Plumage is dominated as dark and light partridge, with some chickens as black or yellow plumage, single comb, no leg feathering. Body weights are 0.4 and 0.3 kg at 90 days of age, 1.7 and 1.1 kg at one year of age for males and females, respectively. A comparison of reproduction performance for Caiji and Leghorn under the same conditions was made (Jiang and Jiang, 1995). Age at first egg for Caiji was earlier than Leghorn, ranging from 143 to 234 days of age for Caiji and from 155 to 238 days of age for Leghorn. Annual egg production was 121 eggs with light brown eggshell for Caiji and 192 eggs for Leghorn. In hens of Caiji, brooders account for 15%. This indicates the breed is more likely an egg-type chicken.
- **Xianju (2.7.03)**: Originating from Xianju county of south China, Xianju is characterized by its performance in egg laying, with annual production as much as 160 to 180 eggs with light brown shell. An excellent hen will lay more than 200 eggs. The body size appears similar to typical layer breeds (e.g., Leghorn), and the adult weighs 1.5 kg and 1.3 kg for male and female, respectively. The main plumage pattern is yellow for both genders, single comb and yellow or blue shanks. Age at first egg changes with the nutrition status, ranging from 150 to 180 days. Only within the county, as many as 500,000 chickens are in production. As it also possesses high slaughter rate (69.95% at age of 90 days) and good quality in flavor, it is also used in the crossbreeding system of quality (meat type) chickens (Tong *et al.*, 1997).

General purpose type

- **Beijing Fatty (3.6.01)**: The breed originates, of course, from Beijing, with a present population of about 10,000 chickens. It appears with three specific features: crest feather, leg feathering, and beard. Most of the chickens are with reddish brown plumage. Adult male weighs 2.1 kg and female weighs 1.7 kg. Under backyard conditions, hens lay 110 eggs annually, with brown shell. However provided with better conditions, annual production can reach 125 eggs. The breed is now used in crossbreeding systems (Li, 1998).
- **Bian (3.2/3.02)**: Characterized by large egg size, quality meat, adaptiveness to cold weather (as low as -30 °C) and coarse feeding conditions, Bian originates from the areas of north China. About 500,000 chickens are reared in its native areas. Cock's plumage is in reddish black or yellow black; plumage color for hen is varied with white, grey, light yellow, partridge yellow, reddish grey, and mixed colors as well. Adult male weighs 1.8 kg and female weighs 1.5 kg. It is slow in growth at early stage, with 84 days of age the cockerel weighs 0.6 kg and pullet weighs 0.5 kg. Annual production is 70 to 96 eggs, with average egg size of 66 g. The striking feature of large egg size may contribute to future breeding purpose.
- **Black Jiuyuan (3.4.03)**: Originating in the mountainous area of Jiuyuan county, east Sichuan province, Black Jiuyuan chickens are known for blue eggshell. It was estimated that among the population 5% hens give blue eggshell. According to the field survey by Jiang (unpublished data), in the native area of Black Jiuyuan, chickens with other colors of plumage also give blue shelled eggs. It is not clear when this character first emerged in the area. Local people believed that the blue shelled eggs have positive effects on human health, and therefore chickens with blue eggshell were selected. Several experiment showed that one advantage for the blue shell was the eggs have higher breaking strength relative to white or brown shelled eggs, either with different or with the same genetic background and management conditions (Yang and Jiang, 1989; Jiang *et al.*, 1991; Jiang *et al.*, 1992). Black Jiuyuan chickens have large body size, white or black skin, single or pea (15.4% for female and 11.8% for male) comb, black plumage. Adult male weighs 2.6 kg and female 1.8 kg. At the age of 180 days, body weight for cocks is 2.2 kg and for pullets 1.6 kg. Annual egg production is 45 to 63 eggs per hen, with egg sized 61 g. Population size is 11,000 chickens in the native district, but actual population size is larger when the nearby areas are accounted

for. There is another breed named Lushi from the neighboring province Shaanxi, which was claimed to have 3% hens producing the blue shelled eggs.

- **Dagu (3.5.04)**: It was developed in Zhuanghe county, Liaoning province, northeast China. The meaning of Dagu is big boned chickens, describing that the breed has large body size. Adult male weighs 2.9 kg and female weighs 2.3 kg. At 90 days of age, body weight for cockerel and pullet was 1.1 kg and 0.9 kg. Annual egg production was 160 eggs on average, but when under better condition, it reached higher than 180 eggs. Egg size was considerably large, 63 g on average. Plumage color pattern for cock is reddish brown, and for hen is partridge yellow, both have single comb and yellow shanks. Population of Dagu chicken is about 4.5 millions.
- **Emei Black (3.4.05)**: Originating from Emei areas, Sichuan, southwest China, Emei Black chickens appear black plumage, big body size in round shape, black beak, blue shanks, white (with a very small proportion in black) skin. Adult male weighs 3.0 kg and female weighs 2.2 kg. Body weight at the age of 90 days was 1.0 kg for cockerel and 0.8 kg for pullet. Annual egg production was 120 eggs, with average weight of 54 g. Shell color is brown or light brown. Investigation showed that in its native area, Emei Black accounted for about 10% of total chicken population. However, the population size is small (about 1,600 chickens) and the breed is endangered (Chen, 1989).
- **Gushi (3.7.06)**: Originating from Henan province, with a population of more than eight millions chickens, Gushi has moderate body size. Plumage of cock is either dark red or yellow with black sickles, blue shanks and beak. Hen has yellow or partridge yellow plumage. Adult male weighs 2.5 kg and female weighs 1.8 kg. At the age of 90 days, cock weighs 0.5 kg and pullet weighs 0.3 kg. Annual egg production is about 140 eggs, with average egg size of 51 g.
- **Jingyuan (3.3.07)**: Native to the Yellow-land plateau region, Jiangyuan is adaptive to the condition of high plateau, cold and dry climate. About 800,000 chickens are in production. Cock has red or black red plumage with well-developed and beautiful sickles. Hen's plumage is varied with yellow, partridge, black, white, or mixed color. Both have grey shanks, and rose combs. Adult male weighs 2.1 kg and female 1.7 kg. At the age of 90 days, body weight is 0.7 kg and 0.6 g for cockerel and pullet, respectively. Annual egg production is about 120 eggs with brown shells.
- **Langshan (3.7.08)**: Langshan is a famous breed worldwide. It originates from Jiangsu province, south China. It has striking appearance of large body size, high egg production, and beautiful purely black plumage (a few will have yellow or white

plumage). Two types are classified, heavy size and light size. Adult male weighs 4.0 to 4.5 kg, and female 3.0 to 3.5 kg for heavy size; and 3.0 to 3.5 kg for male and about 2.0 kg for female for the light size. Although with large body size, the growth rate at early stage is slow. At 90 days of age, cockerel weighs 1.1 kg and pullet weighs 1.0 kg. Considering its large body size, its laying performance is appreciable, with annual production as many as 160 to 170 eggs, on average 59 g per egg. The population size is not known.

- **Lindian (3.5.09)**: Native to Lindian county, Heilongjiang province, northeast China, Lindian chickens possess the characteristics of adaptation to cold areas. The breed appears moderate size, single or rose comb, some with crest or beard, black beak and shanks, some with shank feathering, white skin, yellow or black plumage, long and black tail for cock. Adult male weighs 1.7 kg and female 1.3 kg. Annual egg production is 70 to 90 eggs with light brown or brown shell. The breed has population of 230,000 chickens.
- **Luyuan (3.7.10)**: As a famous breed with high quality meat, Luyuan chickens was originated from Sazhou county, Jiangsu province, southeast China. The breed is also named Luyuan big chicken. It appears three-yellow similar to other breeds, plus yellow skin. Adult male weighs as heavy as 3.1 kg, and female as 2.4 kg. At the age of 90 days, body weight of cockerel was 1.5 kg and of pullet was 1.2 kg. Annual egg production is 140 egg on average with per egg sized 54 g, brown shell. In the native areas, population is about 100,000 chickens.
- **Pengxian Buff (3.4.11)**: Although it was named after its native area, Pengxian county, Sichuan province, southeast China, the breed is vastly distributed in the plain and hilly areas in Sichuan province with a huge population, in native area 300,000 chickens, but about 10 millions in the province. Cock appears reddish yellow plumage and hen yellow plumage. Adult male weighs 2.4 kg and female weighs 1.7 kg. At the age 90 days, body weight of cockerel was 0.9 kg, and of pullet 0.7 kg. Annual egg production was 140 to 145 eggs, with egg size 53.52 g, light brown shell. Currently population size is going down sharply (Li, 1998).
- **Putong (3.7.12)**: Native to the suburb areas of Shanghai, southeast China, Putong chickens is also called Cochin Buff, as it is with large body size and three-yellow in appearance. Three plumage types are seen in the cocks: yellow on both breast and back, red on both breast and back, black breast red back. Hens are with yellow plumage, but differing in the degree of darkness. Adult male weighs 3.6 kg and female weighs 2.8 kg. At the age of 90 days, body weight of cockerel was 1.6 kg and pullet

1.3 kg. Annual egg production is 130 eggs on average, with per egg sized 57.9 g, light brown shell. Population is quite small, as the breed is replaced in production by a later developed breed, New Putong. The New Putong maintains the appearances of Putong chickens, but growth rate was improved, especially at the early stage. In the process of breeding for New Putong, White Plymouth Rock and Red Cornish were used for crossbreeding. At the age of 9 weeks, cockerels weigh 1.9 kg and pullets weigh 1.5 kg; at 10 weeks of age, it is 2.2 and 1.7 kg, respectively. Annual egg production is 170 to 180 eggs. Population is more than 100,000 chickens as parental stock.

- **Shouguang (3.6.13)**: Originating from Shouguang county, Shandong province, the region of Huang-Huan, Shouguang chickens are characterized by their large body size and egg size. The breed is in black plumage, single comb, blue-black beak and shanks. Two types are distinguished: large size and middle size. Adult body weight is 3.6 kg for males and 2.9 kg for females for large size type; for middle size, it is 3.3 and 2.3 kg, respectively. The breed is slow both in feathering and in growth at early stage. At the age of 90 days, cocks weigh 1.3 kg and pullets weigh 1.1 kg. For the large size type, annual egg production is 118 eggs, with per egg sized 65 to 75 g; for middle size type, egg production is 123 eggs, with per egg seized 60 g, brown eggshell. The breed has large population size, more than one million chickens in the native and nearby areas.
- **Xiaoshan (3.7.14)**: Originated from Xiaoshan county, Zhejiang province, southeast China, Xiaoshan chickens are famous for its large body size and high quality meat. The population is about 1.5 million chickens. The cock appears red single comb, red ear lobe, brown in the base of beak, red-yellow at the outer side, and red or yellow plumage with black tail. The hens are with yellow or partridge plumage, single comb, yellow beak and shanks. Adult male weighs 2.8 kg and female weighs 1.9 kg. At the age of 90 days, body weight of cockerel is 1.2 kg, and of pullet is 0.8 kg. Annual egg production is 110 to 130 eggs, averaging 56 g.

Other types

- **Chahua (4.4.01)**: Named after the sound of its crowing, the breed was originated from Yunnan province, southwest China. Chickens are reared in free range, coarse feeding condition. The chickens are similar to red jungle fowl that is also distributed there. Sometimes, Chahua chickens and the red jungle fowls were at the same fields and mated with each other. It is believed that Chahua chicken originates directly from the red jungle fowl. Chahua chickens appear small and short, active, aggressive and run fast and fly; red, single comb, black beak and shanks; cock, red plumage except wing primaries and wing secondaries, tail and sickles in black color; hen, partridge-brown plumage with black wings and tail. Body size differs according to areas, ranging from1.1 to 1.5 kg for male and from 1.0 to 1.1 for female. At the age of 90 days, the body weights for cockerel and pullet are 0.5 and 0.5 kg, respectively; at the age of 180 days, the body weights for cockerel and pullet are 1.0 and 0.90 kg, respectively. More recent data showed the body weights at the age of 90 days for cockerel and pullet while housed are 0.7 and 0.6 kg, respectively (Zhang *et al.*, 1991). Annual egg production is about 70 eggs on average with per egg sized 38.2 g. The population is more than 660,000 chickens.

- **Chinese game (4.4/7.02)**: The history for Chinese game chickens can be dated back to 2,000 years ago. The population of Chinese game chickens is very small, only 10,000 chickens existing. The Chinese game chicken is tall, strong, and long in shape like ostrich; long and strong neck, eagle-style beak, broad in breast. The Chinese game is classified into three types from different regions: Zhongyuan game from central China, Tulufan game from west China, and Xishuanbanla game from southwest China. Zhongyuan game is wedge-shaped, small head, long face, fine feather, no leg feathering, varied in plumage color: black, red, dark red, white and mixed color. Tulufan game is with small and short double-comb, brown beak, and plumage in black, partridge or light brown. Xishuanbanla game has small, wedge-shaped head, pea comb, plumage in black, white or dark-red, yellow shanks, no leg-feathering. Adult body weights for Zhongyuan, Tulufan and Xishuanbanla are 3.9, 4.1 and 1.8 kg for males, and 3.0, 2.8 and 1.1 kg for females, respectively. Annual egg production is about 100, 60-80, and 100-120 eggs for the three types, respectively.
- **Tibitan (4.1.03)**: Distributed in the areas of 2,200 to 4,100 m above sea level, including Tibit and the nearby provinces, such as Sichuan, Qinghai and Yunnan, the Tibitan chickens are very adaptive to the conditions of high plateau, cold climate and coarse feeding. In the history, Tibitan people raised chickens not for food, used the cocks as a timer. In recent decades, the chickens were gradually used more for food, and in this way the performance was improved, especially in Yunnan province. Tibitan chickens appear small size, long and short shaped, raising head and low and long tail, well developed breast muscle, and red, single comb, but some pea comb and crest. Black beak and shanks. Plumage for cock is either red-black or black-red, with small proportion in white or mixed color. Plumage of hen is varied, with black-partridge,

yellow-partridge, brown-partridge, white or mixed color. Adult weights differ according to the regions, ranging from 1.2 to 1.5 kg for males and from 0.9 to 1.2 kg for females. At the age of 90 days, the body weight of cockerel is 0.5 to 0.6 kg, and of pullet was 0.4 to 0.5 kg; at the age of 180 days, the body weights are 1.0 to 1.3 kg and 0.8 to 1.0 kg, respectively. Annual egg production ranges from 40 to 100 eggs, with per egg sized 35 to 50 g, brown, light brown or white eggshell. The population size is about 700,000 chickens.

Genetic Characteristics

Genetic distances among local breeds

Genetic distance represents the genetic differentiation between populations (Nei and Roychoudhury, 1974; Wright, 1978). Estimation of genetic distances among chicken breeds allows some evaluation of the degree of genetic diversity (Siegel *et al.*, 1992). The local breeds in China are classified mainly by ecological-geological isolation, morphology and the related performance data. There are at least two reasons to study genetic distances among local breeds in China. First, it provides one of the basic understandings for the conservation of the breeds, by means of understanding the origin of breeds from a genetic perspective. This is one of the steps in selecting breeds for conservation (Eding and Laval, 1999). Second, it provides insight into the genetic background of the breeds, which is helpful in developing management plans for the sustainable use of farm animal genetic resources, e.g., in commercial breeding programs. The pioneering work in China was carried out by Chen and his colleagues starting in 1980s and their published results (Chen *et al.*, 1991) form the most systematic work on genetic distances of chicken breeds up to now in China. Afterwards, the randomly amplified polymorphic DNA (RAPD) technique was applied to analyze the relatedness and diversity in local chicken breeds (Zhang *et al.*, 1998a; Zhang *et al.*, 1998c).

Chen *et al.* (1991) studied genetic distances among 22 local breeds, based on determining the blood type group (three loci and 12 alleles) and serum protein polymorphisms (four loci and nine alleles). Based on blood group frequencies, Li *et al.* (1995) determined genetic distances between Yugan black-boned chicken (from Jiangxi, south China) and three other breeds including Taihe Silkies (also black-boned chicken). Large genetic distance existed between these two black-boned chicken breeds. Including 32 loci of protein polymorphisms, Zhang *et al.* (1997a) studied four breeds (Chahua, Wuding, Yunnan game and Nixi) in Yunnan province and the highest polymorphism was found in Nixi chickens. The results by Li *et al.* (1995) and Zhang *et al.* (1997a) supported the classification of the clusters by Chen *et al.* (1991). Figure 2 summarizes the genetic distances of 22 local breeds sampled out from 10 provinces in China. Based on the genetic distances among the breeds studied, seven clusters can be distinguished. If considered with the original and distribution locations of the breeds, four clusters are classified (Chen *et al.*, 1991) and they are given in Table 1. As these did not included breeds from all ecological-geological regions, the classification is not a complete one.

Using RAPD technique, Zhang *et al.* (1998a) studied DNA polymorphisms in three black-boned chicken breeds, and the results showed that every breed had specific bands. Based on both protein polymorphisms and RAPD analysis, Zhang *et al.* (1998c) compared the genetic distances among three types of breeds: quality chicken (Huiyang Bearded, Xinhua, Qingyuan Partridge, Taihe Silkie, and Heifeng), white broiler and crossbred laying chickens (imported commercial lines). The results showed that the quality chicken breeds are closer to white broiler than to laying chickens; and the within-breed variability (based on heterozygosity and gene polymorphism within population) was generally highest for quality chicken and lowest for laying chickens.

