IMMUNOGENETIC INFLUENCES ON LITTER TRAITS, VIABILITY AND GROWTH IN BROILER RABBITS

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "IMMUNOGENETIC INFLUENCES ON LITTER TRAITS, VIABILITY AND GROWTH IN BROILER RABBITS" is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled "IMMUNOGENETIC INFLUENCES ON LITTER TRAITS, VIABILITY AND GROWTH IN BROILER RABBITS" is a record of research work done independently by Dr. Marykutty Thomas under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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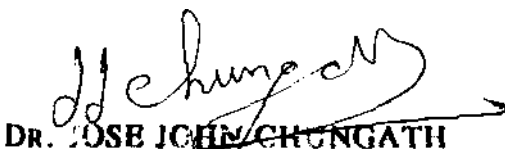

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EXTERNAL EXAMINER

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To my beloved parents

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Introduction

INTRODUCTION

Agroclimatic limitations of humid tropics and socio-economic constraints of our developing economy necessitate the identification of livestock that are prolific and grow faster by converting food stuffs, not utilised by man and would require limited space taking into account, the increased population and consequent urban sprawl. With this background, scientists are of the view that future livestock in the developing tropics would be smaller and more personal. The term microlivestock has been used to describe these animal species.

Rabbits (*Oryctolagus cuniculus*) have a number of characteristics that would make them highly suitable with the tremendous potentiality as a meat animal for developing countries. The unique biological and husbandry attributes of broiler rabbit production include the small body size, short generation interval, utilization of noncompetitive feed, rapid growth rate and high potential for genetic improvement.

Several broiler breeds of rabbits have been developed in temperate countries. The major advantage of these rabbit breeds is its proverbial prolificacy. With a short gestation length of one month and an average litter size at birth of nine, a rabbit doe can produce around 50 bunnies in a year. These bunnies can grow at a rate of 30-35 g/day, reaching a body weight of 2 kg by about two months of age. The optimism based on this tremendous broiler potential has led international organisations like food and Agricultural Organisation (FAO) to predict that by year 2000 A.D., one third of the global meat requirement would be met from rabbit meat alone.

The optimism has led to the propagation of broiler rabbit breeds in almost all developing tropical countries. Broiler rabbits belonging to three temperate breeds viz., New Zealand White, Grey Giant and Soviet Chinchilla were introduced into Kerala State by Centre for Advanced Studies In Animal Genetics and Breeding of Kerala Agricultural University to conduct pure breeding experiments and to assess the suitability of these breeds for being propagated throughout the state. The results of these experiments revealed that climatic stress of the humid tropics would be a limiting factor hindering the expression of production potential of these breeds. The litter size at birth was far below the expectation. There was heavy pre-weaning mortality and growth rate was much below the performance level in the temperate climate. These limitations have also been reported in other tropical regions. The small litter size at birth, heavy preweaning mortality, lowered litter size at weaning and growth rate have been reported to be the stumbling blocks for the broiler rabbit production in the tropical regions of the world.

The litter size at birth, preweaning mortality, litter size at weaning and growth rate are basically viability and fitness traits contributing to the multiplication and perpetuation of the species. Under the tropical stress, litter size at birth dwindled down to five to six with a litter size of weaning of three to four, a preweaning mortality of 60 per cent and body weight average less than 1.5 kg even at 12 weeks.

The differential performance of temperate breeds in fitness and viability traits under tropical and temperate climate necessitates detailed investigation on the factors

influencing the litter traits and preweaning mortality. Heavy preweaning mortality and lowered performance under the tropical stress is indicative of the interference of the immune responses by the environmental stress in the temperate breeds of rabbits. Lowered immune responsiveness has been attributed to the increased incidence of diseases and mortality among all species of livestock including rabbits. This is especially true in the neonatal bunnies during the preweaning period. Genetic consideration involved in selection and testing for disease resistance and immune responsiveness require knowledge of association between disease resistance, immune responsiveness and production traits.

