Genetics of hatchability - egg quality from the perspective of a chick

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Hatchability is a complex age dependent trait. It comprises of several sub-traits which are susceptible to genetic and environmental factors arising from various sources. This review examines the genetic basis of egg production, fertility and egg quality traits and how these relate with hatchability. We suggest that both sire and dam genetic components are important in overall hatchability mostly because of the significance of these components on fertility and early embryo mortality. The dam that laid the egg was the main source of genetic variation in hatch of fertile eggs, suggesting a huge impact of egg quality traits. The genetic effects (paternal and maternal) were found to vary with the age of the flock.

Keywords: hatchability; heritability; egg quality

Introduction

The primary biological purpose of an egg is to provide an environment for the development of the embryo outside of the body of the hen post fertilization. For a single egg the final outcome is a simple binary response i.e. it either hatches or does not. However, the successful production of a chick is a complex process which requires the fulfilments of several conditions;

1) A hen must produce an egg – hatchability depends on genetic and environmental factors affecting laying ability of a dam
2) The egg must be fertilized – hatchability depends on successful mating between the dam and her mate (in naturally mated flocks) or insemination. Formation of a viable

embryo in this process is affected by genetic and environmental factors originating from both the hen and her mate.

3) The laid egg must be of good quality to provide a suitable environment for the developing embryo, which again seems to be primarily a function of dam's genotype and external environment during storage and incubation.
4) The chick must hatch – the ability of a matured chick to break out of the egg shell at hatching could be affected by the genotype of the embryo, the internal egg environment of egg and the environment to which the egg was exposed.

Objective

The objective of this study was to explore the genetic mechanism which controls the various factors affecting hatchability and examine how best to model the trait for the purpose of genetic evaluation and selection for improvement.

Egg production

Egg production is traditionally evaluated as a cumulative record up to a certain age. This approach ignores the fact that eggs are produced over a long period of time during which the laying hen and her mate age and are subjected to changing genetic and environmental factors. For example, Van Vleck and Doolittle (1964) observed that heritability of egg production estimated from sire and dam components differed between early and late stages of production. Ledur *et al.* (2000) revealed significant changes in additive genetic variance, Z-chromosome, and heterotic effects with age.

Various models have been used to analyse egg production in anticipation of changes in variance components as the laying bird ages. For example, cumulative egg production in each month of lay during production has been considered as different traits and analysed with a multi-trait model (Preisinger and Savaş, 1997; Savaş *et al*., 1998; Anang *et al*., 2000). When considered as repeated measures of the same traits over time, it could be analysed with a traditional repeatability model (Wolc *et al*., 2007a) or with fixed regression models where average production curve of a flock is taken into account but genetic effects are assumed constant (Anang *et al*., 2001; Wolc *et al*., 2007b). More recently random regression models where genetic and permanent environmental effects are allowed to vary with age have also been fitted (Anang *et al.*, 2002; Kranis *et al.*, 2007; Wolc *et al.*, 2009a).

The results from these studies suggest that early and late egg production are genetically different traits. Secondly, even though the heritability of egg production is low to moderate, these studies also indicate significant genetic variation in laying performance of modern strains of chickens despite many generations of selection. The studies also indicate that there is scope to genetically improve persistency of lay.

Fertility

The fertility of an egg is affected by factors originating from the hen such as her ability to mate successfully, to store sperm, to ovulate an egg cell and to produce a suitable environment for the formation and development of the embryo (Brillard, 2003). Fertility also depends on her mate's ability to mate successfully, quantity and quality of semen deposited (Wilson *et al.*, 1979; Brillard, 2003). These factors (from both sexes) also seem to be subject to the age of the bird (Branwell *et al.*, 1995, Hocking and Bernard, 2000; Gumułka and Kapkowska, 2005). In many studies, fertility is treated entirely either as a trait of female which produced the egg (female fertility) or the male by averaging over all its female mates. In this regard, fertility has been studied with maternal effects model (Szwaczkowski *et al.*, 2000), model including putative major gene (Skotarczak *et al.*, 2008), repeatability model including random non-genetic effect of mate (Sapp *et al.*, 2004, 2005), threshold model (Bennevitz *et al.*, 2007). A model simultaneously taking into account male and female genetic and permanent environmental effects and covariance between genetic effects was until now applied only for laying date in wild birds (Brommer and Rattiste, 2008).

In view of the known effect of age and heterogeneity of genetic variation in fertility at different ages of the flock, Wolc *et al.* (2009b) recently proposed a sire-dam random regression framework for analysing fertility which accounts for all sources of variation, including age and simultaneously estimates parameters for male and female fertility. Estimates of heritability at various ages were generally below 10% for both maternal and paternal components but genetic variation at these ages were substantially different, suggesting that hatchability may also vary genetically as the bird ages.