Genetic parameters for performance traits

When searching through the literature, it appears that there are only a few reports on the estimation of genetic parameters for local Chinese chicken breeds. Lou *et al.* (1991) estimated heritabilities (male and female separately) and genetic correlations of traits (both production and reproduction) for Wuding chickens. For each of the seven generations in a selected dam line for meat-type chickens, genetic parameters were estimated, and in total eight traits for male and 13 traits for female were included. Heritabilities ranged from 0.25 to 0.44, and from 0.28 to 0.43 for male body weight at 60 and 90 days of age, respectively; from 0.30 to 0.62 and from 0.31 to 0.65 for female body weight at 60 and 90 days of age, respectively. Heritability was 0.10 to 0.25 for egg production and 0.20 to 0.53 for egg size at 300 days of age. Genetic correlations of egg size at 300 days of age with days at first egg (0.13) and egg size at 500 days of age (0.31) were positive. Negative genetic correlations were found between days at first egg and egg production at 300 or 500 days of age (between −0.15 and −0.50), and between egg size at 300 or 500 days of age and egg production at 300 or 500 days of age (ranging from −0.01 to −0.46). Li *et al.* (1998) estimated heritabilities and genetic correlations of eight traits

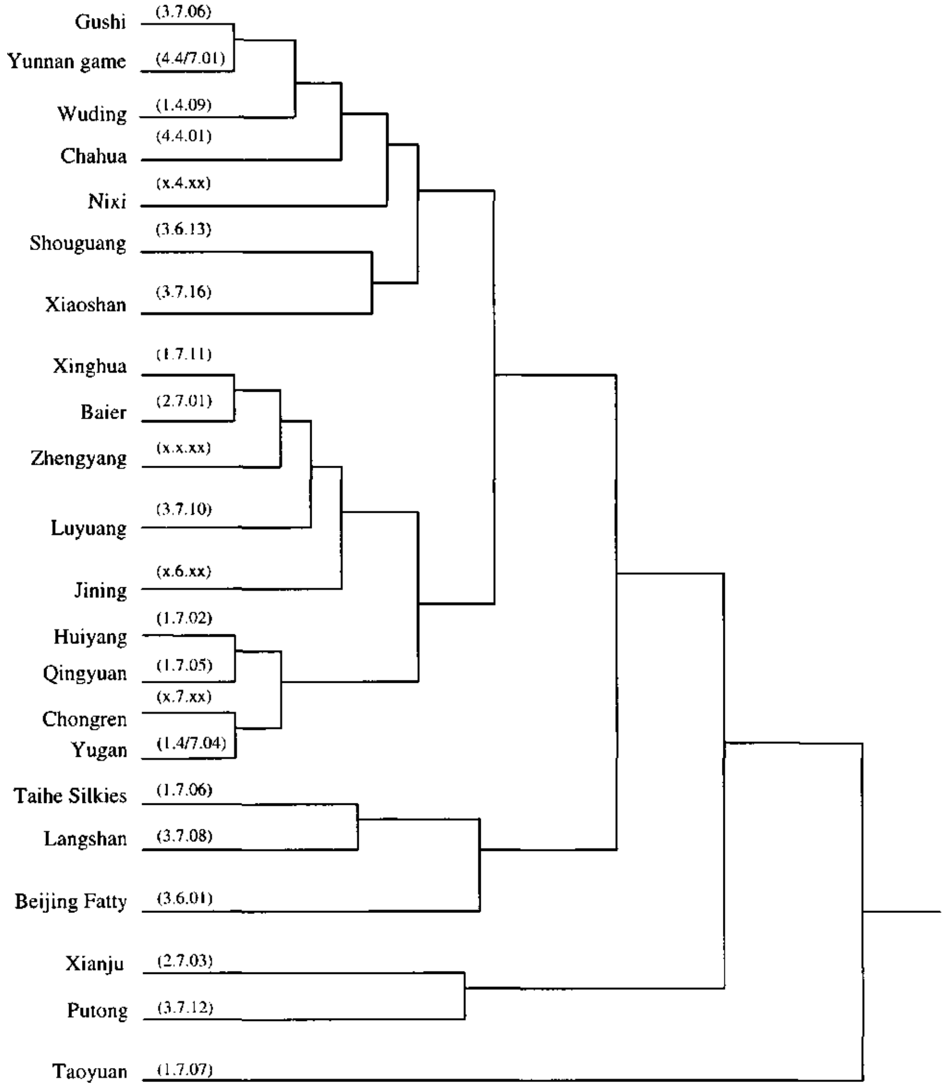


FIGURE 2. Genetic grouping of 22 local chicken breeds, adapted from Chen *et al.* (1991), Li *et al.* (1995) and Zhang *et al.* (1997a). The breed code number is shown in brackets. For breed without code number, the region number is given, e.g., Nixi chickens.

TABLE 1. Clusters of local chicken breeds based on genetic distances among them.* The breed code number is shown in brackets. For breed without code number, the region number is given, e.g., Nixi chickens.

Cluster of breeds	Description
Chinese game in Yunnan (4.4/7.02); Wuding (1.4.09); Chahua (4.4.01); Nixi (x.4.xx); Gushi (3.7.06).	These four breeds distributed in Yunnan province (mountainous region of southwest China) with unique gene frequencies (high frequencies for Es-1^{A} alleles, low frequencies for Es-1^{C}). This cluster of breeds is connected with the cluster of breeds in central China, via Gushi chickens.
Xiaoshan (3.7.14); Xinghua (1.7.11); Buff Baier (2.7.01); Zhengyang (x.x.xx); Luyuan (3.7.10); Taihe Silkies (1.7.06); Langshan (3.7.08); Beijing Fatty (3.6.01); Jining (x.6.xx); Shouguang (3.6.13).	This cluster is distributed in east China. Within the cluster, different types of breeds are formed (Meat-type, egg-type, dual-purpose, and the unique breed Silkies). This cluster can be regarded as the bridge through which the breeds in central, north and south China are connected.
Huiyang bearded chicken (1.7.02); Qingyuan partridge (1.7.05); Chongren partridge (x.7.xx); Yugan balck boned (1.4/7.04).	This cluster of breeds is distributed in Guangdong and Jiangxi provinces (the region of southeast China), with feature as meat-type and small body size. It is regarded as the bridge through which breeds in south, central and east China are connected.
Putong (3.7.12); Taoyuan (1.7.07); Xianju (2.7.03).	Here in this cluster, Putong and Taoyuan chickens are in relatively large body size, meat-type; their blood types and protein polymorphisms is significantly different from the others. Xianju chicken is as a bridge through which this cluster is connected to the breeds in east China.

*Adapted from Chen *et al.* (1991), Li *et al.* (1995) and Zhang *et al.* (1997a).

of laying performance for Yugan black-boned chickens, again based on sire variance. Heritability for egg number was 0.38 for either 300 days or 500 days of age. Heritability for egg size was again relatively high, ranging from 0.34 to 0.76 with different ages. With a new line Jinshui silkie chickens (selected for four generations, based on Taihe Silkies), Pi *et al.* (1999) estimated heritabilities and genetic correlation among three traits for laying performance. Comparing estimated heritabilities with those by Li *et al.* (1998), lower heritabilities for egg number at 40 weeks of age (0.13), egg size at 40 weeks of age (0.58), and age of first egg (0.41) were found in Jinshui relative to Yugan. Pi *et al.* (1999) concluded that one of the reasons might be that although both breeds are characterized by black-boned, their origination and appearances are different, e.g., Yugan with normal feathering vs Jinshui with silky feathering. It is worth notifying that results from the abovementioned reports on genetic parameters were within the range of the parameters as reviewed by Chambers (1990) and Fairfull and Gowe (1990).

Qualitative traits and their inheritance

Qualitative traits are economically important for most local chicken breeds in China. Consumers' tendency for acceptance or refusal of products from the local breeds, is largely dependent on its appearances. There at least are two aspects. First, consumers have direct preference for some specific characters that are qualitative traits. Second, consumers believe that there is close relationship between the appearance and the inner quality of the products, e.g., three-yellow vs quality meat, black-skin (black-boned chickens) vs both medical and quality meat, and tinted egg shell vs eggs from local breeds, and so on. As a reason for this, whenever developing breeding strategies, the qualitative traits with specific characters must be considered soundly. Understanding the heredity of qualitative traits is a prerequisite for breeding for quality chickens.

Black-boned character

In China, so called black-boned chickens represent the chickens with black (or dark) skin, meat and membrane on bone (sometimes also called three-black). This is equivalent to the melanism or fibromelanosis as often referred to in scientific literature. According to Stolle (1968, reviewed by Smith, 1990), fibromelanosis is due to sex-linked id^+ together with a dominant enhancer gene *Fm*; combinations of these genes resulted in different degrees of darkness of connective tissue pigmentation.

Genotype			Phenotype
Enhancer gene	Sex-linked gene		
	Female	Male	
$Fm/-$	id^+/W	id^+/id^+	darkly pigmented
$Fm/-$	Id/W	$Id/-$	faintly pigmented
fm^+/fm^+	id^+/W	id^+/id^+	unpigmented
fm^+/fm^+	Id/W	$Id/-$	unpigmented

As indicated by Smith (1990), considerable variation in the degree of fibromelanotic pigmentation suggests that a number of other factors can modify the expression of the trait. Some of these factors may also be related to plumage color although fibromelanotic Silkie chickens exist with white, black, blue and partridge patterns.

The three-black trait was first observed in Silkies (White and Eastick, 1953). In China, black-boned character appears in two types of chickens: Silky-like feathering chickens (e.g., Taihe Silkies) and normal feathering Chickens. According to the observation of three-black trait in a black-boned population with normal feather, Du *et al.* (1996) concluded that the three-black trait is heritable in the normal feathering population. On the basis of the observations of black skin in a black feather Silkies population, Huang *et al.* (1993) indicated that the inheritance of black skin followed the genetic pattern by Stolle (1968, reviewed by Smith 1990). However, Huang *et al.* (1993) did not experimentally prove this. Based on segregation analysis, Chen *et al.* (1998) found that the skin fibromelanosis was due to polygenic effects, and the estimated heritability was 0.41, implying that it is effective to select for the trait directly. In fact, in establishing the black-boned chicken population, direct selection has been done by institutions in China, although they did not reveal the inheritance of three-black trait in advance.

Three-yellow character

Few reports are found from local research on the inheritance of yellow (buff) plumage for specific local breeds in China.

Although the number of genes for buff color is unknown, it is known that the buff birds carry allele *s*, for gold color on a sex-linked locus, and the Buff Orpingtons have the same type of restricted black gene (*e*) as Rhode Island Red and Columbians (Hutt, 1949). Therefore, the genotype for buff males is *e/e s/s*, and for buff females *e/e s/W*. However, these same alleles are found in Rhode Island Red. The genes that make buffs different in color from Rhode Island Reds have yet to be discovered. The black commonly found in the neck, wings, and tail of buff birds supports the contention that most of them are genetically black fowls with the *ee* type of restriction. As explained by Smith (1990), although both melanins and carotenoid pigments contribute to the feather color of certain avian species, the melanins determines the plumage color and patterns of the domestic fowls. Brumbaugh and Hollander (1966) indicated that buff plumage was not a single mutant, but that it is determined by four or five loci. The genotypes for buff plumage are:

Genotype	Phenotype
e^b/e^b Co/Co db^+/db^+ mh^+/mh^+	Buff or Light Brahma
e^y or $e^{bc}/?$ Co/Co db^+/db^+ Mh/Mh Di/Di	Buff Minorca

The yellow coloration of the skin, shanks, beak, body fat, and egg yolk, is dependent on the carotenoid pigment. Yellow skin color is a breed characteristic of many standard breeds (Smith, 1990). The genetic basis for shank and foot color is complex, depending on the cumulative and interactive effects of several major genes, plus unidentified modifiers. The genotypes for different shank and foot colorings are as fellows (according to the review by Smith, 1990):

Genotype	Phenotype
w/w Id/Id e^+/e^+	Yellow shanks and feet
w/w id^+/id^+ e^+/e^+	Green shanks with yellow soles
W^+/W^+ id^+/id^+ e^+/e^+	Blue shank with white soles
w/w id^+/id^+ E/E	Black shanks with yellow soles
W^+/W^+ id^+/id^+ E/E	Black shanks with white soles
W^+/W^+ Id/Id e^+/e^+	White shanks and feet
W^+/W^+ Id/Id E/E	Near-black with white soles
w/w Id/Id E/E	Near-black with yellow soles

Apart from yellow shanks, character of blue shanks is also regarded as a symbol of local breeds in some markets in China (Chen, 1998).

Blue eggshell

There are two countries in the world that have chickens laying blue shelled eggs: China and Chile. The blue eggshell is rarely seen in chickens, and was first reported in the native south American breed known as Araucana (Punnett, 1933). In 1983, it was also found in the local chicken breed Black Jiuyuan, in east Sichuan, China. It was claimed that in the Black Jiuyuan chicken population, 5% of the hens give eggs with blue shell. In Shaanxi province (neighbouring province of Sichuan), a local breed named Lushi chickens was also claimed to have about 3% hens laying blue shelled eggs. In Jiangxi province, a small sized breed named Changxi also lays blue shelled eggs (Huang *et al.*, 1999). Both areas (Chile and China) are far remote from each other geographically. Concerning the origin of Araucana, Stromberg (1996) wrote "The Secretary of the Araucanas Club in England wrote that there is a claim that tribes from Peking migrated to South America bringing the Araucanas. This might be a possibility since some chickens did originate in China. However, I know of no chicken in China with the genes to lay colored eggs." It is remarkably controversy that seven pages after this statement in the same book, it reads "(Chinese) Black Jiuyuan chickens are known for laying blue shelled eggs."

Inheritance of blue shell is due to the presence of an autosomal dominant gene (*O*), which was first shown by Punnett (1933) with Araucana chickens. For the trait of blue shell in Jiuyuan chicken, Jiang and Luo (1991) and Jiang *et al.* (1991) revealed the same inheritance. According to Jiang and Luo (1991), the *O* gene on the multigenetic background for white shell color (crossbred between Jiuyuan and White Leghorn) resulted in a blue shell color, the same as the original blue shelled eggs from Jiuyuan chickens, while the *O* gene on the multigenetic background for brown shell color (crossbred between Jiuyuan and Rhode Island Red) resulted in a lighter blue shell color, similar to the olive drab color as described by Punnett (1933). According to the review by Bitgood and Somes (1990), the locus of blue shell was mapped in Group III, on the short arm of chromosome 1, linked to pea comb locus (*P*); the linear order was centromere – *P* – *O*. The linkage distance between *P* and *O* was 4 map units.

The value of blue shelled eggs is that they are regarded as "health eggs" in the native area of Jiuyuan county. People there believe there is a link between blue eggshell and the nutritive and healthy values of the eggs, but they do not know the physiological background. In Shaanxi province, blue shelled eggs from Lushi chickens are also called "Medicine eggs" by the local people (Sheng *et al.*, 1999). It is interesting that the same claim existed for Aruacanas, which was stated by Hickman (1974; cited by Somes *et al.*, 1977), among others, that the eggs were found "no cholesterol, 20% more protein, and 20% more iron." To verify the alleged attributes of Araucana eggs, several studies in North America were carried out. In comparisons between Araucana eggs with eggs of white or brown shell, Cunningham (1977) reported that there was no difference in the kind or amount of yolk or albumen protein, or percent solids, but 4.0% higher cholesterol content than white shelled eggs (from Leghorn) while brown shelled eggs (from Plymouth Rock) were intermediate. Somes *et al.* (1977) found blue shelled Araucana eggs to be lower in protein but higher in cholesterol contents than either white or brown eggs. Sadjadi *et al.* (1983) found no difference in the yolk cholesterol of blue and white eggs. Simmons and Somes (1985) indicated significantly more total cholesterol (27%), yolk cholesterol (7%), yolk protein (11%), zinc (10%), iron (3%) and total egg protein (5%) in eggs from Araucanas than eggs from White Leghorns. These studies did not determine the contents of amino acids of the eggs. All these studies, at least, revealed the fact that the cholesterol content of blue shelled Araucana eggs is not lower than white or brown eggs.

Luo *et al.* (1990) determined the composition of blue shelled eggs from Chinese Black Jiuyuan chicken, with regard to both chemical composition and contents of amino acids. Comparisons were made among blue shelled eggs from Jiuyuan chicken, both blue shelled and white shelled eggs from crossbred of White Leghorn × Black Jiuyuan, and brown shelled eggs from Rhode Island Red. Chickens for the experiment were hatched together in the same incubator, and then were reared in the same house with same diet. Determination was carried out at the 40 weeks of age. The results indicated that protein content was the highest for blue shelled egg of Jiuyuan (13.2%), lowest for brown egg of RIR (12.3%), and blue egg of White Leghorn × Black Jiuyuan was in the intermediate (12.9%). Blue eggs also contented more ash (1.0%) than the brown eggs (0.9%). However, these differences were not statistically significant. The same is true for the comparisons of the contents of 17 amino acids; although there were some differences among eggs with different shell colors, striking characters were not found.

The studies in both North America and China did not prove the eggs with blue shell to be "health eggs". Nevertheless, in some markets blue eggs are welcomed with high price, e.g., in North America (Stromberg, 1996). The same is true in the native area of Black Jiuyuan chicken in China. Even in The Netherlands, the Araucana blue shelled eggs can be seen in supermarkets with price 2.5 times as much as brown or white shelled eggs.

Another alleged attribute of blue Araucana eggs was "shells harder to break" (Somes *et al.*, 1977). Cunningham (1977) found Araucana eggs had slightly but nonsignificantly thicker shell than white or brown eggs. Using Araucana chickens, Sadjadi *et al.* (1983) indicated there was no difference between white and blue eggs for shell strength as measured by Instron measures and Marius deformation, while the study was based on the same genetic background, that is, the difference between genotypes within a crossbred originates only from the *O/o* alleles.

For Jiuyuan chickens, while compared based on different genetic backgrounds, Chen and Wang (1986) and Yang and Jiang (1989) found significantly higher breaking strength and shell thickness in blue eggs from Jiuyuan than brown eggs from Rhode Island Red. To reveal whether or not the *O* gene had the pleiotropic effect on eggshell quality, Jiang *et al.* (1992) made the comparisons based on the same genetic background. The results are summarized in Table 2.

TABLE 2. Averages of breaking strength and shell thickness of crossbreds with Black Jiuyuan chickens and two commercial lines (L = White Leghorn; RRI = Rhode Island Red)*.

Crossbred	Genotype	Shell color	Breaking strength (kg/cm^2)	Shell thickness (micron)
RIR×Jiuyuan	*Oo*	blue	4.83	358.1
	oo	brown	4.35	331.4
L× (L×Jiuyuan)	*Oo*	blue	3.96	327.9
	oo	white	3.55	346.0

* Source: Jiang *et al.* (1992).

The results suggested the *O* allele had effects on shell quality, resulting in significantly higher breaking strength. As shell strength is an important character for chicken industry, it should be noted that the *O* gene in Jiuyuan chickens may contribute to laying chicken breeding (Jiang, 1992).

CHICKEN PRODUCTION AND CONSUMPTION IN CHINA

General feature

China is a big country, not only for its population size, but also for its poultry production and consumption. The unprecedented changes that took place in China for the last twenty years have led to rapid growth in GNP and per capita income. Still, China has big potential to increase its economic status. The striking differences can be found from the comparison with developed countries. Figure 3 shows comparison for human population and GNP between China, USA and The Netherlands. Among these three countries, China has the highest average annual growth (10.8%) of gross domestic product (GDP) for 1991-1998, comparing USA with 2.6% and The Netherlands with 2.6% (International Monetary Fund, 1999). Increase in human population size and economic status in China will result in further increased production and consumption of poultry.

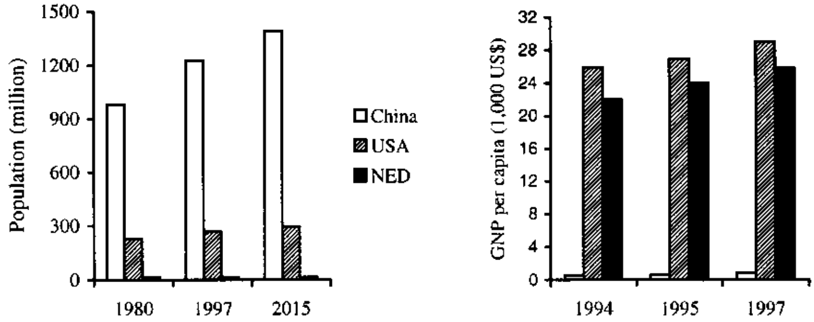


FIGURE 3. Human population and per capita gross national product (GNP) of China, USA and The Netherlands (NED) (source: World Bank, 1999).

The past decades have witnessed the rapid growth of animal production in China, and animal production has become increasingly more important among sectors of agriculture than ever before. In 1949, the output value of animal production was 12% of total agricultural output value; in 1988, it was 20%; in 1993, it was 27% (Ministry of Agriculture of China, 1995).