Humoral immune responsiveness to complex antigens like erythrocytes have been reported to be complex, polygenic in inheritance and associated with several bacterial and viral diseases. An understanding of the association among disease resistance, immune responses and production traits is very important for the future breeding efforts which are to be employed to improve disease resistance and production performance simultaneously.

Direct selection for disease resistance by challenging would be costly, hazardous and may require thorough standardisation of specific challenge and also require maintenance of isolation facilities. Indirect approaches to selection for genetic resistance have been proposed as an appropriate method and immune responsiveness has been suggested as a clear indicator of disease resistance.

Leitner *et al.* (1992) have pointed out that defective immune status predisposes animals to high morbidity and mortality. Any type of stress, especially thermal stress was reported to have an immunosuppressive effect. Adverse effect of tropical stresses on the immune responsiveness might contribute to a high preweaning mortality and lowered performance of temperate broiler breeds of rabbits.

This background information necessitates a detailed investigation into the genetic and environmental factors influencing litter traits, growth and viability among the three breeds of broiler rabbits propagated in the state namely New Zealand White, Soviet Chinchilla and Grey Giant. The effect of breed and sire on litter traits, growth and viability of the rabbit bunnies would have to be assessed. It is also imperative to assess the genetics of antibody responses to particulate antigen and to analyse the relationship between humoral immune response, growth and viability.

The present investigation was undertaken in three broiler breeds of rabbits namely New Zealand White, Grey Giant and Soviet Chinchilla maintained at Rabbit Research Station under Centre for Advanced Studies in Animal Genetics and Breeding of Kerala Agricultural University with the following objectives.

1) To estimate the genetic and environmental factors influencing litter traits, growth and viability among three breeds of broiler rabbits.

2) To assess the heritability of humoral immune response in broiler rabbits.

3) To analyse the relationship between humoral immune response, litter traits, growth and viability.

Review of Literature

REVIEW OF LITERATURE

Socio-economic and agroclimatic constraints of the developing tropics necessitate the identification and propagation of animal species which are highly prolific and grow faster by converting noncompetitive feeds to man to produce high quality animal protein. In this context scope and potential of broiler rabbit production appears to be tremendous taking into account its unique biological peculiarities and husbandry requirements. This is particularly true to the small holder, subsistence type integrated farming and gardening food production systems in developing countries. Fully recognising this potential, Vietmeyer (1985) coined the term "microlivestock" to describe these animal species. According to him, livestock of choice for developing countries would be smaller and more personal in future.

High prolificacy and fast growth rate make rabbit an ideal animal for meat production in developing tropics. Food and Agricultural organisation (FAO) has even predicted that by the year 2000 AD, one third of the total global meat requirements would be met from rabbit meat alone (Lebas, 1983). However, these optimisms have ueen often unfulfilled due to a variety of factors including poor acclimatization of the temperate broiler breeds in tropics (Rajadevan *et al.*, 1987).

Crossbreeding experiment involving local nondescript, Soviet Chinchilla and New Zealand White rabbits conducted at Centre for Advanced Studies in Animal Genetics and Breeding, Kerala Agricultural University demonstrated that the

performance of temperate breeds were inferior to local nondescript for viability and litter traits. The performance of temperate breeds were found to be much below their reproductive and production potential under the temperate climate (Mukundan *et al.*, 1993). The high preweaning mortality of the temperate breeds appeared to be the direct effect of tropical stress including the high incidence of diseases and thermal stress.

The humid tropical climate often contribute substantially to stress and increased incidence of diseases by interfering with the immune response. Leitner *et al.* (1992) have suggested that any type of stress especially thermal stress has an immunosuppressant effect. This situation makes it obligatory for detailed analysis of litter traits, growth, preweaning mortality and also their association with immune responses along with factors influencing immune responses.

Opoku and Lukefahr (1990) while trying to develop synthetic tropical breed in Ghana demonstrated that natural selection for higher mature weight, smaller litter size and fewer litters produced in a year are conservative measures that enhance survival of rabbits in less-than-optimal environments, such as in tropics and arid regions of the world. Finzi (1992) has also clearly stated the need for testing and comparing exotic and local breeds under different stress conditions for the development of rabbit genotypes suited to different agroclimatic conditions.