Egg quality

The overall quality of an egg can be discussed under two broad categories namely "external" and "internal" quality (Monira *et al.*, 2003). The external quality of the egg is determined by features such as the size and shape of the egg as well as the structure, thickness and strength of the shell (Bain, 2005). The internal quality is measured on the basis of the quality of the albumen as indicated by the Haugh units (HU), the relative size of the various internal components, and the integrity of the shell membrane. Several studies have looked at these egg quality assessment in chickens (Tona *et al.*, 2002; de De Ketelaere *et al.*, 2004; Bain, 2005) as well as changes in the micro environment provided by the egg during storage and early incubation and how these affect hatchability (Narushin and Romanov, 2002; Tona *et al.*, 2002; Reijrink *et al.*, 2008). For example, Tona *et al.,* (2002) found that HU declines and Albumen PH increase with storage time and suggested that molting improved hatchability if eggs were stored for a long time because molting improved HU of eggs at all storage times. These studies generally agree that several egg quality traits have an effect on hatchability with optimum being at moderate rather than extreme values. Estimated heritability values were moderate and tend to change with age of the flock.

Embryo survival

Embryonic mortality is not evenly distributed over the incubation period and shows two peaks in first and third trimester of incubation (Payne, 1919 after Kuurman *et al.,* 2003). The shape of mortality curve was recently described by a diphasic Weibull distribution (Kuurman *et al*., 2003). The probability of embryo survival (also described as hatch of fertile) can be seen as a function of its genotype which depends on genes received from sire and dam, and the egg environment which generally depends entirely on the dam. Liptói and Hidas (2006) in their review, attributed early embryo mortality to chromosomal aberrations and lethal genes which suggests that embryo survival is a trait of both the sire and the dam. Earlier, Beaumont *et al*., (1997) observed that the heritability of susceptibility to embryonic death decreases with the stage of development from 0.09 for early mortality to 0.05 for late mortality based on sire component and from 0.25 to 0.18 based on dam component. Others have suggest low direct heritability of hatchability based on linear (Sapp *et al.*, 2004) and threshold models (Bennevitz *et al.*, 2007) with hatchability treated as a trait of the dam.

In our preliminary analysis aimed at testing the hypothesis that hatchability is a trait of the embryo (with both maternal and paternal components), a set of linear (L1-L5) and Threshold (T1 – T5) models with increasing complexity and assuming varying sources of variation (Table 1) were applied to broiler hatchability data. The results indicate that the hatchability of a fertile egg was primarily a trait of the dam which laid the egg rather than of the developing embryo. This conclusion was reached because the paternal component of genetic variation was non existent and fitting maternal genetic effect made embryo component essentially zero with an increased likelihood, which suggests that the quality of the egg which defines the micro-environment of the developing embryo was mostly responsible for the successful hatching of the egg. This implies that egg quality was important in hatchability and can make substantial contribution to the genetic improvement of hatchability.

Conclusion

In chickens, the hatchability of all set eggs is a function of both the hen and her male mate. This is mostly due to the significant effect of both maternal and paternal components on fertility and early embryo survival. Genetic variation in hatchability of a fertile egg however, arises mostly from the dam which laid the egg. This significant effect of the dam is attributable to the quality (external and internal) of the laid egg which affects successful development of the embryo to a chick during incubation and the emergence of the chick from the egg at hatching.

Table 1. Estimated Variance components and Log likelihoods from linear and threshold models with various terms used to model repeated hatch of fertile (HOF) records

Model			Sources of Variation			Log Likelihood
Linear model						
	embryo	Dam	sirepe	Dampe	residual	logL
L1	0.000	0.002	0.000	0.003	0.095	156107.9
L2	0.002	*	0.000	0.004	0.094	156068.8
L3	0.003			0.003	0.094	156065.6
L4	0.024		0.000		0.084	155905.4
L5	0.024				0.084	155905.3
Threshold model						
	embryo	Dam	sirepe	Dampe	residual	Deviance
T1	0.000	0.149	0.033	0.184	3.290	153988.4
T2	0.067		0.023	0.280	3.290	152573.6
T3	0.117			0.276	3.290	151622.9
T4	0.816		0.019		3.290	139847.8
T5	0.829				3.290	139638.9

Notes: embryo – additive genetic effect of embryo, dam – additive genetic effect of female which laid the egg, sirepe – non-genetic effect of service sires, dampe – non-genetic effect common to all observations of a given dam, residual – unexplained part of the model; *- if the cell is empty the effect was not fitted in the respective model

Acknowledgements

The authors would like to express sincere gratitude to W.G. Hill, I.M.S. White and S. Avendano for helpful discussions on modelling of poultry reproductive data.

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