Comparing 1970 and 1996, per capita food consumption in the U.S. changed markedly, with eggs decreasing by 23%, red meat decreasing by 15%, poultry meat increasing by 90%. In 1997, this trend continued; Americans consumed less red meat, more poultry meat and fish than before (U.S. Department of Agriculture, 1998). The same trend is seen in China. In the total meat production in China, poultry meat accounted for 8% in 1985, 11% in 1990, and 18% in 1995 (Ministry of Agriculture of China, 1996).

Total poultry egg production in China approached USA in 1986, with China in the leading position afterwards (Ministry of Agriculture of China, 1995). According to Watt Publishing Co. (1997), in 1996 the hen egg production in China was 14.00 million tons, with USA (4.51 million tons) ranking second (Figure 4, Watt Publishing Co., 1997). Watt Poultry Statistics (Watt Publishing Co., 1997) showed egg consumption in 1994 was 11.31 kg/person for China, 13.36 kg/person for USA, and 14.78 kg for The Netherlands, considering the world average level is 7.06 kg in that year (Figure 4).

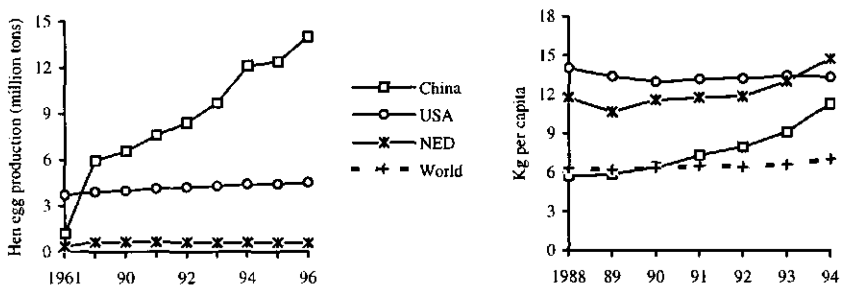


FIGURE 4. Hen egg production and poultry egg consumption per capita for China, USA and The Netherlands, compared with the world average level (source: Watt Publishing Co., 1997).

Poultry meat production was unbalanced for different regions, for example, in 1995, east China accounted for 66.7%, central China 23.2%, and west 10.1% of the total production (Ministry of Agriculture of China, 1996). Chicken meat is the major part of poultry meat in these three countries. However, China produces more duck meat than USA and The Netherlands, whereas USA and The Netherlands have much higher proportion for turkey meat than China (Figure 5).

In poultry meat production, more chickens are slaughtered in the USA than in China (Figure 6). Although poultry meat output in China was ranked second in 1996, it is catching up on the USA, that is ranked first. There is a close correlation between the growth in GNP/person and per capita poultry meat consumption. Meat has a high income elasticity, especially in developing countries, so, when income rise, meat consumption increases, replacing grain (Watt Publishing Co., 1997). According to the FAO data, poultry meat consumption per capita in 1994 was 6.7 kg for China, 43.97 kg for USA, and 16.31 for The Netherlands, considering the world average level was 8.87 kg (Figure 7). More recent data showed poultry consumption per capita in China in 1998 reached close to 9.0 kg (Ma, 1999). The data of USDA showed broiler meat consumption per capita in 1996 was 3.9 kg for China, 36.4 for USA, and 15.9 for The Netherlands. Prediction showed that in the year 2010, poultry meat consumption per capita in China will reach as much as 18 to 20 kg (Ma, 1998); the expected increase is about 1.5 to 2.0 times the consumption level in 1994 (6.7 kg).

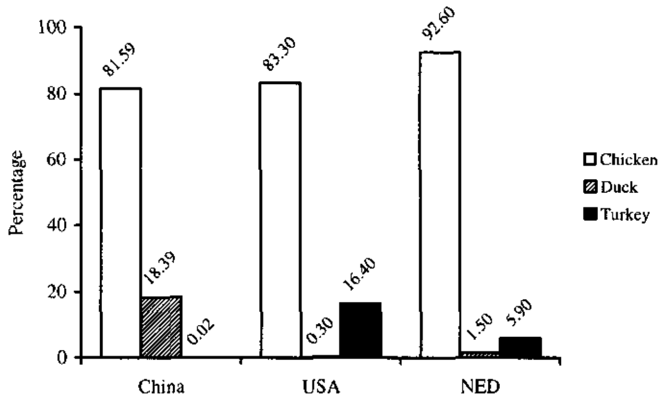


FIGURE 5. Proportions of chicken, duck and turkey meat to total poultry meat in 1996 for China, USA and The Netherlands (NED) (source: Watt Publishing Co., 1997).

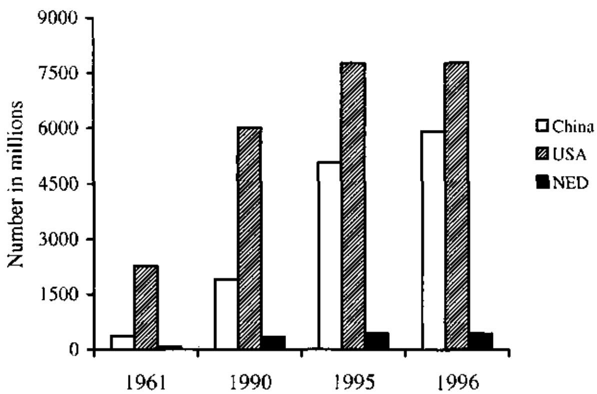


FIGURE 6. Yearly number of chickens slaughtered for China, USA and The Netherlands (NED) (source: Watt Publishing Co., 1997).

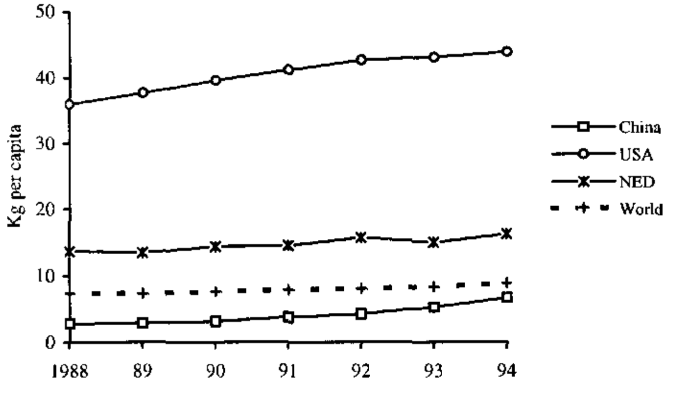


FIGURE 7. Poultry meat consumption for China, USA and The Netherlands (NED), compared with the world average level (source: Watt Publishing Co., 1997).

Quality chicken production and consumption in China

Worldwide, the white broiler is the most popular meat-type chicken; it accounts for about 70% of the world market (Watt Publishing Co., 1996), and in developed countries it accounts for almost the whole market. However, in other regions of the world, especially in east and south Asia, considerable proportions of chicken meat come from local breeds, e.g., 70% to 75% in India (Mukherjee, 1990). In the past two decades in Taiwan, market share of local breeds is about 50% for chicken meat (Taiwan Provincial Department of Agriculture and Forestry, 1996, as cited by Lee *et al*, 1997a). Although the production efficiency for local breeds is lower than that of white broiler chickens, the local breeds are preferred by the consumers due to pigmentation, taste, leanness, and their availability for special dishes (Horst, 1988; Lee *et al*, 1997a).

According to Nardone and Valfrè (1999), the concept of quality consists of hygienic, compositional, nutritional, sensory and technological aspects. For the (semi-) quality chickens in China, the term meat quality generally refers to sensory quality, i.e., color, flavor, taste, tenderness and juiciness. Meat-type chickens (broiler) in China are classified into three types according to the degree of meat quality.

- Type I with the highest quality meat is called **Quality chicken**, which comes directly from the local breeds that have not been crossbred or industrialized.
- Type II with the middle degree of meat quality, is regarded as **Semi-quality chicken**, which comes from the crossbred among local breeds and the imported broiler-type

chicken, based on the goal to improve the performance of local breeds; this type of crossbred chickens is also called "Simulated Native Chicken" in Taiwan (Roan and Hu, 1997).

- Type III with the lowest meat quality is the **White broiler chicken** from western countries, which is crossbred among specialized sire and dam lines; this type of chickens is also regarded as Fast-Big chicken in China, addressing its character of fast growth and big body size. The term not only refers to the white plumage, but to any commercial broiler line that is developed in a western country. Therefore, imported broiler such as Redbro also belongs to this type although the plumage is red or yellow.

The concept of (semi-) quality chickens is somewhat various in different regions in China (Chen and Sun, 1997). For example, in all south provinces, local purebred hens more than one year old are regarded as specially nourishing and the three-yellow is regarded auspicious. Therefore, the stewed chickens are regarded nourishing for people, especially aged people. In Jiangsu, Anhui, Henan and Jiangxi provinces, yellow cockerels of 100 to 150 days old are regarded high quality. In Guangdong province, Hong Kong and Macao, high quality chickens are those pullets which at 100 to 140 days old weigh about 1.6 kg. Another definition is that the (semi-) quality chickens are the pullets of 1.4 to 1.8 kg weigh, which are close to sexual maturity and with yellow or partridge yellow plumage. A very brief definition is that: the (semi-) quality chickens are either local purebred or its crossbred that can reach 1.2 to 1.5 kg of market body weight at the age of 60 to 90 days (Meng *et al.*, 1999). The black-boned chickens (either silky or normal feathering) also follow this definition although their three-black character is addressed.

There is a grand culture of cuisine in China. Different regions and provinces have their own character of the cuisine. The eight national recognized cuisine styles include Guongdong cuisine, Sichuan cuisine, Beijing cuisine and others. Only in Guangdong cuisine, more than 200 different chicken dishes are listed in the standard menu (Chen, 1997). Each cuisine style or even dish has dedicated demand for the meat quality of chickens (e.g., Chen, 1997). For some of (semi-) quality chickens, more detailed classifications of the quality grade are made according to the market demand. For example, concerning the Shiqi chickens in Guangdong province, the detailed classifications are based on the demand of well recognized dishes (Chen, 1997). Surely, cuisine culture in China is one of the important factors to maintain the chicken breed diversity and to gear the direction of breeding of quality chickens.

Starting in the 1920s, foreign (standard) breeds were gradually imported to China. In the 1950s crossbreeding with these standard imported breeds was carried out aiming to improve the performance of local breeds. By the end of 1970s, specialized laying stocks and broiler stocks from western countries found their way to China. Due to the commercial white broiler chickens and the attached husbandry technology, the meat-type chicken production in China has been changed from backyard to industrialized production, and during 1980s white broiler production increased tremendously. The increase in chicken meat production in 1980s was basically due to white broiler production in China. After 1990, the speed of increase in importing white broiler lines slowed down, e.g., in 1993 China imported 269,000 chickens of broiler grandparent stock, which was 11.4% less than the previous year (Li, 1994). This slowing down of the increase in importing white broiler lines is because of, among other reasons, more demand for quality of meat chickens due to the increase in living standard of the Chinese consumers. This tendency is more apparent in south provinces of China, e.g., Guangdong province, than north ones (Mu *et al.*, 1998). This is well illustrated by the market prices. According to Chen and Sun (1997), in the region southeast China, the market prices per kilogram live broiler in 1996, were 16 to 24 Yuan[1] for quality chickens (purebred local breeds), 12 to 16 Yuan for semi-quality chickens (crossbred with local breeds), and 7 to 9 Yuan for white broiler. Concluding, in the past decades the importance of the local breeds in China showed a wave-like pattern: starting as the only source for meat production, then dominated by imported white broiler lines, and then gradually receiving more attention again.

The importance of appearances of (semi-) quality chickens is well shown in markets in China, where the chickens are sold as either live birds or carcass ("whole bird" base) with a few feathers left; further-processed chickens are rarely practiced for (semi-) quality chickens (personal communication with managers of three-yellow chicken breeding farms in Guangdong province). Although crossbred, the semi-quality chicken also possesses the appearances of quality chickens, and it is therefore difficult to distinguish between the quality chickens and the semi-quality chickens in the market.

The data sources in China (e.g., Ministry of Agriculture of China, 1995; Ministry of Agriculture of China, 1996; State Statistical Bureau of China, 1997) did not distinguish the production and the consumption for different types of broiler at national level. Ministry of Agriculture of China (1995, cited by Ministry of Agriculture, Nature Management and Fisheries of The Netherlands, 1996; Xu, 1999) estimated that in total poultry meat production in China, white broiler accounts for 45.0%, eliminated hens

[1] Yuan: Chinese currency. 1.00 Yuan = 0.12 $US, approx.

finishing egg production for 22.8%, water fowl for 26.7%, and three-yellow chicken for 5.5%. It is obvious that production with local breeds was not completely accounted for. Li (1994) estimated that in 1993 there were 269,000 birds as imported grandparent stock and 110,000 birds as locally produced grandparent stock for broiler production. Based on this figure, we still can not calculate the production proportions, because it is most likely that the backyard production with the local breeds were not accounted for, as the term "grandparent stock" is not used for this backyard chickens. However, data for production at some regional levels are available.

Yan (1998) estimated that there is a large market in China for (semi-) quality chicken. In 1994, the yearly marketed number of (semi-) quality chickens from chicken farms was about 1,000 millions, and during 1995 and 1997, it was 1,200 millions. Note that these figures excluded the backyard production. According to Mu *et al.* (1998), in Guangdong province, the broiler breed distribution for three-yellow:white broiler:other type is 82:15:3. Among three-yellow, the distribution for large size yellow:middle size yellow:small size yellow is 30:50:20. There are 840.5 million birds of broiler produced in 1996 in Guangdong. In recent years, the production of three-yellow chickens in Guangdong province increased by 14% annually; in 1998, the number of three-yellow chickens in production was 690 million birds (Chen and Chen, 1999). According to the projection to year 2000 by Wu *et al.* (1998), production of black-boned chickens is 30 million birds, of three-yellow chickens is 50 million birds, and of Chongren Partridge (a local chicken breed) 50 million birds in Jiangxi province. Also, in provinces in south, east, southeast and southwest China, the administration departments have recognized the importance of production with local breeds as a way to provide higher quality meat, comparing to white broiler. Because of the shrink in market for white broiler, even in the largest white broiler production province, Shandong, three-yellow chicken production has recently started (Wang and Xu, 1999). The market demand for (semi-) quality chickens is also growing in Taiwan (Lee *et al.*, 1997a; Roan and Hu, 1997) and Hong Kong and Macao (Mu *et al.*, 1998). To promote the knowledge in breeding, nutrition, management and marketing of (semi-) quality chickens, a regular symposium on (semi-) quality chickens started from 1989, cooperated by Chinese mainland, Taiwan and Hong Kong (Chen and Huang, 1999). Therefore, production of (semi-) quality chicken is of great importance at present and promising in future China.

BREEDING FOR BROILER WITH THE LOCAL BREEDS

Nowadays, the commercial broiler and layer stocks have a worldwide dissemination. The commercial chicken breeding programs are under operation by just a few large organizations. For example, only the two largest breeding groups account 75% laying breeders market share in the world (Flock, 1998). For this reason, there is a significant probability of losing genetic variability in commercial chickens (Siegel *et al.*, 1992). Although in China there is a considerable number of local chicken breeds, protecting the local breeds is of great importance today because of the vast use of commercial crossbred lines in industry and also the change of husbandry system (e.g., from backyard to housing). The direct use of the imported crossbred lines in industry of China, and the fact of not paying enough attention to the conservation of genetic resources while practicing crossbreeding between local breeds and commercial crossbred lines, has made some of the local breeds endangered or shrunk the size of population (Li, 1998; Shen, 1996) and this has been destroying the diversity of chicken genetic resources in China. However, according to FAO (FAO, 1998), utilization is the most efficient form of genetic conservation. Therefore, the goal of breeding with local breeds is twofold: economically using genetic resources and efficiently conserving these resources. The common shortcoming of the local breed is lower performance for production and reproduction traits. Therefore, to make more use of local breeds, it is very important to improve their performance, and meanwhile maintaining their superiority in meat quality. To meet these two demands in the same time is not an easy job, as there probably is genetic conflict between these two aspects. However, for the past two decades, much work has been done in China.

In breeding for (semi-) quality chickens it can be seen from the above description that breeding goal has to be set differently from those of white broiler. Although there is no systematic definition of breeding goals for (semi-) quality chickens, clues can be found in papers by Chen (1997), Chen and Sun (1997), Mu *et al.*, (1998) Li (1998), Wu (1998), and Meng *et al.*(1999), among others. Accordingly, the general goal of breeding for (semi-) quality chickens is to get the chickens weighing around 1.5 kg at the age of 70 to 80 days with accepted "color and flavor". More detailed description includes the following aspects:

- **Plumage color**: In China, generally speaking, white color is regarded as un-auspicious, and almost all local chicken breeds are with colored plumage. Yellow plumage is a symbol of local breed in most regions. In breeding for (semi-) quality chickens, yellow plumage (with a few black feathers on neck and wings) and yellow partridge plumage are the favorite pattern for most regions of China. However, in some regions, black plumage is also favored by consumers. One exception is the Taihe Silkies with white silky plumage, but more other types of black-boned chickens are with black plumage.

- **Sexual maturity**: Chickens near to sexual maturity are with reddish faces and complete plumage, and this appearance is favored by consumers in Guangdong and Hong Kong, and other regions. Most chemical constitutions of animal muscle other than moisture increase with age (Lawrie, 1985). At sexual maturity there is considerable amount of vitamins, amino acids, minerals and (intramuscular) fat in bird body, therefore, meat from chickens close to sexual maturity is especially nourishing and nutritive, and has good taste and flavor (Chen and Sun, 1997). Selection for earlier sexual maturity would favor production efficiency and also marketing values of the chickens.
- **Conformation and carcass appearance**: The (semi-) quality chickens are middle body size, shaped rectangle, plumy breast but less fat than white broiler. Yellow and fine skin is favorable in market. Fat under skin is not thick, and fat in yellow color will markedly increase the appearance quality of the carcass.
- **Reproductive performance**: It is a marked shortcoming that local breeds have low reproductive performance. Selection for reproduction traits is relevant.
- **Body weight at given age**: For (semi-) quality chickens, growth and body weight are intermediate optimum, due to that the market does not accept large sized chickens and also growth rate is negatively correlated with meat taste and flavor (Lee *et al.*, 1997b; Chen and Sun, 1997).
- **Meat Quality**: Sensory quality (meat color, flavor, taste, tenderness, and juiciness etc.) is stressed by the Chinese market. Systematic method for the evaluation of sensorial quality is available in China (e.g., Chen, 1993; Yu and He, 1993).
- **Production efficiency**: For (semi-) quality chickens production, the improvement in production efficiency could not be obtained by the usual way applied in white broiler, i.e., the increased growth rate and feed efficiency. Presently, the practiced way is selection for earlier sexual maturity. This is being practiced in the Chinese Mainland (Chen and Sun, 1997) and Taiwan (Lee *et al.*, 1997b). To decrease the cost price of day-old chicks, the imported recessive white Rock, especially the dwarf line, is used as dam line for cross (e.g., Li and Li, 1995; Wei *et al.*, 1995; Liu *et al.*, 1997). The dwarf line is also developed in local breed population (e.g., Liu *et al.*, 1998).

It is worthy to note that the breeding goals are different in regions within China, and choices are always made according to market demand.