2.1 Litter traits

Litter traits like litter size at birth and at weaning, litter weight at birth and at weaning and preweaning mortality are important economic traits among polytocous meat species like rabbits and pigs. Performance levels being achieved in developed temperate countries are 45-50 young reared per doe per year (approximately six litters), with fryer rabbits reaching a slaughter weight of 2 kg in eight to ten weeks of age (Owen, 1976). It has been reported that annual number of litters produced per female averaged 7.8 with a litter size at birth of 9.5, producing 57 rabbits of 2.36 kg slaughter weight (Koehl et al., 1994), yielding 113 kg of rabbit meat annually in France (Koehl, 1995).

2.1.1 Litter size at birth

Litter size at birth contribute substantially to litter size at weaning and litter weight at weaning (Khalil et al., 1986, 1987a; El-Sheikh and EL-Bayoni, 1994; Nandakumar and Thomas, 1998a). Doe productivity (kit/doe/year) is a major factor in commercial broiler rabbit production.

Litter size at birth though had a low heritability (Rollins et al. 1963; Lampo and Broeck, 1975) had a high variation ranging from 1-21 (Weisbroth et al., 1974; Lebas, 1983).

Damodar and Jatkar (1985) showed that litter size at birth of temperate rabbit breeds were only 4-6 under tropical climate. Rasthogi (1988) while studying the

reproductive performance of rabbits in tropical Trinidad, found that litter size at birth averaged 4.9 and the number of live born per litter was 4.4. Opoku and Lukefahr (1990) found that average litter size at birth among different breeds of rabbits in tropical Ghanna averaged 4.9±0.19. Das *et al.* (1997) demonstrated litter size at birth of 5.65 and 4.75 respectively for White Giant and local rabbits. Literature on litter size at birth among New Zealand White, Grey Giant and Soviet Chinchilla breeds from different parts of the world are presented in Table 2.1.

2.1.1a Effect of breed

Lee *et al.* (1988) and Afifi *et al.* (1989) found significant effect of breed on litter size at birth. Radhakrishnan (1992) reported significant breed differences for litter size at birth among Grey Giant, Soviet Chinchilla and New Zealand White rabbits. On the contrary Mukundan *et al.* (1993) could not find significant effect of breed on litter size at birth among New Zealand White and Soviet Chinchilla breeds of rabbits. Khalil *et al.* (1995) observed nonsignificant effect of breed on litter size at birth. Ohiosimuan *et al.* (1996) observed significant effect of breed on litter size at birth. Das *et al.* (1997) detected insignificant effect of genetic group on litter size at birth. Nandakumar and Thomas (1998a) reported the significant breed differences for litter size at birth in broiler rabbits. Gurmej Singh (1998) demonstrated insignificant breed component of variance for litter size at birth.

2.1.1b Effect of sire

Rollins *et al.* (1963) studied the sire component of variance for litter size at birth among New Zealand White breed and estimated it to be near zero. Randi and Scossiroli (1980) estimated negative sire component of variance for litter size at birth

among New Zealand White rabbits. Kadry and Afifi (1983) observed that buck did not contribute substantially to the variance of litter size at birth. Khalil and Afifi (1991) reported significant effect of sire on litter size at birth among rabbits. Khalil (1993) could not observe the significant effect of sire on litter size at birth. Yamani *et al.* (1994) found that differences between dams within sires were substantially higher, compared to difference between sires and litter size at birth had been attributed as a trait of dam. Ayyat *et al.* (1995) documented that sire component of variance for litter size at birth was not significant.

2.1.2 Litter weight at birth

Litter weight at birth is an important economic trait having highly significant correlations with litter size and litter weight at weaning and preweaning mortality (Khalil, 1986). Khalil (1986) estimated heritability of litter weight at birth to be 0.12.

Das *et al.* (1997) reported an average litter weight at birth of 250.03 among various breeds of rabbits from Bengal. Gurmej-Singh (1998) documented average litter weight at birth of 375.1 g from semiarid tropics of Rajasthan from India. Data on litter weight at birth among New Zealand White, Grey Giant and Soviet Chinchilla are documented in Table 2.2.