Box 1. Shiqi chickens

Shiqi chickens originate from Xiaonan town of Shiqi city in Guangdong province, south China. The first name of Shiqi chickens is the ancient Jiaozi chickens that could date back to about 2,000 years ago. According to Chen and Huang (1999), in the process of formation of Shiqi chickens, the red jungle fowl was used in the breeding. Besides, the formation of Shiqi was largely dependent on the rich natural resources, advanced agriculture, and especially, the cuisine in its native area. As the cuisine disseminated through the Guangdong province, and then to Hong Kong and Macao, more demand for Shiqi chickens was a driving force for the improvement of the breed to a higher meat quality. In 1960s, for improving the productive performance, breeders in Hong Kong used western broiler, including Redbro and Tegel, to cross the Shiqi chickens, and in this way, a new line was named Shiqi-Za (Za means hybrid). In 1980s, Kabir broiler from Israel was also used to cross Shiqi-Za. These Shiqi-Za chickens were imported back to Guangdong in 1980s (Mu *et al*, 1998; Zhao, 1993). However, the crossbreeding made Shiqi-Za chickens grow faster, but with less taste and flavor. As a reason of this, original Shiqi chickens from Xiaonan town were again recognized (Chen and Huang, 1999), and a new line of Shiqi chickens was developed (Chen, 1993 and 1995).

The breeding for (semi-) quality chickens for commercial perspective started 20 years ago, as a goal to meet the market demand in south part of China. Up to now, there are more than 20 commercially developed stocks of (semi-) quality chickens, and more are under development, due to the booming market demand for it (Chen and Sun, 1997; Meng *et al.*, 1999). At first the breeding and production of (semi-) quality chickens originated from Guangdong province, for providing the Hong Kong and Macao markets. Chickens named Shiqi were the first three-yellow quality chicken exported to Hong Kong and Macao. As Shiqi chickens played an important role in the development of (semi-) quality chicken breeding, the history of Shiqi chickens is regarded a well reflection of the history of (semi-) quality chicken breeding in China. Shiqi has been used to develop commercial brand labeled semi-quality chickens for commercial production (Zhao, 1993).

The usual way of breeding and production for (semi-) quality chickens in China is as follows:

(1) Pureline selection and production. Selection is carried out within local breed and the purebred is directly used for producing final products. Breeding for black-boned

chickens follows this way (e.g., Liu *et al.*, 1995; Zhang *et al.*, 1997b), and so does breeding for some three-yellow chickens (e.g., Qingyuan Partridge chickens, Chen and Chen, 1999). This system can also follow the broiler production system as described by Groen *et al.* (1998), but the stage of multiplier may be un-necessary and the purebred final products are produced at commercial grower stage. The advantage of this breeding and production structure is that the final products directly come from purebred local breed; the products belong to quality chickens, thus with high market price. The disadvantage is that this system is with relatively low production efficiency due to low performance in growth and reproduction traits. Therefore, the existence of this system must rely on the high market prices if it is adopted by intensive commercial producers. In the backyard raising condition with low-input and low-output, this breeding structure is quite adequate. More recently, a modification of this system is being carried out. Selection for specialized sire and dam lines within breed is being practiced, e.g., using Taihe Silkies. The main goal is to improve the reproduction performance in the dam lines and to increase the uniformity of the final products by crossing sire and dam lines, apart from maintaining the meat quality.

(2) Crossbreeding between local breeds. This way is in favor of meat quality and livability, but the growth rate is not improved significantly (Wu, 1998). Considering that heterosis is in favor of the traits with low heritabilities, such as reproduction and livability traits, this system is quite practical for improving reproduction and maintaining meat quality, as there is variety of local breeds in China. It is suggested here that, e.g., for two-way cross, selection for specialized sire or dam line should be carried out within local breed. Sire line could come from meat-type local breed with stress on its growth performance, and dam line from egg-type or general-purpose-type local breed with stress on its reproduction performance. The striking advantage of this breeding and production system is that either sire or dam line is purebred local breed with quality meat, therefore the final product is quality chickens. In addition, when three-way or four-way cross is adopted, heterosis for reproduction performance could be utilized. In choosing the breeds for the crossbreeding system, the result of genetic distance between breeds is useful, particularly while aiming at using heterosis. The third advantage of this system is that the final product (commercial grower) uniformity is improved by crossbreeding which is welcomed by intensive commercial producers. The authors feel that this system would be very promising in quality chicken production in China, as long as growth rate is improved adequately to meet the requirements of intensive production but not at the expense of meat quality. Besides, the commercial chicks can also be used in backyard condition.

(3) Breeding of synthetic strain using a local breed with one or more imported white broiler, but the local breed contributed most part of the genes to the line. For example, a synthetic strain named New Shiqi chickens is composed of $\frac{1}{8}$ genes from recessive White Rock chickens (Chen, 1993 and 1995). The synthetic strain is used either for direct production of final products or as a sire line to take part in crossbreeding. The new shiqi chickens were developed by using Shiqi chickens and an imported broiler line (Kabir). Grading mating was applied (Figure 8). The grading resulted in the second back-cross generation (BC_2) carried $\frac{7}{8}$ of the inheritance of Shiqi chickens and $\frac{1}{8}$ of Kabir chickens. The new line was improved in growth rate, feed conversion and reproductive traits, but maintained the three-yellow character and meat quality of the original Shiqi chickens (Chen, 1995). It is obvious that the goal of breeding of a synthetic strain is to improve the production and reproduction performance, and in the same time to maintain the meat quality. While the detected Quantitative Trait Loci (QTL) for the required characters are available, use of marker-assisted introgression of QTL will be more efficient (see Hospital and Charcosset, 1997).

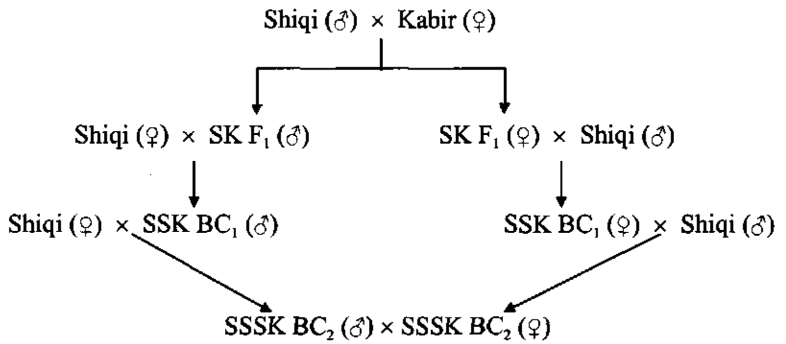


FIGURE 8. The development of a synthetic line, example of New Shiqi (source: Chen, 1995).

(4) Single cross between a local breed and an imported broiler, and the resulting F_1 is directly used to produce the final products. This way is practiced in Jiangsu province, Shanghai and other regions, either for meat production (Chen and Sun, 1997; Liu *et al.*, 1999) or for egg production (Zhang *et al.*, 1995a; Zhang *et al.*, 1995b). In general, to produce the final products with three-yellow character, the imported line used in this crossbreeding is with red or yellow plumage, e.g., Redbro. The imported broiler line can be used as either sire line or dam line. The F_1 chickens weigh about 1.5 kg at the age of

70 days (Chen and Sun, 1997). This crossbreeding is particularly used for backyard production of semi-quality chickens.

Box 2. The term *PeiTaoXi*

Both pure-breeding and crossbreeding are carried out as ways to use local breeds genetically and commercially in China. A term very popularly used for the animal breeders is "*PeiTaoXi*" that means a complete set of specialized lines for cross in form of either two-, three- or four-way. So, breeding for the "*PeiTaoXi*" means breeding for specialized lines. In this way many commercially labeled "*PeiTaoXi*" are developed. Actually, the final products by using these crosses are semi-quality chickens. In breeding for the "*PeiTaoXi*", efforts have been made to try to maintain the meat quality, in the same time to increase the production efficiency. Besides, direct use of purebred of the local breeds to produce the final products is also in practice (e.g., production of Silkies), due to higher market price.

(5) Crossbreeding by using local breeds and imported lines with recessive white plumage genes. The final products are crossbreds of local breed and an imported white broiler with recessive white plumage genes (Chen and Sun, 1997). There are different ways to produce semi-quality chickens different in growth rate (so-called "high quality type" and "middle growth rate type"). For producing the "high quality type" chickens, the male parent is purebred local breed, and female parent is a cross between local breed (male) and the recessive white plumage chickens (female). The growers reach 1.6 to 1.9 kg at the age of 90 to 120 days, close to sexual maturity. For producing the "middle growth rate type" chickens, the male parent is either a synthetic strain like Shiqi-Za chickens, or a cross between local breed and an imported broiler line, and the female parent comes from a cross between local breed (male) and the recessive white plumage chickens (female). The growers reach 1.5 to 1.6 kg at the age of 70 days. Chen (1998) described three-way crossbreeding to produce the three-yellow chickens with blue shanks, in which a local breed (e.g., Gushi chickens), a synthetic strain (e.g., Shiqi-Za), and the recessive white plumage chickens were included. Breeding for (semi-) quality chickens in the form of *PeiTaoXi* is also practiced by, e.g., Fu and Hua (1995 and 1997), Liu *et al.* (1997), Lou *et al.* (1991),Tong (1997), Wang *et al.* (1997), Yang *et al.* (1995), and Zhao *et al.* (1997). This form of crossbreeding is used mainly for intensive commercial production, where the production efficiency is stressed, apart from meat quality. The breeding and production structure is quite similar to that as described by Groen *et al.* (1998). Selection for dam lines emphasizes on the reproduction traits. To

maximize genetic response on reproduction traits, it is suggested that the method of combined crossbred and purebred selection (see Jiang and Groen, 1999) could be applied when performance records from crossbred are available.

In animal breeding, meat quality is a complex traits, referring to the compositional, visual and sensory traits of a carcass, or its retail cuts (Thompson, 1998). Up to now, eating quality is stressed by consumers, which refers to the sensory attributes of cooked product, i.e., tenderness, flavor, juiciness and color. As the consumers have always played a major role in the definition of the given meat quality (Nardone and Valfrè, 1999), it is reasonable to put the sensory quality as one of the goals in breeding for quality chickens.

Box 3. Kabir as dam lines

Some broiler breeding companies outside China, for example, Kabir Chicks Ltd. from Israel, have a well understanding for the market diversity in the world (see Katz, 1995). Aiming at the market in China (particularly in south China), Kabir proposed a basic breeding and production structure for three-way and four-way crosses, in which the dam line is fixed but with alternating the other two or three lines different types of final products are obtained. For example, with a specialized dam line D (named K2700, recessive white plumage, genotype *i/i k/k s/s e/e* for male and *i/i k/- s/- e/e* for female), five different forms of three-way crosses are proposed by using Chinese local breeds as sire lines, to produce the three-yellow chickens as final products, and in this way grandparent stocks of line D are sold to the local breeding farms in China (personal communication with Katz). The advantage is more choices left for clients (e.g., multiplier). This is different from the crossbreeding structure, where the lines for the crosses are supposed fixed because they have been decided based on the combining ability tests, and the advantage is, of course, the production efficiency is optimized (or maximized).

There are many factors related to the meat quality (e.g., by the point of view in biochemical aspects). Dikeman (1994) concluded the reasons for the difficulties in improving meat quality. Progress in improving meat quality through genetic selection has been greatly hindered by the fact that the most meat quality traits cannot be evaluated, or at least not evaluated accurately, in breeding animals. This is especially true for traits that related to consumer acceptance (meat color, fat color) and eating quality (tenderness, flavor, juiciness). Progeny testing has been the only accurate method in selecting for these traits, but it is slow, expensive and often impractical. Sensory evaluation for meat palatability rarely is used in any breeding program, primarily because it is too expensive and time consuming. Secondly, the relative economic importance of meat quality is less than that of growth rate, and especially less than that of reproduction. Thirdly, there is genetic antagonism between some meat quality traits and carcass composition. For example, there is genetic antagonism between meat quality and growth rate in selection for quality chickens (Lee *et al.*, 1997b). However, to include meat quality traits in selection programs, estimates of the genetic variance are required, and some of them (e.g., eating quality and fatty acid composition) are under study or already available (Thompson, 1998). As stated by Thompson (1998), molecular techniques in the form of candidate genes and QTL can be used to improve the rate of genetic progress in meat quality traits. Although the nature of meat quality of local chickens is not known now in China, there is a practical way to consider that character in the breeding program, that is, the choice of breeding materials (Zhang and Yang, 1998). The success of breeding for quality chickens is to large extent judged by the market, especially breeding for the *PeiTaoXi* by breeding companies. However, sounder breeding programs need to be made based on a systematic method, especially the definition of breeding goals (see Jiang *et al.*, 1998 and 1999).

In the process of breeding for (semi-) quality chickens, genes for qualitative traits were also applied either to develop feathering sexing lines (e.g., Xiong *et al.*, 1995; Zhang *et al.*, 1998b) or to improve the productive efficiency of dam lines (e.g., dwarf gene: Huang *et al.*, 1998b; Jiang and Wang, 1993; Li and Li, 1995; Li *et al.*, 1991; Liu *et al.*, 1997; Liu *et al.*, 1998; Wei *et al.*, 1995; Zhou *et al.*, 1997). Attention was also paid to disease resistance (e.g., Li *et al.*, 1993).

DISCUSSION AND CONCLUSION

Many breeds and commercial crossbred lines (34 in chicken, 10 in duck, and two in goose) have been imported in China from North America and Europe (Li, 1994). The vast increase in poultry meat production in China in the past two decades is largely due to this importation of western broiler crossbred stocks (white broiler) in conjunction with improved nutrition and management technologies. Production of white broiler has made considerable contribution for providing the protein food for human population of China. As stated by Mercier (1997, cited by Nardone and Valfrè, 1999), when countries became able to cover their needs for quantity, the next step was to obtain products of high quality to satisfy the consumers who ask for "safe and tasty" products. Besides, the culture and cuisine style defined the specific character of the products. For these two reasons, presently meat quality is the most important factor in the breeding goal for local breeds in China. Chicken meat quality is defined by several aspects, such as sensory, hygienic, compositional, nutritional and technological quality (Nardone and Valfrè, 1999). The term meat quality has a different definition among countries and among producers, processors, retailers and consumers (Dikeman, 1994). The needs of consumers for meat quality is dependent on the culture background (for example, three-yellow character is equal to (semi-) quality chickens), traditionally nutritional and medical beliefs (e.g., the black-boned chickens), and cuisine style. Also in western countries, the social request for animal welfare corresponds to the diffuse feeling that animals reared under "natural" conditions give "better" products. Although this is not always true, this feeling must be considered as a positive factor, as it is helpful for both the economic and market development (Nardone and Valfrè, 1999). As genetic improvements in (white) broilers has led to improved weight gain, but at the same time to a reduction in meat quality. Therefore, the un-industrialized local breeds in China can make considerable contributions to meet the demands in meat quality.

Politiek (1962, cited by Groen, 1989) defined the general goal of animal breeding is: obtaining a new generation of animals that will produce the desired products more efficiently under future farm economic and social circumstances than the present generation of animals. Based on this definition of breeding goal, two items are emphasized: "desired product" and "efficiency". As there is large market demand for quality chickens in both present and future China, breeding for chickens with quality meat is of great importance. Concerning the breeding goals for sustainable production system for the local chicken breeds in China, firstly a definition of sustainable production is desired. Following Olesen *et al.* (1999), seeing and considering animal breeding in view of its impact on genetic diversity, environment and society is a prerequisite for being able to find and carry out significant actions towards animal breeding for sustainable production systems. Amer *et al.* (1998) defined breeding goals for sustainable production systems. They defined production systems in developing countries as subsistence production systems or commercial production systems. For the subsistence production systems, attention should be given to maintaining and enhancing adaptive characteristics of local breeds while at the same time improving productivity. For intensive commercial production, the breeding goals should stress the increase in production and the improve of the animals' capacity for efficient use of feed. For extensive commercial production systems, the goal should be to improve survival and productivity in the relevant environment. For the local chicken breeds in China, there are also two production systems (subsistence and commercial). In the countryside of China, almost every family tends to keep chickens either for family needs or for both family needs and commercial. A common way is that the family keeps the pullets for laying eggs and markets the cockerels. Although this production system is less efficient, it provides a way to conserve the genetic resources of chicken breeds and to provide the market with high quality chickens (based on its purebred and natural rearing conditions). Better marketing conditions for backyard chickens (e.g., in Sichuan province) is a driving force for the small holders to produce local purebred chickens more commercially than before.

According to Hammond (1998), about 30% of the world animal genetic resources at the breed level are at high risk of loss. He argued that the general approach to genetic development of domestic animals resulted in a very small number of breeds for producing a single product under high input production conditions. This situation is especially true in poultry sector in the world (See Sørensen, 1997; Delany and Pisenti, 1998; Flock, 1998) and in China (Shen, 1996; Li, 1998). Since the beginning of this century, China has been engaged in an intense effort to assimilate modern western science. In making such an effort, many things were perhaps adopted without sufficient critical reflection (Chai, 1993). The fast dissemination of the western broilers in China for the past two decades is one of the examples, with the annual number of marketed white broilers increasing from almost zero to more than 3,000 millions (Huang, 1997). The positive effect of this importation has been reflected in the fast increase in poultry meat production, and has been well appraised in the national press (e.g., Huang, 1997; Ma, 1998). However, negative effects are also attached. First, if this dissemination continues, what will happen in the future? Domestic animal diversity will be destroyed further. The existence of a local breed is dependent upon its adaptation to the local environment, and its economic values for the local (and outside) market. Second, is the present approach of the use of local chicken breeds in south China an adequate way to meet both demand of consumers market and genetic resources conservation? In conserving the genetic resources, both *in situ* and *ex situ* conservations are suggested. The breeding programs in the local breeding companies perform the way of *ex situ* conservation, but the backyard production is a way of *in situ* conservation. To facilitate this role of *in situ* conservation, it is necessary to maintain and possibly improve the existing backyard production systems.

Nutrition requirements of (semi-) quality chickens are different from that of white broilers. Although there is research on the nutrition requirement of local breeds, standard nutrition requirement is still not available (Xu, 1997). Therefore, more research is asked for this field, as it is related to the quality of the chickens. Husbandry systems for the production of (semi-) quality chickens should be addressed. Huang *et al.* (1998a) observed that husbandry systems are also in relation to the darkness of color in three-yellow chickens, and they suggested that the complete housing system has made a lighter color of the three-yellow chickens. More research should be carried out to look for genotype by environment interaction on the character of three-yellow.

It is very important for the (semi-) quality chicken breeding organizations in China that any improvement in production efficiency should not be at expense of product quality. Otherwise, the breeding for quality chickens would be back to the same way of breeding for white broiler as practiced in western countries, and all the significance of quality chicken breeding and production would then disappear. Based on the above description and discussion, the authors strongly feel that it is necessary to combine the two aspects together, that is, quality from local breeds in China and production efficiency from western countries. The genetic resources belong to and can contribute to mankind all over the world. The worldwide research on the reproduction characteristics of Chinese Meishan pigs is a good example that poultry scientific institutions and breeding organizations may follow. It is suggested that a cooperation between western and Chinese chicken breeding companies in the use of Chinese local chicken breeds should aim at economic and sustainable use of the local chicken breeds. If this is successful, it seems that China will be able to maintain the diversity in breeds for quite a long time.

ACKNOWLEDGMENT

Prof. Dr. E. W. Brascamp is acknowledged for many useful comments.

REFERENCES

Amer, P. R., N. Mpofu, and O. Bondoc, 1998. Definition of breeding objectives for sustainable production systems. Vol. 28, Pages 97–104 *in*: Proceedings of the Sixth World Congress on Genetics Applied to Livestock Production. Armidale, NSW, Australia.

Bitgood, J. J., and R. G. Somes, Jr., 1990. Linkage relationships and gene mapping. Pages 469–495 *in*: Poultry Breeding and Genetics. R. D. Crawford, ed. Elsevier, Amsterdam, The Netherlands.

Brown, E., 1985. Races of domestic poultry. Nimrod Book Service, Hants, England.

Brumbaugh, J. A., and W. F. Hollander, 1966. Genetics of buff and related color patterns in the fowl. Poultry Sci. 45:451–457.

Chai, C. K., 1993. Developing the native pig breeds of China. Pig News and Information 14(1):27N-30N.

Chambers, J. R., 1990. Genetics of growth and meat production in chickens. Pages 599-643 *in*: Poultry Breeding and Genetics. R. D. Crawford, ed. Elsevier, Amsterdam, The Netherlands.

Chen, G., D. Zhou, L. Wu, Z. Duan, L. Wang, S. Liu, and T. Zhang, 1991. Blood group and protein polymorphisms in Chinese local breed chickens. Pages 129-133 *in*: Proceedings of the Fifth Conference of Chinese Poultry Science Association. Chengdu, China (in Chinese).

Chen, J., and B. Wang, 1986. Comparison of eggshell quality between blue eggs from Black Jiuyuan and brown eggs from Rhode Island Red chickens. J. Sichuan Animal Sciences and Veterinary, Issue No. 3 (in Chinese).

Chen, K., 1998. Breeding for meat-type chickens with blue shanks. Pages 9-11 *in*: Proceedings of the Fifth Conference on Improvement and Production for Quality Chicken in China. Y. Feng and G. Wang, ed. Wuyishan, Fujian, China (in Chinese).

Chen, K., and Y. Sun, 1997. The present and the future of (semi-) quality chickens in China. Pages 142-145 *in*: Proceedings of the Eighth Conference of Chinese Poultry Science Association. Suzhou, China (in Chinese).

Chen, Q., 1993. A new line of Shiqi three-yellow chickens. Pages 214-216 *in*: Proceedings of the Sixth Conference of Chinese Poultry Science Association. Beihai, China (in Chinese).

Chen, Q., 1995. The development of a new line of Shiqi chickens and its crosses. Pages 134-136 *in*: Proceedings of the Seventh Conference of Chinese Poultry Science Association. Hangzhou, China (in Chinese).

Chen, Q., 1997. The judgment, management and marketing of Shiqi three-yellow chickens. Pages 146-148 *in*: Proceedings of the Eighth Conference of Chinese Poultry Science Association. Suzhou, China (in Chinese).

Chen, Q., and D. Huang, 1999. The history of Shiqi chickens. China Poultry, 21(1):22-24 (in Chinese).

Chen, T., and P. Chen, 1999. Qingyuan Partridge chicken entered markets of Guangzhou. Guangzhou Daily, 28 July, Guangzhou, China (in Chinese).

Chen, Y., 1989. The endangered livestock breeds in East Asia. Pages 207-212 *in*: Animal Genetic Resources: A global programme for sustainalbe development. G. Wiener, ed. FAO, Rome, Italy.

Chen, Z., L. L. G. Janss, Y. He, S. Li, and Y. Li, 1998. Segregation analysis of black skin pigmentation in Silkies. Pages 49-51 *in*: Proceedings of the Fifth Conference on Improvement and Production for Quality Chicken in China. Y. Feng and G. Wang, ed. Wuyishan, Fujian, China (in Chinese).

Crawford, R. D., 1990. Origin and history of poultry species. Pages 1-41 *in*: Poultry Breeding and Genetics. R. D. Crawford, ed. Elsevier, Amsterdam, The Netherlands.

Cunningham, F. E., 1977. Composition of Araucana eggs. Poultry Sci. 56:463-467.

Delany, M. E., and J. M. Pisenti, 1998. Conservation of poultry genetic research resources: consideration of the past, present and future. Poultry and Avian Biology Review, 9(1):25-42.

Dikeman, M. E., 1994. Genetics of meat quality. Vol. 19, Pages 437-449 *in*: Proceedings of the Fifth World Congress on Genetics Applied to Livestock Production. Guelph, Ontario, Canada.

Du, X., Q. Zhu, and Z. Yang, 1996. Heredity of plumage and skin colors of Sichuan Mountain black-boned chickens. J. Sichuan Agricultural University, 14(1):32-35 (in Chinese).

Eding, J. H., and G. Laval, 1999. Measuring genetic uniqueness in livestock. Pages 33-58 *in*: Genebanks and the Conservation of Farm Animal Genetic Resources. J. K. Oldenbroek, ed. DLO Institute for Animal Science and Health, Lelystad, The Netherlands.

FAO, 1998. Primary guidelines for development of national farm animal genetic resources management plans:domestic animal diversity information system. FAO, Rome, Italy.

FAO, 1999a. DAD-IS Breeds Database <http://www.fao.org/dad-is/>, FAO, Rome, Italy.

FAO, 1999b. FAOSTAT <http://apps.fao.org>, FAO, Rome, Italy.

Fairfull, R. W., and R. S. Gowe, 1990. Genetics of egg production in chickens. Pages 705-759 *in*: Poultry Breeding and Genetics. R. D. Crawford, ed. Elsevier, Amsterdam, The Netherlands.

Flock, D., 1998. Genetic improvement of laying performance. Guide to Chinese Poultry, 15(3):11-12 (Chinese version translated by Y. Zhang).

Fu, Z., and S. Hua, 1995. Reproductive performance of hens of Qianhuang three-yellow chickens. Pages 162-163 *in*: Proceedings of the Seventh Conference of Chinese Poultry Science Association. Hangzhou, China (in Chinese).

Fu, Z., and S. Hua, 1997. A further report on productive performance of Qianhuang three-yellow chickens. Pages 157-159 *in*: Proceedings of the Eighth Conference of Chinese Poultry Science Association. Suzhou, China (in Chinese).

Groen, A. F., 1989. Cattle Breeding Goals and Production Circumstances. Ph.D. Thesis, Department of Animal Breeding, Wageningen Agricultural University, Wageningen, The Netherlands.

Groen, A. F., X. Jiang, D. A. Emmerson, and A. Vereijken, 1998. A deterministic model for the evaluation of broiler production systems. Poultry Sci. 77:925-933.

Hammond, K., 1998. Development of the global strategy for the management of farm animal genetic resources. Vol. 28, Pages 43-50 *in*: Proceedings of the Sixth World Congress on Genetics Applied to Livestock Production. Armidale, NSW, Australia.

Horst, P., 1988. Native fowls as reservoir for genomes and major genes with direct and indirect effects on productive adaptability. Pages 99-104 *in*: Proceedings of 18th World's Poultry Congress. Nagoya, Japan.

Hospital, F., and A. Charcosset, 1997. Marker-assisted introgression of quantitative trait loci. Genetics, 147:1469-1485.

Huang, S., 1997. The past, present and future of poultry industry in China. Poultry Industry Science and Technology 13(10):4-8 (in Chinese).

Huang, F., H. Wu, X. Zhou, and S. Lin, 1999. A breed with blue eggshell: Changxi chickens. China Poultry 21(4):45-46 (in Chinese).

Huang, F., X. Zhang, and Q. Zhou, 1993. Inheritance of feathering and skin color in a Silkie chicken population of black plumage. Pages 134-135 *in*: Proceedings of the Sixth Conference of Chinese Poultry Science Association. Beihai, China (in Chinese).

Huang, F., Q. Zhou, X. Zhang, and D. Wang, 1984. Studies on the properties and performance of local chicken breeds in China. Report of Project No. Mu01-4. Jiangsu Research Institute of Poultry Science, Jiangsu, China (in Chinese).

Huang, D., J. Xu, G. Ying, and J. Zhou, 1998a. Thinkings about breeding and production of three-yellow chickens. China Poultry 20(9):27-28 (in Chinese).

Huang, Q., J. Li, Z. Zhou, Q. Tai, Z. Gu, and H. Ji, 1998b. Breeding of dwarf line for three-yellow chickens. Pages 77-82 *in*: Proceedings of the Fifth Conference on Improvement and Production for Quality Chicken in China. Y. Feng and G. Wang, ed. Wuyishan, Fujian, China (in Chinese).

Hutt, F. B., 1949. Genetics of the fowl. McGraw-Hill Book Company, Inc., New York, USA.

International Monetary Fund, 1999. World economic outlook. Issue: May. Washington, DC, USA.

Jiang, F., and L. Jiang, 1995. The performance of Hebei Caiji chickens. Pages 169-171 *in*: Proceedings of the Seventh Conference of Chinese Poultry Science Association. Hangzhou, China (in Chinese).

Jiang, Y., and H. Wang, 1993. The dwarf gene (*dw*) applied in crossbreeding with Taihe Silkies. Pages 180-183 *in*: Proceedings of the Sixth Conference of Chinese Poultry Science Association. Beihai, China (in Chinese).

Jiang, X., 1992. Studies on the blue eggshell in chickens, a review. China Livestock and Wildlife Magazine (Taiwan) 24(10):23-26 (in Chinese).

Jiang, X., H. Du, and C. Yang, 1991. Genetic study on blue eggshell in Jiuyuan chickens. Pages 23-24 *in*: Proceedings of the Fifth Conference of Chinese Poultry Science Association. Chengdu, China (in Chinese).

Jiang, X., H. Du, and C. Yang, 1992. Effect of blue eggshell allele with different paternal origin on egg shell quality of crossbred chickens. Vol. 3, page 121 *in*: Proceedings of the 19th World's Poultry Congress. Amsterdam, The Netherlands.

Jiang, X., and A. F. Groen, 1999. Combined crossbred and purebred selection for reproduction traits in a broiler dam line. J. Anim. Breed. Genet. 116:111-125.

Jiang, X., A. F. Groen, and E. W. Brascamp, 1998. Economic values in broiler breeding. Poultry Sci. 77: 934-943.

Jiang, X., A. F. Groen, and E. W. Brascamp, 1999. Discounted expressions of traits in broiler breeding programs. Poultry Sci. 78: 307–316.

Jiang, X., and C. Luo, 1991. Inheritance of blue eggshell in Jiuyuan chickens. China Poultry 11(2):35–36 (in Chinese).

Katz, Z., 1995. Breeders have to take nature into account. World Poultry, Vol. 11, No. 4.

Lawrie, R. A., 1985. Meat science. Pergamon Press. Oxford, U.K.

Lee, Y.-P., P.-L. Chiang, and H.-H. Huang, 1997a. A study on the optimal marketing age of Taiwan country chicken. J. Chin. Soc. Anim. Sci. 26(3):285–296 (in Chinese).

Lee, Y.-P., L.-T. Yeh, and H.-H. Huang, 1997b. A study on the production system of Taiwan Country chicken: growth traits of three-strain cross country chickens. J. Chin. Soc. Anim. Sci. 26(3):271–284 (in Chinese).

Li, D., 1998. On crossbreeding with local chicken breeds of China. Pages 16–19 *in*: Proceedings of the Fifth Conference on Improvement and Production for Quality Chicken in China. Y. Feng and G. Wang, ed. Wuyishan, Fujian, China (in Chinese).

Li, D., and X. Li, 1995. Breeding of a dwarf line of Rock chickens. Pages 187–190 *in*: Proceedings of the Seventh Conference of Chinese Poultry Science Association. Hangzhou, China (in Chinese).

Li, D, L. Luu, M. Huang, and X. Li, 1991. Selection for ecological adaptation in a broiler dwarf line. Pages 113–115 *in*: Proceedings of the Fifth Conference of Chinese Poultry Science Association. Chengdu, China (in Chinese).

Li, F., J. Xie, and D. Jiang, 1998. Estimation of genetic parameters of traits for Yugan black-boned chickens. China Poultry 20 (3):4–6 (in Chinese).

Li, F., J. Xie, L. Wang, Y. Zhang, Z. Duan, S. Liu, and G. Chen, 1995. Genetic differentiation among Yugan black-boned chickens and other three breeds based on blood group frequencies. Pages 96–99 *in*: Proceedings of the Seventh Conference of Chinese Poultry Science Association. Hangzhou, China (in Chinese).

Li, K., P. Wei, M. Liang, Z. Zeng, Q. Fan, S. He, and C. Li, 1993. Breeding for Marek's disease resistance in Xiayan chickens. Pages 202–207 *in*: Proceedings of the Sixth Conference of Chinese Poultry Science Association. Beihai, China (in Chinese).

Li, W., 1994. Breeding stock in China. Poultry International 33 (12):30–34.

Liu, H., H. Zhao, Z. Chen, K. Chen, H. Lin, and D. Zhang, 1997. Breeding of a dwarf line for Kangdaer three-yellow chickens. Pages 154–156 *in*: Proceedings of the Eighth Conference of Chinese Poultry Science Association. Suzhou, China (in Chinese).

Liu, J., X. Du, F. Wang, F. Shao, and Z. Chen, 1995. The inheritance of some traits of Chishui black-boned chickens with black plumage. Pages 172–173 *in*: Proceedings of the Seventh Conference of Chinese Poultry Science Association. Hangzhou, China (in Chinese).

Liu, J., F. Shao, X. Du, Z. Chen, and Q. Tian, 1998. Breeding for dwarf Chishui black-boned chickens with black plumage. China Poultry 20(1):8–9 (in Chinese).

Liu, Y., Z. Yang, and Q. Zhu, 1999. The performance of cross between Sichuan Mountain black-boned chickens and a broiler line. China Poultry 21(4):13-15.

Liu, Z., C. Ruan, S. Ye, and T. Liao, 1997. Family selection for egg production of Bobei three-yellow chickens. Pages 117-119 *in*: Proceedings of the Eighth Conference of Chinese Poultry Science Association. Suzhou, China (in Chinese).

Lou, Y., P. Xie, M. Yu, J. Huang, and L. Song, 1991. Breeding of a dam line in Wuding Chickens. Pages 33-41 *in*: Proceedings of the Fifth Conference of Chinese Poultry Science Association. Chengdu, China (in Chinese).

Luo, C., X. Jiang, C. Yang, J. Chen, and B. Wang, 1990. Egg production and chemical compositions of eggs in Jiuyuan chickens. J. Sichuan Animal Sciences and Veterinary, Issue No.3 (in Chinese).

Ma, C., 1998. Prediction for poultry meat production and consumption in China in year 2010. Guide to Chinese poultry, Vol. 15, No. 1 (in Chinese).

Ma, M., 1999. The dilemma and rethinking for poultry industry in China. Guide to Chinese poultry, Vol. 16, No. 16 (in Chinese).

Meng, Q., K. Xiang, and X. Wu, 1999. The poultry genetic resources and the poultry breeding in China. China Poultry, 21(3):12-15 (in Chinese).

Ministry of Agriculture of China, 1995. Agriculture yearbook of China. Agricultural Publishing House of China, Beijing, China (in Chinese).

Ministry of Agriculture of China, 1996. Report for the development of agriculture in China. Agricultural Publishing House of China, Beijing, China (in Chinese).

Ministry of Agriculture, Nature Management and Fisheries of The Netherlands (1996), De Chinese pluimveesector. Den Haag, The Netherlands.

Mu, D., S. Huang, and Z. Xiao, 1998. Studies on the strategy for development of poultry industry in Guangdong province. Project report, <http://www.poultryinfo.com.cn/gdzlyj/>, Guangdong, China (in Chinese).

Mukherjee, T. K., 1990. Breeding and selection programs in developing countries. Pages 1049-1060 *in*: Poultry Breeding and Genetics. R. D. Crawford, ed. Elsevier, Amsterdam, The Netherlands.

Nei, M., and A. K. Roychoudhury, 1974. Sampling variances of heterozygosity and genetic distance. Genetics, 76:379-390.

Nardone, A., and F. Vafrè, 1999. Effects of changing production methods on quality of meat, milk and eggs. Livest. Prod. Sci. 59:165-182.

Olesen, I., A. F. Groen, and B. Gjerde, 1999. Definition of animal breeding goals for sustainable production systems. J. Anim. Sci. (accepted).

Pi, J., J. Du, J. Sheng, Z. Fu, and Z. Liang, 1999. Genetic analysis on egg production traits of Jinshui Silky fowl. China Poultry. 21(2):6-7 (in Chinese).

Punnett, R. C., 1933. Genetic studies in poultry, IX. The blue egg. J. Genetics 27:465-470.

Qiu, X., 1989. On the property and improvement of quality meat-chicken. Pages 8–13 *in*: Proceedings of the first Conference on Improvement and Production for Quality Chicken in China. China (in Chinese).

Qiu, X., 1996. China. Pages 215–237 *in*: Poultry of the World. L. Stromberg, ed. Silvio Mattacchione & Co., Ontario, Canada.

Qiu, X., E. Chen, and Y. Chen, 1989. Poultry breeds in China. Shanghai Scientific & Technical Publishers, Shanghai, China (in Chinese).

Roan, S.-W., and C.-L. Hu, 1997. Growth performance and carcass characteristics of Taiwan simulated native chickens. J. Chin. Soc. Anim. Sci. 26(2):163–176.

Sadjadi, M., J. A. Renden, F. H. Benoff and J. A. Harper, 1983. Effects of the blue shell allele (*O*) on egg quality and other economic traits in the chicken. Poultry Sci. 62:1717–1720.

Shen, C., 1996. Diversity of animal genetic resources and sutainable development of animal production in China. Animal Genetic Resources Information. Vol. 20:3–8. FAO, Rome, Italy.

Shen, X., and Y. Yun, 1999. Survey of Tunchong Snow chicken resources. China Poultry 21(2):8–9 (in Chinese).

Sheng, X., H. Han, and X. Chen, 1999. Lushi chickens. China Poultry 21(3):47 (in Chinese).

Siegel, P. B., A. Haberfeld, T. K. Mukherjee, L. C. Stallard, H. L. Marhs, N. B. Anthony, and E. A. Dunnington, 1992. Jungle fowl–domestic fowl relationships: a use of DNA fingerprinting. World's Poult. Sci. J. 48:147–155.

Simmons, R. W. III, and R. G. Somes, Jr., 1982. Physical characteristics of Araucana chicken eggs. Poultry Sci. 61:1777–1781.

Simmons, R. W. III, and R. G. Somes, Jr., 1985. Chemical characteristics of Araucana chicken eggs. Poultry Sci. 64:1264–1268.

Smith, J. R., Jr, 1990. Genetics of plumage, skin and eye pigmentation in chickens. Pages 109–167 *in*: Poultry Breeding and Genetics. R. D. Crawford, ed. Elsevier, Amsterdam, The Netherlands.

Somes, R. G., Jr., P. V. Francis, and J. T. Tlustohowicz, 1977. Protein and cholesterol contents of Araucana chicken eggs. Poultry Sci. 56:1636–1640.

Sørensen, P., 1997. The population of laying hens loses important genes: a case history. Animal Genetic Resources Information. Vol. 22:71–78. FAO, Rome, Italy.

State Statistical Bureau of China, 1997. China statistical yearbook. China Statistical Publishing House, Beijing, China.

Stromberg, S., 1996. Poultry of the World. Silvio Mattacchione & Co., Ontario, Canada.

Thompson, J. M., 1998. Meat quality. Vol. 25, Pages 147–148 *in*: Proceedings of the Sixth World Congress on Genetics Applied to Livestock Production. Armidale, NSW, Australia.

Tong, H., K. Wang, and K. Chen, 1997. The use of Xianju and Buff Baier chickens in breeding for high quality three-yellow meat-type chickens. Pages 170–173 *in*: Proceedings of the Eighth Conference of Chinese Poultry Science Association. Suzhou, China (in Chinese).

U.S. Department of Agriculture, 1998. Agriculture fact book. Washington, U.S.A.

Wang, B., and D. Xu, 1999. Chicken production in future China. China Poultry 21(1):1-2 (in Chinese).

Wang, K., H. Tong, S. Li, and K. Chen, 1997. The use of egg-type line in the crossbred of three-yellow chickens. Pages 165-169 *in*: Proceedings of the Eighth Conference of Chinese Poultry Science Association. Suzhou, China (in Chinese).

Watt Publishing Co., 1996. Watt poultry statistics yearbook 1996. Poultry International, Mt Morris, IL, USA.

Watt Publishing Co., 1997. Watt poultry statistics yearbook 1997. Poultry International, Mt Morris, IL, USA.

Wei, F., X. Huang, D. Li, Y. Liao, Z. Yang, and M. Liu, 1995. Selection of a dwarf line from Rock chickens. Pages 137-140 *in*: Proceedings of the Seventh Conference of Chinese Poultry Science Association. Hangzhou, China (in Chinese).

West, B., and B.-X. Zhou, 1989. Did chickens go north? New evidence for domestication. World's Poult. Sci. J. 45:205-218.

White, R. F., and H. L. Eastlick, 1953. The development of melanophores in the down feathers and skin of the Silkie fowl. Poultry Sci. 32:235-247.

Wright, S., 1978. Evolution and the genetics of populations. Volume 4: Variability within and among natural populations. The University of Chicago Press, Chicago, USA.

World Bank, 1999. Development data <http://www.worldbank.org/data/>, The World Bank, Washington, DC, USA.

Wu, C.,1998. On heterosis in crossbreeding for quality chickens. Pages 1-4 *in*: Proceedings of the Fifth Conference on Improvement and Production for Quality Chicken in China. Y. Feng and G. Wang, ed. Wuyishan, Fujian, China (in Chinese).

Wu, H., F. Huang, and L. Liu, 1998. Poultry production in Jiangxi province: projection to year 2000. China Poultry 20(3):42-44 (in Chinese).

Xiao, Z., M. Lin, L. Zhan, S. Li, and D. He, 1998. Selection of a new line of Xinhua chickens. Pages 71-76 *in*: Proceedings of the Fifth Conference on Improvement and Production for Quality Chicken in China. Y. Feng and G. Wang, ed. Wuyishan, Fujian, China (in Chinese).

Xiong, Y., B. Wen, C. Yang, and K. Bao, 1995. The production performance of a new line of feathering sexing from Lingnan three-yellow chickens. Pages 123-125 *in*: Proceedings of the Seventh Conference of Chinese Poultry Science Association. Hangzhou, China (in Chinese).

Xu, A., 1997. Studies on the nutrition requirements of native chickens. Poultry Industry Science and technology 13(7):11-13 (in Chinese).

Yan, H., 1998. The present and future of quality chicken industry in China. China Poultry, 20(8):3-5 (in Chinese).

Yang, C., and X. Jiang, 1989. The measurement of blue eggshell quality in Juiyuang chickens. China Poultry, 9(2): 16-17 (in Chinese).

Yang, C., B. Wen, K. Guo, D. Su, and G. Hu, 1995. The growth performance of different crosses with Lingnan three-yellow chickens. Pages 118–120 *in*: Proceedings of the Seventh Conference of Chinese Poultry Science Association. Hangzhou, China (in Chinese).

Yang, Z., and F. Zeng, 1998. Selection and crossbreeding for the norm-feathered black-boned chicken in Sichuan. Pages 12–15 *in*: Proceedings of the Fifth Conference on Improvement and Production for Quality Chicken in China. Y. Feng and G. Wang, ed. Wuyishan, Fujian, China (in Chinese).

Yu, W., and Y. He, 1993. A method to quantify the meat quality of three-yellow chickens. Pages 97–101 *in*: Proceedings of the Sixth Conference of Chinese Poultry Science Association. Beihai, China (in Chinese).

Zhang, D., and S. Yang, 1998. On meat qaulity in breeding for quality chickens in China. China Poultry, 20(9): 1-2 (in Chinese).

Zhang, T., Y. Tang, Y. Zhou, and Q. Feng, 1995a. The performance of crosses with Wuding Chickens. Pages 166–168 *in*: Proceedings of the Seventh Conference of Chinese Poultry Science Association. Hangzhou, China (in Chinese).

Zhang, T., Y. Tang, Y. Zhou, S. Wu, and H. Guan, 1991. Characteristics of Chahua chickens. Pages 121–123 *in*: Proceedings of the Fifth Conference of Chinese Poultry Science Association. Chengdu, China (in Chinese).

Zhang, T., P. Zhou, and B. Su, 1997a. Protein polymorphisms of local chicken breeds in Yunnan province, China. Pages 181–183 *in*: Proceedings of the Eighth Conference of Chinese Poultry Science Association. Shuzhou, China (in Chinese).

Zhang, X., and C. Huang, 1998. Survey of Chaoke chicken resources in Sichuan. Pages 86–89 *in*: Proceedings of the Fifth Conference on Improvement and Production for Quality Chicken in China. Y. Feng and G. Wang, ed. Wuyishan, Fujian, China (in Chinese).

Zhang, X., F. Huang, T. Geng, H. Zhou, K. Wang, and D. Zhao, 1998a. Analysis of genetic constitution of population in black-boned chicken breeds by randomly amplified polymorphic DNA technique. China Poultry 20 (5):1–2 (in Chinese).

Zhang, X., F. Huang, and Y. Su, 1995b. Crosses using Xianju and Gushi chickens with imported lines. Pages 176–178 *in*: Proceedings of the Seventh Conference of Chinese Poultry Science Association. Hangzhou, China (in Chinese).

Zhang, X., F. Huang, Y. Su, and D. Zhao, 1998b. The genetic pattern of feathering speed in some local chicken breeds in China. Pages 45–48 *in*: Proceedings of the Fifth Conference on Improvement and Production for Quality Chicken in China. Y. Feng and G. Wang, ed. Wuyishan, Fujian, China (in Chinese).

Zhang, X., F. Huang, Y. Su, K. Chen, and S. Li, 1997b. The productive performance of black-boned chickens with black plumage. Pages 187–190 *in*: Proceedings of the Eighth Conference of Chinese Poultry Science Association. Suzhou, China (in Chinese).

Zhang, X., Z. Liang, G. Chen, G. Yang, and C. Wu, 1998c. Genetic polymorphisms of quality chickens: I. Protein polymorphisms and analysis. Pages 57–60 *in*: Proceedings of the Fifth Conference on Improvement and Production for Quality Chicken in China. Y. Feng and G. Wang, ed. Wuyishan, Fujian, China (in Chinese).

Zhao, H., 1993. The present and the perspective of Shiqi-Za chickens in Guangdong province. Pages 87–89 *in*: Proceedings of the Sixth Conference of Chinese Poultry Science Association. Beihai, China (in Chinese).

Zhao, H., H. Zeng, X. Ou, and Q. Chen, 1997. Breeding for Kangdaer three-yellow chickens. Pages 149–151 *in*: Proceedings of the Eighth Conference of Chinese Poultry Science Association. Suzhou, China (in Chinese).

Zhou. Z., D. Su, K. Guo, C. Yang, and Y. Xiong, 1997. Measurement of shank length of three-yellow chickens. Pages 123–125 *in*: Proceedings of the Eighth Conference of Chinese Poultry Science Association. Suzhou, China (in Chinese).

Chapter 7

General Discussion

X. JIANG

Animal Breeding and Genetics Group, Wageningen Institute of Animal Sciences, Wageningen University, Wageningen, The Netherlands

There is a sound future for local breeds serving consumer demands for quality products, simultaneously serving the maintenance of domestic animal diversity. This future will be based on the long-term prevalence of low-input/low-output production systems in large parts of the world.

As described in Chapter 1 of this dissertation, the broiler breeding industry has been primarily shaped by the desire to reduce costs. Increasingly, cost reduction, quality improvement, versatility and ethics will be driving forces in a more balanced way. Cost reduction has been dealt with in respect of economic breeding goals and selection schemes, which has been described in Chapters 2, 3, 4 and 5. Aspects of quality improvement and versatility of products have been discussed in Chapter 6. With the changing market demand and the increasing ethical considerations for animal production and its products, more considerations have to be incorporated into the future broiler breeding programs. This general discussion is devoted to two topics: 1) breeding goals while changing perspectives, and 2) synergism between conservation and use of genetic resources.

BREEDING GOALS — CHANGING PERSPECTIVES

The Importance of Weighing Traits

Definition of breeding goals is an important aspect of animal breeding; in defining breeding goals, relative emphasis has to be put on animal traits in selecting males and females which will become parents of next generation of animals (Groen, 1989). In the selection index for multi-trait, the aggregate genotype is defined as a linear function of the breeding value for the component traits weighed by their (discounted) economic values (Hazel, 1943). The weighing factor of a trait should reflect the economic value of improvement of the trait for the organization that is responsible for the breeding program (Elsen *et al.*, 1986). Smith (1983) proved that the economic value is an important factor in determining the efficiency of index selection for multi-trait. Smith *et al.* (1983) also showed that the definition of breeding goals affected genetic changes.

Broiler breeding worldwide is improved by more advanced computerized statistical procedures (e.g., BLUP). Marker-assisted selection will soon be applied in breeding practice. New technologies, such as cloning and transgenics, will possibly be implemented in future breeding programs. Based on Harris and Newman (1994), economic breeding goal will remain pertinent, also when these new techniques become practical. The economic breeding goals specify which traits contribute in what degree to the relevant genetic variability that is the real object of selection. A formal definition of the breeding goals is a necessary foundation for designing genetic evaluation procedures, selection practice, and integrated animal breeding programs (Harris and Newman, 1994).

Henderson (1963) described the sub-index approach to derive selection indices (see also Hazel *et al.* 1994). The modification separated application of the selection index into two steps. The first step is prediction of individual breeding values for each trait included in the definition of aggregate genotype. The second step is application of the (relative) economic weights. Hazel *et al.* (1994) mentioned two advantages of this modification. It permits use of the most complex and accurate multi-trait BLUP techniques to estimate individual breeding values for each index trait, including adjustment for differing amounts of information, and it then allows the economic weights applied to vary with differing selection goals, depending upon how different breeds are used in a breeding system or the particular production and marketing system, without recalculating breeding values. Enhanced reproduction techniques (e.g., cloning) will increase the intensity of selection and possibly increase the rate of dissemination of genetic improvement. Application of marker-assisted selection may increase the rate of genetic improvement. Transgenics may give a different form of genetic improvement. However, recording, evaluation, expansion and dissemination will still be needed. Groen *et al.* (1997) stated that there is not justification to change the economic breeding goal for traits with detected QTL on DNA level. Harris and Newman (1994) concluded that also in the future, economic breeding goals will be relevant to facilitate decisions concerning modification of genetic improvement and production systems and for performing benefit-cost assessment.

Broader Perspectives

The essence of genetic improvement is to improve the efficiency of a production system: saving inputs of production factor per unit product and a change towards use of cheaper production factors. Saved production factors can either be used in the system where they are saved (and thus expand product output of this system) or can be transferred to another system (via the market) (Willer, 1967, cited by Groen *et al.*, 1997). The perspective taken in deriving economic values includes the interest of selection and the base of evaluation; differences between perspectives will lead to differences in economic values when the values of (saved) production factors differ between alternative use (Groen, 1989). Breeding for high input systems in the western and industrialized world only is not sufficient to serve the worldwide markets with breeding stocks, nor is it culturally and socially acceptable to simply transfer such high input systems to developing countries together with the breeding stock (Olesen *et al.*, 1999).

Hazel (1943) indicated that economic values for traits would vary with the particular locality or nature of the enterprise. Animal breeding has so far focused on cumulative shot-term genetic change, because breeding optimization has largely been based on market economy; many examples show that animal breeding has led to unwanted side effects, which are in conflict with sustainable agriculture (Rauw *et al.*, 1998; Olesen *et al.*, 1999). This results in worldwide demand for a broader definition of animal breeding goals and more emphasis on long-term genetic change that is based on sustainable systems. In broiler breeding industry, the same phenomenon is seen especially in recent years.

Since 1940s, great progress has been made in selection for broiler growth. Unfortunately, a related negative response has occurred with respect to animal adaptability and product quality (Chambers, 1990; Havenstein *et al.* 1994a and 1994b; Dunnington and Siegel, 1996; Rauw *et al.*, 1998). This unfavorable response tends to be a limiting factor for further improvement for growth from the viewpoint of physiological and economic balance. In addition, public awareness (e.g., human and animal welfare) also asks for this balance. The disruption of physiological homeostasis may in future represent significant physiological or economic barriers to continued improvements in growth performance (Emmerson, 1997). Some of these complications have been partially ameliorated through modified selection schemes but all will require greater emphasis in the future. Traits negatively associated with growth and feed conversion might someday represent physiological or economic limits to future progress. Albers (1998) calculated that it could take less than 20 years to reach the biological maximum for genetic progress in both broilers and layers. Genetic and nongenetic solution to these homeostatic concerns and a more integrated approach to genetic improvement will be required for historic genetic gains to be sustained in the future. Therefore, breeding organizations should develop new breeding strategies to deal with this situation (Albers, 1998).

Considering the biological maximum for broiler growth, and worldwide the increasing consumers' demand for sensory and technical quality of broiler meat, it might be a choice for broiler breeding organizations to change their emphasis. Among the driving forces of broiler breeding industry, the relative importance of quality improvement, product versatility and ethical considerations has been closer to that of cost reduction in 1990s, and the trend will continue in future (Ewart, 1993). With this worldwide new situation, broiler breeding industry should be well prepared. In Chapter 6 of this thesis, quality improvement and product versatility have been discussed with regard to the circumstances in China by making use of the local chicken breeds. However, more general considerations are necessary, especially for broader perspectives of definition of breeding goals.

Land (1981) noted that the perspectives of animal breeding might be affected by social changes, e.g., welfare legislation and ethical attitudes. More recently, definition of breeding goals for sustainable production systems was stressed, and broader perspectives of animal breeding goals were proposed. For each production system and in each environment there will be specific effects on the breeding goals; maintenance of variation among lines and breeds through diversification in breeding goals remains justified to serve various markets and environments and to deal with risk (Brascamp *et al.*, 1998). Amer *et al.* (1998) defined the existing animal breeding goals in developing world for two types of production system: subsistence production system and commercial production system. Definition of breeding goals was then proposed for these two production systems respectively based on sustainability.

Olesen *et al.* (1999) considered the impact of sustainable-animal-production elements on the definition of animal breeding goals. These elements include resource efficiency, profitability, productivity, environmental soundness, biodiversity, social viability and ethical aspects. They stressed the changing perspectives for animal production. High product quality is asked due to increased human welfare, and it is also associated with public concerns about the production system (e.g., animal welfare). Under low and intermediate current production levels, increased yields and efficiency will be more environmentally sustainable than extensive goals, but very intensive production systems rely on fossil fuels would also result in some ecological and economical risks. Where land is restricted, focus should be put on animals that can contribute to increase the farmers' production per hectare rather than on increased production per animal.

Methodology to Derive Broader Weights

For production efficiency, economic values are derived based on interests to maximize profit, to minimize costs per unit of product, or to maximize revenues/costs; three possibilities of the base of evaluation, which establish the size of the system considered in deriving economic values, are a fixed number of animals within the system, a fixed amount of input of a production factor into the systems, or a fixed amount of output of a product out of the system (Groen, 1989). The derivation of economic values based on production efficiency was illustrated by Groen *et al.* (1997).

However, for the abovementioned broader perspectives, other methods have to be used to derive (economic) weights; approaches only based on economic efficiency are no longer the sole relevant and feasible way, because the question is not merely an issue that can be economically addressed.

Non-objective and objective methods: Non-objective method does not derive economic values by direct calculation of influences of improvement of a trait on the increase in efficiency of the production system (Groen *et al.*, 1997). A major justification of an insufficient knowledge to model (all) relevant aspects involved. Selection index for desired or restricted gain is useful for this perspective. The main tool used in objective methods to derive economic values is modeling (Groen *et al.*, 1997). However, for the broader perspectives, modeling also needs to consider more aspects. The model for economic appraisal of traits related to animal welfare is being developed (see Groen *et al.*, 1997). Constructing such a model needs knowledge on economics and marketing principles, and actual values on required parameters that reflect the flexibility of the demand and supply curves for product. For traits with an intermediate optimum (e.g., part of meat quality traits such as ultimate pH), a method to derive marginal-income functions and to calculate economic values was derived by Hovenier *et al.* (1993).

Broader definition of trait value: Olesen *et al.* (1999) argued that the usual way to weigh traits by means of (discounted) economic values is not adequate; the ecological, social and ethical priorities can not be incorporated properly because it is not always possible to value these priorities. They suggested that benefits from improved resource efficiency as well as risks of foreseen and unforeseen negative consequences should be taken into account. Some negative consequences may be taken into consideration via genetic correlations. They proposed that the traits' values could be split in two parts: ethical values and economic values. The breeding goals were then defined accordingly. The total genetic gain is the sum of ethical genetic gain and economic genetic gain.

For the situation of (semi-) quality chicken breeding in China as described in Chapter 6, definition of breeding goals should follow a more systematic way. As breeding goals are dependent upon performance levels, market conditions, and production (or husbandry) systems, among other conditions (Jiang *et al.*, 1998), there are still many research topics that have to be done before a sound definition of breeding goals could be made. It has to be decided whether intensive, or extensive, or any other forms of production systems are proper for the (semi-) quality chicken production. Economic evaluations for (semi-) quality chicken production systems are needed based on systematic methods (e.g., Groen *et al.*, 1998; Jiang *et al.*, 1998; Jiang *et al.*, 1999). A formal investigation for the consumption tendency is also needed, especially to predict future consumption based on quantitative marketing analysis. According to the discussion in Chapter 6 of this dissertation, it is obvious that a further understanding of genetic distance among breeds, inheritance of specific traits and genetic parameters of performance traits is required for local chicken breeds although much work has been done up to now for a limited number of breeds. The genetic analysis for chicken meat quality needs to be carried out to determine how to set meat quality traits into breeding goals. In addition, considerations should also be made with regard to system level (animal, farm, sector, national or international level), and planning term (short-term, or long-term).

SYNERGISM BETWEEN THE CONSERVATION AND THE USE OF GENETIC RESOURCES

There is a worldwide competition among breeding organizations. The number of breeding organizations has been shrinking sharply, which resulted in the existing globally operating breeding organizations that use the leading techniques, breeding scientists, and facilities. They are making genetic improvements on production efficiency year by year. Their products are worldwide excellent ones in this respect. These breeding organizations have done satisfactorily on the production efficiency, but they have ignored the versatility of consumers' demand worldwide. Although this diversity in product demand has been noted by people in academic institutions in western countries (e.g., Horst, 1998), only few western breeding organizations sometimes tried to make response to this (e.g., commercial laying chickens for tinted eggs for Chinese market). However, in the next century worldwide consumers demand high quality products. Quality aspects are considered to be aspects of sensory quality including tenderness, color, flavor and taste, and nutritive value (Mulder and Fletcher, 1998).

The broiler breeding strategy in China should rely on the use of local breeds, and aims at breeding for (semi-) quality chickens. This is the way to produce the custom-tailored birds and to make use of local animal genetic resources. In doing this, further work should be based on the following aspects (apart from definition of breeding goals):

(1) Breeding programs for (semi-) quality chickens have to be adjusted for production systems and production conditions. Decision needs to be made on whether purebreeding or crossbreeding being adopted. In crossbreeding, whether or not imported (dam) lines are to be used in the breeding programs, is dependent upon the consideration on breeding

for efficiency or quality. Besides, in crossbreeding systems, both purebred and crossbred information can be used to maximize genetic improvement in performance like reproduction traits (e.g., Jiang and Groen, 1999).

(2) Feed and feeding are also among the factors that influence the meat quality, apart from the production efficiency. Currently there is a lack of knowledge on nutritional aspects of (semi-) quality chickens, such as nutrition requirements. Feed evaluation using local feed resources (e.g., those can not be used as food for human population directly) for (semi-) quality chickens is especially relevant for a sustainable production system. Also, there is a lack of (detailed) information on optimum management of (semi-) quality chicken production, which causes that commercial grower and multiplier producers do not have a "guide" in the process of production. Breeding organizations need to take into consideration on these topics when making breeding programs.

The importance of domestic chickens, based on FAO (1998a), comes from their ability to convert (by-product) feeds into high-quality human food and from their role as locally available source of food and other products to suit local community needs. Domestic chickens (or poultry) are of considerable importance for food security in China.

For the increasing human population in China, food security is a very serious problem to be dealt with. Food security is often referred to the products of agriculture (e.g., grains). However, according to Liu and Ge (1997), animal production can play an important and indispensable role in this respect by means of high-nutritive-quality animal products (e.g., based on protein quality) and this role can not be replaced by the consumption of grains by human population in China, especially in rural areas where people consume less animal products than those in urban districts. Their calculations showed that increasing poultry production in China and consuming more poultry products can be a more sustainable way to promote the living status of the rural population than feeding the rural population more grains only. Liu and Ge (1997) stated that western type of poultry production (including the crossbreds from western breeding organizations) is the best choice in dealing with the food security in China, owing to its high production efficiency (e.g., with regard to the conversion rate of feed into poultry meat and table eggs). However, it is argued here that at least this is not the only efficient way, due to 1) the feed for chickens of western crossbreds have to be completely (100%) from formulated feed (Ma, 1998) that need grains as main ingredients; 2) as the living standard promoted, people tend to consume more higher quality chickens than before. Based on this consideration, the low-input/low-output breeds (local and un-industrialized chicken breeds) can be an alternative way (see Oldenbroek, 1999). Besides, the production with local breeds can provide the market with a versatility of animal products. This is important not only for developing countries like China where the traditional consumption pattern has been formed for a long history, but also for developed world where it is observed that an increase in income leads to rise in the demands for specialized foods generated by a diversification of animal production systems (Oldenbroek, 1999). According to Chai (1993), the average amount of grain per capita in China is lower than the world average. The increase in grain production can not keep pace with the increase in human population. It is necessary to raise local chicken breeds on coarse feed conditions with free range husbandry, so that the chickens will find feed from the natural resources. As it is described in Chapter 6, local chicken breeds in China have adapted to the local coarse conditions. In fact, this husbandry system also provides *in situ* conservation. Consequently, synergism exists between conservation and use of the genetic resources.

The conservation of animal genetic resources, like the protection of monuments, is a traditional activity of mankind because its object is a product of human activity and creativity. However, the professional preservation of domestic is a relatively young activity (Alderson and Bodó, 1992), and the first Global Technical Consultation on Genetic Resources was held by FAO in 1980 (Oldenbroek, 1999). FAO is carrying out a global basis to reinforce the view that animal genetic resources are an integral part of global biological diversity and further that use and conservation of animal genetic resources are inseparable issues. The utilization of appropriate farm animal resources to achieve and maintain sustainable production systems which are capable of responding to human needs, is necessary to national and global food security (FAO, 1998a; Hammond, 1998). One of the actions based on Global Strategy for the Management of Farm Animal Genetic Resources is "developing and making better use of animal genetic resources adapted to the world's major medium-input and low-input production environments, so as to enable their agricultural systems to intensify sustainably" (FAO, 1998b). In making use of local chicken breeds, genetic improvement is always carried out to meet the needs of producers. In making such breeding programs, traits proposed for selection should be accurately evaluated for their genetic correlations with those that determine the conservation value of the breed, in order to avoid the deterioration of its conservation value; selection schemes should take into consideration the maintenance of genetic variation within the breed and risk associated with a high rate of inbreeding (Gandini and Oldenbroek, 1999). These considerations are relevant to the breeding for (semi-) quality chickens in China, especially when local breeds used in the breeding programs are those already well adapted to some specific circumstances as described in Chapter 6. The existence of a local chicken breed is dependent upon its ability to adapt to its natural environment and upon its economic value as well.

REFERENCES

Albers, G. A. A., 1998. Future trends in poultry breeding. Pages 16–20 *in*: Proceedings of the 10th European Poultry Conference. Jerusalem, Israel.

Alderson, L., and I. Bodó, 1992. Genetic conservation of domestic livestock. Vol. 2. C.A.B International, Wallingford, UK.

Amer, P. R., N. Mpofu, and O. Bondoc, 1998. Definition of breeding objectives for sustainable production systems. Vol. 28, Pages 97–104 *in*: Proceedings of the Sixth World Congress on Genetics Applied to Livestock Production. Armidale, NSW, Australia.

Brascamp, E. W., A. F. Groen, I. J. M. de Boer, and H. Udo, 1998. The effect of environmental factors on breeding goals. Vol. 27, Pages 129–136 *in*: Proceedings of the Sixth World Congress on Genetics Applied to Livestock Production. Armidale, NSW, Australia.

Chai, C. K., 1993. Developing the native pig breeds of China. Pig News and Information 14(1):27N–30N.

Chambers, J. R., 1990. Genetics of growth and meat production in chickens. Pages 599–643 *in*: Poultry Breeding and Genetics. R. D. Crawford, ed. Elsevier, Amsterdam, The Netherlands.

Dunnington, E. A., and P. B. Siegel, 1996. Long-term divergent selection for eight-week body weight in White Plymouth Rock chickens. Poultry Sci. 75:1168–1179.

Elsen, J. M., B. Bibé, E. Landais, and G. Ricordeau, 1986. Twenty remarks on economic evaluation of selection goals. Vol. XII, Pages 345–354 *in*: Proceedings of the Third World Congress on Genetics Applied to Livestock Production. Lincoln, NE, USA.

Emmerson, D. A., 1997. Commercial approaches to genetic selection for growth and feed conversion in domestic poultry. Poultry Sci. 76:1121–1125.

Ewart, J., 1993. Evolution of genetic selection techniques and their application in the next decade. Br. Poult. Sci. 34:3–10.

FAO, 1998a. Primary guidelines for development of national farm animal genetic resources management plans: domestic animal diversity information system. FAO, Rome, Italy.

FAO, 1998b. Secondary guidelines for development of national farm animal genetic resources management plans: management of small populations at risk. FAO, Rome, Italy.

Gandini, G. C., and J. K. Oldenbroek, 1999. Choosing the conservation strategy. Pages 11–31 *in*: Genebanks and the Conservation of Farm Animal Genetic Resources. J. K. Oldenbroek, ed. DLO Institute for Animal Science and Health, Lelystad, The Netherlands.

Groen, A. F., 1989. Cattle breeding goals and production circumstances. Ph.D. Thesis. Department of Animal Breeding, Wageningen Agricultural University, Wageningen, The Netherlands.

Groen, A. F., X. Jiang, D. A. Emmerson, and A. Vereijken, 1998. A deterministic model for the evaluation of broiler production systems. Poultry Sci. 77:925-933.

Groen, A. F., T. Steine, J. J. Colleau, J. Petersen, J. Pribyl, and N. Reinsch, 1997. Economic values in dairy cattle breeding, with special reference to functional traits. Report of an EAAP-working group. Livest. Prod. Sci. 49:1-21.

Hammond, K., 1998. Development of the global strategy for the management of farm animal genetic resources. Vol. 28, Pages 43-50 *in*: Proceedings of the Sixth World Congress on Genetics Applied to Livestock Production. Armidale, NSW, Australia.

Harris, D. L., and S. Newman, 1994. Breeding for profit: synergism between genetic improvement and livestock production (a review). J. Anim. Sci. 72: 2178-2200.

Havenstein, G. B., P. R. Ferket, S. E. Scheideler, and B. T. Larson, 1994a. 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., P. R. Ferket, S. E. Scheideler, and D. V. Rives, 1994b. Carcass composition and yield of 1991 vs 1957 broilers when fed "typical" 1957 and 1991 broiler diets. Poultry Sci. 73:1795-1804.

Hazel, L. N., 1943. The genetic basis for constructing selection indexes. Genetics 28: 576-490.

Hazel, L. N., G. E. Dickerson, and A. E. Freeman, 1994. The selection index — then, now and for the future. J. Dairy Sci. 77:3236-3251.

Henderson, C. R., 1963. Selection index and expected genetic advance. Pages 141-163 *in*: Proceedings of Statistical Genetics and Plant Breeding. W. D. Hanson and H. F. Robinson ed. NAS-NRC Publication 982, Washington, DC, USA.

Horst, P., 1998. Breeding possibilities in hot climates with special reference to tropical countries. Pages 71-76 *in*: Proceedings of the 10th European Poultry Conference. Jerusalem, Israel.

Hovenier, R., E. W. Brascamp, E. Kanis, J. H. J. Van der Werf, and A. P. A. M. Wassenberg, 1993. Economic values of optimum traits: the example of meat quality in pigs. J. Anim. Sci. 71:1429-1433.

Jiang, X., and A. F. Groen, 1999. Combined crossbred and purebred selection for reproduction traits in a broiler dam line. J. Anim. Breed. Genet. 116:111-125.

Jiang, X., A. F. Groen, and E. W. Brascamp, 1998. Economic values in broiler breeding. Poultry Sci. 77:934-943.

Jiang, X., A. F. Groen, and E. W. Brascamp, 1999. Discounted expressions of traits in broiler breeding programs. Poultry Sci. 78:307-316.

Land, R. B., 1981. An alternative philosophy for livestock breeding. Livest. Prod. Sci. 8:95-99.

Liu, S., and X. Ge, 1997. The significance of poultry industry for agricultural development in China. Poultry Industry Science and Technology 13(9):4-7 (in Chinese).

Ma, C., 1998. Prediction for poultry meat production and consumption in China in year 2010. Guide to Chinese Poultry, Vol. 15, No. 1 (in Chinese).

Mulder, R. W. A. W., and D. L. Fletcher, 1998. Poultry meat science towards the 21st century. Pages 121-125 *in*: Proceedings of the 10th European Poultry Conference. Jerusalem, Israel.

Oldenbroek, J. K., 1999. Introduction. Pages 1-9 *in*: Genebanks and the Conservation of Farm Animal Genetic Resources. J. K. Oldenbroek, ed. DLO Institute for Animal Science and Health, Lelystad, The Netherlands.

Olesen, I., A. F. Groen, and B. Gjerde, 1999. Definition of animal breeding goals for sustainable production systems. J. Anim. Sci. (accepted).

Rauw, W. M., E. Kanis, E. N. Noordhuizen-Stassen, and F. J. Grommers, 1998. Undesirable side effects of selection for high production efficiency in farm animals: a review. Livest. Prod. Sci. 56:15-33.

Smith, C., 1983. Effects of changes in economic weights on the efficiency of index selection. J. Anim. Sci. 56:1057-1064.

Smith, C., G. D. Dickson, M. W. Tess, and G. L. Bennett, 1983. Expected relative response to selection for alternative measures of life cycle economic efficiency of pork production. J. Anim. Sci. 56:1306-1314.

Summary

In the last three score years, broiler breeding has made tremendous contribution to food security through a dramatic genetic improvement in performance of chickens. There are four major driving forces behind this progress: cost reduction, quality improvement, product versatility and ethical considerations. The balance of these driving forces has been changing continuously, and for some time periods clear accents were put on one or two forces. It is expected that in the future all of the four driving forces will play a more equivalent role in broiler breeding industry. Based on this expectation, this dissertation considered three aspects of broiler breeding: definition of breeding goals, selection schemes for specialized lines, and the usefulness of local chicken breeds for food security and quality in China.

Breeding Goal

The breeding goal defines the direction of a technological development, i.e., relative improvement of genetic merit for different performance traits. Economic values are main factors in defining the breeding goals. The economic value of a trait expresses the extent to which improvement of genetic merit of a trait can contribute to an improvement of economic efficiency of animal production systems. Only few sets of economic values in poultry breeding have been presented in the scientific literature.

In Chapter 2, a deterministic model for the economic evaluation of broiler production and the derivation of economic values in broiler breeding was developed and tested. The model distinguished four production stages:

- multiplier breeder,
- hatchery,
- commercial grower, and
- processor.

Quantity of product output for the system was fixed by a predetermined amount of kilogram carcass of final product broilers finished by the commercial grower. The model calculated costs and revenues for different participants of broiler production system, and can be used to analyze the economic status of broiler enterprise. Economic values were derived considering influences of changes in genetic merit for performance traits on profitability or costs price, for integrated and nonintegrated production systems. Exogenous parameters are easily changeable in order to calculate profitability and cost price for different production levels or production circumstances. By changing exogenous

parameters, the model can also be used to analyze profitability or derive economic values for other meat-type poultry, such as turkey.

Chapter 3 reports on derived economic values in broiler breeding and determined their relationship with production circumstances. Nonintegrated and integrated broiler production systems were studied. The difference between these originates from different definitions of cost components and scaling aspects. The Dutch broiler performance data and prices were input into the model as the representative situation. For the nonintegrated system, economic values were derived, expressed as Dutch guilders (Dfl) per unit of product, where the unit of product depends on the stage of the production system (an egg for the multiplier breeder, a day-old chick for the hatchery, and a marketable broiler for both commercial grower and the processor). For the integrated system, economic values were expressed as Dfl.marketable broiler^{-1}.unit^{-1}. Resulting levels of economic values were illustrated by showing underlying cost or profit changes in the production system. Economic values of traits in the integrated system were also derived for situations where technical parameters or prices of production factors were changed (20% increase or decrease). A general conclusion from these sensitivity analyses is that the economic values are dependent upon production levels, product prices and feed prices; there are both linear and nonlinear relationships between economic values and production circumstances.

In Chapter 4, a systematic design for the application of discounted gene flow methodology to derive cumulative discounted expressions (*cde*) for production and reproduction traits in broiler breeding was developed. The commercially grown broiler usually is a crossbred from specialized sire and dam lines. The position of a purebred line in the crossbreeding system influences its genetic contribution to expression of productive and reproductive performance at different stages of the production column and, thus, influences the breeding goal for a given line. In broiler breeding, *cde* should be considered to define breeding goals for multi-trait selection. Factors considered as influencing the magnitude of *cde* were

- crossbreeding system (two-way, three-way and four-way cross),
- selection scheme (with and without progeny testing and intensity of selection),
- selection path,
- trait (production at commercial stage and reproduction at either nucleus or multiplier stage),
- interest rate, and
- time horizon for evaluation.

Performance data from a commercial breeding stock were applied in the analysis. Results indicated that levels of *cde* were significantly affected by all factors studied. The more pure lines were included in the crossbreeding system, the lower the *cde* for a particular selection path. However, the summation of all selection paths did not differ much among crossbreeding systems. Progeny testing decreased *cde* by increasing generation intervals. *cde* for reproduction traits were higher than those for production traits mainly as a result of earlier expression of reproduction traits.

Selection Schemes

Chapter 5 defines a breeding goal and a realistic scheme for the application of combined crossbred and purebred selection (CCPS) in a specialized dam line of broiler and appraised the relative value of purebred and crossbred performance information in such a realistic scheme. It was studied to what extent the application of CCPS will improve genetic response when the breeding goal aims at improving both purebred and crossbred performance at different stages of broiler production. A three-way crossbreeding system was assumed. The breeding goal was defined based on economic values and cumulative discounted expression of hatching egg number. Two selection procedures were proposed,

- with shortened generation interval (30.5 to 32.1 wk of age, SGI), and
- with normal generation interval (47.3 to 49.1 wk of age, NGI).

Results showed that in a realistic scheme, increasing the number of crossbred offspring always resulted in additional genetic gain over pure line selection. Selection procedure SGI resulted in higher genetic gains than NGI, due to shorter generation interval. The effect of family structures and genetic parameters on the efficiency of CCPS were evaluated. It was concluded that including crossbred information gives an increase in genetic gain, but the efficiency of CCPS is dependent on selection procedures, family structures and genetic parameters.

Local Breeds for China

The abovementioned studies in this dissertation have mainly dealt with cost reduction aspect in broiler breeding. However, more is required for future broiler breeding. That is quality and versatility of products, and ethical consideration (e.g., welfare). Besides, different parts of the world have different market demand for broiler products. Therefore,

this dissertation considered a more specific situation in China. Chapter 6 illustrates the origin and formation of the local breeds in relation to ecological, economic and social circumstances. A general description was given for representative local chicken breeds. Economically important characteristics, e.g., three-yellow and black-boned, were described. The quality chickens were defined as those final products from purebred of local breeds, and semi-quality chickens were those from crossbred of local breeds with specialized broiler (sire or dam) lines from western breeding organizations. The present status of the chicken production and the market in China, in comparison with the western countries, was reviewed, indicating that there is large market demand for (semi-) quality chickens in the present and future China. Breeding for (semi-) quality chickens stresses the sensory quality of chicken meat. The present status of breeding for (semi-) quality chickens with the local breeds was illustrated, including breeding goals and the existing breeding programs. The potential role of local breeds in breeding programs in China was discussed in relation to both providing higher quality (than commercial hybrid broilers) of chicken meat for the local market and meeting the objectives of genetic resource conservation. Besides, further research topics on breeding for (semi-) quality chickens were suggested. It was concluded that, given the fast change in markets in and outside of China, and the rapid shrink of animal genetic diversity in the world, the local chicken breeds can make considerable contributions to food security and food quality in China and in the rest of the world as well.

Finally in Chapter 7, the general discussion considered breeding goals while changing perspectives. Synergism between conservation and use of genetic resources was illustrated. Ethical considerations for broiler breeding industry were also addressed in this chapter.

Samenvatting

Gedurende de laatste zestig jaar heeft de geïndustrialiseerde fokkerij van vleeskippen (*broilers*) een belangrijke bijdrage geleverd aan de voedselvoorziening; door genetische verbetering is een enorme vooruitgang in de prestaties van de dieren gerealiseerd. Drijvende kracht achter de gerealiseerde vooruitgang is het streven naar kostprijsreductie, kwaliteitsverbetering, meer produktflexibiliteit en naar een produkt dat ethisch aanvaardbaar is. De balans tussen deze aspecten is in de loop van de tijd voortdurend aan verandering onderhevig geweest en voor bepaalde perioden lagen er duidelijke accenten op één of twee van de aspecten. Voor de toekomst wordt verwacht dat de vier aspecten een meer gelijkwaardige rol zullen spelen in de fokkerij van *broilers*. Vanuit deze visie gaat dit proefschrift in op een drietal aspecten van de *broiler*-fokkerij: fokdoeldefinitie, selectieschema voor gespecialiseerde ouderlijnen en het belang van locale kippenrassen voor de voedselvoorziening in China.

Fokdoel

Het fokdoel definieert de beoogde richting van een technologische ontwikkeling, i.e., de relatieve verbetering van de genetische aanleg voor de verschillende diereigenschappen. De zogenaamde 'economische waarden' zijn hierbij belangrijke factoren. De economische waarde van een kenmerk brengt tot uitdrukking in welke mate een verbetering van de genetische aanleg van de eigenschap kan bijdragen aan de vooruitgang in economische efficiëntie van dierlijke produktiesystemen. De wetenschappelijke literatuur geeft maar weinig informatie over economische waarden voor de definitie van fokdoelen in de pluimveefokkerij.

In Hoofdstuk 2 wordt een deterministisch simulatiemodel beschreven en getest. Dit model kan gebruikt worden voor de economische evaluatie van een *broiler*produktiesysteem en het berekenen van economische waarden van genetische verbetering van diereigenschappen. Het model onderscheidt vier produktiefasen:

- vermeerdering,
- broederij,
- vleeskuikenhouderij en
- slachterij.

De totale produktieomvang van het systeem wordt vooraf vastgesteld aan de hand van het aantal kilogrammen karkas van de vleeskuikens afgeleverd door de mesterij. Het model berekent vervolgens de kosten en opbrengsten in de verschillende produktiefasen van het systeem, en analyseert de economische efficiëntie van produktie (i.e., winstmarges en kostprijzen) voor systemen met geïntegreerde en niet-geïntegreerde produktiefasen. Economische waarden worden berekend door het effect van kleine veranderingen in de genetische aanleg voor diereigenschappen op de winstmarges en de kostprijzen te bepalen.

Het model is flexibel; door wijzigingen in externe modelparameters kunnen winstmarges, kostprijzen en economische waarden uitgerekend worden voor diverse produktieniveaus en –omstandigheden (i.e., marktprijzen voor produkten en produktiefactoren). Door wijzigingen in externe parameters kan het model ook geschikt gemaakt worden voor de analyse van andere pluimveesectoren gericht op vleesproduktie, zoals kalkoenen.

Hoofdstuk 3 geeft de resultaten van de berekende economische waarden in de *broiler*produktiesystemen voor Nederlandse produktie-omstandigheden. Een gevoeligheidsanalyse illustreert de afhankelijkheid van economische waarden voor veranderingen in produktie-omstandigheden. Voor een beter begrip van de gevoeligheden worden de uiteindelijk gevonden economische waarden uitgesplitst in achterliggende componenten van (meer)kosten en (meer)opbrengsten. Verschillen in economische waarden tussen systemen met en zonder integratie van produktiefasen komen voort uit verschillen in definities van kostencomponenten en schalingseffecten. Bij niet-geïntegreerde produktiefasen worden economische waarden uitgedrukt in guldens per kilogram produkt voor die fase (per ei voor de vermeerderaar, per eendagskuiken voor de broederij, per afgeleverd vleeskuiken voor de vleeskuikenhouderij en de slachterij). Bij een volledige integratie van alle produktiefasen worden economische waarden uitgedrukt per afgeleverd vleeskuiken. De algemene conclusie van de gevoeligheidsanalyse is dat economische waarden in belangrijke mate afhangen van aangenomen prijzen voor vleesprodukten en voor voer; de relaties kunnen zowel lineair als niet-lineair zijn.

Hoofdstuk 4 beschrijft een systematische benadering voor de toepassing van de zogenaamde '*gene flow* methode' voor de berekening van 'cumulatieve, verdisconteerde expressies' (*cde*) in de *broiler*-fokkerij. Doorgaans zijn de *broilers* in de vleeskuikenhouderij kruisingsprodukten van ouderlijnen. Deze ouderlijnen zijn gespecialiseerde vader- en moederlijnen; geselecteerd op respectievelijk uitstekende produktie-eigenschappen (als groei) danwel vruchtbaarheids-eigenschappen (als aantal eieren). Het specifieke gebruik van een ouderlijn in het kruisingsschema beïnvloedt de mate waarin de genetische eigenschappen van die ouderlijn ook daadwerkelijk bijdragen aan de expressie van produktie- en vruchtbaarheids-eigenschappen van de dieren in de verschillende fasen van het systeem. En daarmee beïnvloedt het specifieke gebruik van een ouderlijn het fokdoel voor die ouderlijn – de *cde* brengen die invloed tot uitdrukking.

In dit hoofdstuk worden *cde* berekend voor Nederlandse produktie-omstandigheden en commerciële produktieniveaus als basissituatie. Uitkomsten zijn getoetst op afhankelijkheid van

- het kruisingsschema (twee-weg-, drie-weg- of vier-weg-kruisingsschema, met respectievelijk twee, drie of vier ouderlijnen achter het gekruiste vleeskuiken),
- het selectieschema (met en zonder nakomelingentoets, en met verschillende intensiteiten van selectie van ouderdieren),
- het selectiepad,
- de diereigenschap (groei van het vleeskuiken of aantal eieren van de hen in de vermeerdering),
- het rentepercentage, en
- de tijdsperiode waarover de toekomstige genetische verbetering tot expressie komt.

De resultaten van deze toetsing geven aan dat de *cde* sterk afhankelijk zijn van elk van deze factoren. Des te hoger het aantal ouderlijnen, des te lager de *cde* voor elke lijn; echter, de som van de cde's over lijnen is nagenoeg constant. Toepassing van nakomelingenonderzoek verlengt de generatie-intervallen en verlaagt daarmee de *cde*. De gevonden cde voor reproduktie-eigenschappen zijn hoger dan die voor produktie-eigenschappen, voornamelijk als gevolg van het feit dat reproduktie-eigenschappen in de eerdere fasen van het produktiesysteem tot expressie komen.

Selectie-schema

De verschillende fasen in de *broiler*-produktiesystemen maken gebruik van verschillende typen dieren: (zuivere) ouderlijndieren en gekruiste dieren. Eigenschappen van deze verschillende typen dieren zijn niet per definitie aan elkaar gelijk te stellen; als een haan zuivere ouderlijn-dochters geeft die zeer hoge eiproduktie hebben, dan is niet per definitie de eiproduktie van gekruiste dochters van deze haan ook zeer hoog. Bovendien is het zo dat het belang van verbetering van eiproduktie van zuivere en gekruiste dochters anders ligt, simpel doordat een haan doorgaans meer gekruiste dan zuivere dochters kan hebben. In hoofdstuk 5 wordt gekeken naar de genetische vooruitgang van een selectie-schema dat gebruikt maakt van informatie over de prestaties van zowel (zuivere) ouderlijn dieren als informatie over de prestaties van gekruiste dieren in het produktiesysteem (*combined crossbred and purebred selection, CCPS*). In hoofdstuk 5 wordt een fokdoel gedefinieerd voor een selectie-schema dat gericht is op genetische verbetering van zowel zuivere als gekruiste dieren, en wordt een realistisch selectie-schema voor CCPS ontworpen, uitgaande van een drie-weg kruising. Het fokdoel wordt gedefinieerd op basis van economische waarden en *cde*'s voor aantal geproduceerde eieren per zuivere hen en per gekruiste hen. Het voorgesteld selectie-schema kent twee varianten:

- met een verkort generatie-interval (30.5 tot 32.1 weken leeftijd, *SGI*) en
- met een normaal generatie-interval (47.3 tot 49.1 weken leeftijd, *NGI*).

De resultaten van de studie laten zien, dat in een dergelijke schema een vergroting van de informatie van gekruiste nakomelingen (meer dochters met prestatie-gegevens) altijd leidt tot extra genetische vooruitgang ten opzichte van selectie op basis van uitsluitend informatie van zuivere nakomelingen. De variant *SGI* geeft meer genetische vooruitgang dan *NGI*, vanwege de verkorting van het generatie-interval (een snellere verspreiding van superieure genen). Ook het effect van familiestructuur in de informatie over prestaties van nakomelingen en het effect van verschillende genetische parameters is in dit hoofdstuk bekeken. De algemene conclusie is dat het meenemen van informatie over gekruiste nakomelingen altijd een hoge genetische vooruitgang geeft, maar de te behalen winst is afhankelijk van aannames ten aanzien van het generatie-interval, de familie-structuur en de genetische parameters.

Lokale Rassen voor China

De studies beschreven in de voorgaande hoofdstukken van dit proefschrift gaan met name uit van kostprijsreductie als drijvende kracht achter genetische verbetering. De toekomst vraagt echter om een fokdoeldefinitie, een afweging van het belang van selectie op diverse eigenschappen vanuit een breder perspectief met aandacht voor kwaliteitsverbetering, flexibiliteit en ethische overwegingen (bijvoorbeeld ten aanzien dierwelzijn). Daar komt bij, dat verschillende delen van de wereld verschillende marktvragen voor pluimveeprodukten kennen. Daarom wordt in dit proefschrift ook specifiek ingegaan op de situatie van de pluimveeproduktie in China. In Hoofdstuk 6 wordt allereerst ingegaan op de oorsprong en de ontstaansgeschiedenis van de lokale rassen, in relatie tot ecologische, economische en sociale omstandigheden. Daarna wordt een algemene beschrijving van een aantal representatieve lokale rassen gegeven. Belangrijke eigenschappen van lokale rassen, als 'drievoudig-geel' (*three-yellow*) en 'zwart-bot' (*black-boned*) worden beschreven. De zogenaamde 'kwaliteits' kip wordt gedefinieerd als een vleeskuiken van zuivere lokale rassen, en de 'semi-kwaliteits' kip is een kruising van een lokaal ras met een gespecialiseerde, westerse ouderlijn. Uit een vergelijking van produktie- en marktcijfers voor China met die van westerse landen blijkt, dat er in China een grote, in de toekomst verder groeiende vraag is naar kwaliteits en semi-kwaliteits kippen. De fokkerij zal hierop moeten inspelen door aandacht voor handhaving en zomogelijk verbetering van de kwaliteitseigenschappen van pluimveevlees.

De huidige stand van zaken in China met betrekking tot de fokkerij en produktie van (semi-)kwaliteits kippen is beschreven. De mogelijke rol van lokale rassen in een fokprogramma wordt bediscussieerd vanuit de vraag naar kwaliteits vlees en vanuit de wens tot behoud van genetische diversiteit. Suggesties worden gegeven voor onderzoeksvragen relevant voor het opzetten van selectieschemas voor (semi-)kwaliteits kippen.

Algemene conclusie is dat, gegeven de snelle veranderingen in de marktvraag en de snelle achteruitgang in genetische diversiteit, de lokale rassen een belangrijke bijdrage kunnen leveren aan de voedselvoorziening en voedselkwaliteitsverbetering in China, en ook wereldwijd.

Tot slot wordt in Hoofdstuk 7 in de algemene discussie met name ingegaan op

- de veranderingen in fokdoeldefinitie die gepaard gaan met een verbreding van het perspectief op een meer gebalanceerde invloed van kostprijsreductie, kwaliteitsverbetering, flexibiliteit en ethische overwegingen, en
- de synergie tussen het bewaren en het gebruik van genetische bronnen.

List of Publications

1. Jiang, X., X. Qiu, and F. Zeng, 1986. Analysis of crossbreeding for meat-type ducks with Partridge Sichuan and several breeds *J. Sichuan Agricultural University*, 4(1):87-94 (in Chinese).
2. Jiang, X., F. Zeng, L. Wang, and X. Qiu, 1987. The growth at early stage for several duck breeds and their crosses. *China Poultry*, Issue No.2 (in Chinese).
3. Jiang, X., F. Zeng, and X. Qiu, 1988. The growth and carcass characteristics of crosses between Partridge Sichuan ducks and several meat-type breeds. Page 170 in: *Proceedings of the Satellite Conference of the 18th World's Poultry Congress*. Beijing, China
4. Jiang, X., F. Zeng, L. Wang, and X. Qiu, 1988. Analyses of growths of several duck breeds and their crosses in the condition of nomadizing in paddy fields. Page 171 in: *Proceedings of the Satellite Conference of the 18th World's Poultry Congress*. Beijing, China.
5. Jiang, X., C. Luo, and C. Yang, 1989. Inheritance of shortened legs in Miyi chickens. *China Poultry*, Issue No.5 (in Chinese).
6. Yang, C., and X. Jiang, 1989. The measurement of blue eggshell quality in Jiuyuan chickens. *China Poultry*, Issue No.2 (in Chinese).
7. Jiang, X., C. Luo, C. Yang, J. Chen, and B. Wang, 1990. The growth and carcass performance of Jinyang and Miyi chickens. *J. Sichuan Animal Sciences and Veterinary*, Issue No.3 (in Chinese).
8. Jiang, X., 1990. On the conservation of local chicken breeds in China. *China Poultry*, Issue No.4 (in Chinese).
9. Luo, C., X. Jiang, C. Yang, J. Chen, and B. Wang, 1990. Egg production and chemical compositions of eggs in Jiuyuan chickens. *J. Sichuan Animal Sciences and Veterinary*, Issue No.3 (in Chinese).
10. Jiang, X., 1991. On the strategy of breeding for laying chickens in China. *J. Sichuan Animal Sciences and Veterinary*, Issue No.1 (in Chinese).
11. Jiang, X., and C. Luo, 1991. Inheritance of blue eggshell in Jiuyuan chickens. *China Poultry*, Issue No.2 (in Chinese).
12. Jiang, X., H. Du, and C. Yang, 1991. Genetic study on blue eggshell in Jiuyuan chickens. Pages 23-24 in: *Proceedings of the Fifth Conference on Poultry Science in China*. Chengdu, China (in Chinese).
13. Jiang, X., C. Luo, C. Yang, J. Chen, and B. Wang, 1991. Inheritance of silky like feather in Jinyang chickens. Pages 142-143 in: *Proceedings of Fourth Sichuan Conference on genetics*. Chengdu, China (in Chinese).
14. Jiang, X., 1992. Studies on the blue eggshell in chickens, a review. *China Livestock and Wildlife Magazine* (Taiwan), Vol. 24, No. 10 (in Chinese).

15. Jiang, X., H. Du, and C. Yang, 1992. Effect of blue eggshell allele with different paternal origin on eggshell quality of crossbred chickens. Page 121 in: *Proceedings of the 19th World's Poultry Congress*, Vol. 3. Amsterdam, the Netherlands.
16. Du, H., X. Jiang, C. Luo, and C. Yang, 1992. The effect of rations with and without animal protein sources on the growth of pullets of parental laying stock. *J. Sichuan Animal Sciences and Veterinary*, Issue No. 2 (in Chinese).
17. Qu, Y., X. Jiang, and Q. Li, 1996. Performance of African ostrich in Chengdu area of China. *J. Sichuan Animal Sciences and Veterinary*, Issue No.3 (in Chinese).
18. Qu, Y., X. Jiang, and Q. Li, 1996. Analysis of factors affecting fertility and hatchability in parental laying stock of chicken. *J. Sichuan Animal Sciences and Veterinary*, Issue No.3 (in Chinese).
19. Jiang, X., 1997. Chapter eight: Broiler Production. In: Qiu, X (ed.), Chicken Production. Sichuan Scientific and Technical Publishing House, Chengdu, China (in Chinese).
20. Jiang, X., 1997. Chapter nine: Chicken Health. In: Qiu, X (ed.), Chicken Production. Sichuan Scientific and Technical Publishing House, Chengdu, China (in Chinese).
21. Groen, A. F., X. Jiang, D. A. Emmerson, and A. Vereijken, 1998. A deterministic model for the evaluation of broiler production systems. *Poultry Sci.* 77: 925-933.
22. Jiang, X., A. F. Groen, and E. W. Brascamp, 1998. Economic values in broiler breeding. *Poultry Sci.* 77: 934-943.
23. Jiang, X., and A. F. Groen, 1998. Economic evaluation of broiler production systems. Pages 755-758 in: *Proceedings of 10th European Poultry Conference*. Jerusalem, Israel.
24. Du, H., X. Jiang, and Q. Li, 1998. The effectiveness of vitamins for laying chickens: comparisons among products fròm different producers. *J. Sichuan Animal Sciences and Veterinary*, Issue No.1 (in Chinese).
25. Liu, G., X. Jiang, H. Du, and Q. Li, 1998. An incubation scheme adjusted for low ambient temperature. *J. Sichuan Animal Sciences and Veterinary*, Issue No.2 (in Chinese).
26. Jiang, X., A. F. Groen, and E. W. Brascamp, 1999. Discounted expressions of traits in broiler breeding programs. *Poultry Sci.* 78: 307-316.
27. Jiang, X., and A. F. Groen, 1999. Combined crossbred and purebred selection for reproduction traits in a broiler dam line. *J. Anim. Breed. Genet.* 116:111-125.
28. Jiang, X., 1999. Chapter one: Chicken Breeds. In: Jiang, X (ed.), Chicken Husbandry for Small Farms. Sichuan Scientific and Technical Publishing House, Chengdu, China (in Chinese).
29. Jiang, X., 1999. Chapter five: Broiler Husbandry. In: Jiang, X (ed.), Chicken Husbandry for Small Farms. Sichuan Scientific and Technical Publishing House, Chengdu, China (in Chinese).
30. Jiang, X., 1999. Poultry breeding goals in relation to production circumstances. *J. Sichuan Animal Sciences and Veterinary*, supplemental issue (in Chinese).

31. Li, Q., H. Du, X. Jiang, and G. Liu, 1999. Quantifying the weight loss of hatching eggs during incubation for different commercial chicken strains. *J. Sichuan Animal Sciences and Veterinary*, Issue No.1 (in Chinese).
32. Li, Q., H. Du, X. Jiang, and G. Liu, 1999. Analysis of embryo mortality for parental laying stock of chicken. *Poultry Production and Disease Control*, Issue No. 2 (in Chinese).

Curriculum Vatae

Xiaosong Jiang was born on 31 July 1962 in Sichuan, China. He started his university education in October 1978 at the department of Animal Sciences, Sichuan Agricultural University, China. He obtained his Bachelor's degree in July 1982. In September 1982 he was accepted at the same department for a three-year Master study on poultry breeding and genetics. He received his Master's degree in July 1985, with the thesis entitled Analysis of Crossbreeding for Partrige Sichuan Ducks with Several Meat-type Breeds. From July 1985 onwards, he is employed by Sichuan Research Institute of Animal Science and Veterinary (now Sichuan Academy of Animal Sciences), Chengdu, Sichuan, where he started as a research assistant. He was promoted as associate research fellow in July 1993. His research interest included studying on the characteristcs of the local chicken breeds and poultry production. Now he is the vice-chairman of the academic committee of the Academy and the director of the poultry section. From June 1994 to June 1995, he was a visiting researcher at the Animal Breeding and Genetics Group, Department of Animal Sciences, Wageningen University, The Netherlands. During this period he worked on the economic model for broiler production and defining the breeding goals under the guidence of Dr. Ab Groen. Since March 1997, he has been working on his Ph.D. research project in the same group.