2.1.2a Effect of breed

Effect of breed on litter weight at birth was reported to be highly significant among different rabbit breeds and breed types contributed substantially to the

phenotypic values (Granat and Zelnik, 1972; Afifi et al., 1987; Gupta et al., 1992). Mukundan et al. (1993) documented the insignificant effect of breed on litter weight at birth. Viroji Rao et al. (1994) could find no significant effect of breed on litter weight at birth among New Zealand White, Grey giant, Soviet Chinchilla and White Giant rabbits. Das et al. (1997) reported litter weight at birth of 328.60 g and 184.06 g respectively for White Giant and local rabbits. They reported significant breed differences for these trait. Gurmej Singh (1998) could not find significant breed difference for litter weight at birth. Nandakumar and Thomas (1998b) demonstrated the insignificant effect of breed on litter weight at birth among temperate broiler rabbits.

2.1.2b Sire effects

Khalil and Afifi (1991) observed the significant effect of sire on litter weight at birth. Afifi et al. (1992) could find no significant effect of sire on this trait. Yamani et al. (1994) documented that dams within sires contributed more to the variance of litter weight at birth than between sires.

2.1.3 Litter size at weaning

Litter size at weaning possesses great commercial importance. Genetic progress in number of bunnies born has little worth, if it does not result in an increase in number of rabbits weaned. Similarly, selection for number of bunnies born may not change the number of rabbits weaned, if mothering capacity of the rabbit doe is a limiting factor. Thus litter size at weaning would be a better selection criterion than litter size at birth.

Rajadevan *et al.* (1987) reported that litter size at weaning averaged 3.4 ± 0.3 among crossbred rabbits in Sri Lanka. Khalil *et al.* (1987a) while studying the performance of Bauscat and Giza White rabbits observed litter size at weaning of 4.91 and 4.68 respectively. Rastogi (1988) documented litter size at weaning to be 3.4 under the tropical climate of Trinidad. Literature on litter size at weaning among three broiler rabbit breeds are presented in Table 2.3.

2.1.3a Breed effects

The contribution of breed to the litter size at weaning has been reported to be significant by Lee *et al.* (1988), Afifi *et al.* (1989), Radhakrishnan (1992), Khalil *et al.* (1995). According to them genetic improvement for litter size at weaning could be made by breed substitution.

On contrary, Viroji Rao *et al.* (1994) and Ohiosimuan *et al.* (1996) reported the insignificant effect of breed types on litter size at weaning. In 1998, Gurmej Singh observed the insignificant effect of breed type on litter size at weaning.

2.1.3b Sire effects

Rollins *et al.* (1963) while working on New Zealand White rabbits observed sire component of variance for litter size at weaning was close to zero. Afifi *et al.* (1980) showed that the difference between dams within sires was substantially larger than the between sire component for litter size at weaning. Dragnev and Tsocheva (1983), Khalil and Afifi (1991) observed significant sire and dam influence on litter

size at weaning. Khalil (1993) observed that sire of the litter had little effect on litter size at weaning. Yamani *et al.* (1994) estimated that sire component of variance for litter size at weaning was negligible. Ayyat *et al.* (1995) documented that effect of sire for the variation of litter size at weaning was significant.

2.1.4 Litter weight at weaning

Litter weight at weaning represents a combination of other reproductive traits and reflects the maternal environment provided by the does.

Table 2.4 presents the literature on litter weight at weaning among the New Zealand White, Grey Giant and Soviet Chinchilla rabbits. Khalil *et al.* (1987a) on studying the litter performance of Bauscat and Giza white rabbits observed litter weight at weaning of 2071 g and 2000.30 g respectively among Bauscat and Gizza white rabbits. Opoku and Lukefahr (1990) reported that litter weight at weaning averaged 2596±73.6 g among different rabbit breeds in Khana.

2.1.4a Breed effects

Khalil *et al.* (1988) found significant breed differences for litter weight at weaning among rabbits. Mc Nitt and Moody (1990) could observe significant effect of breed on litter weight at weaning with heavier New Zealand White litters than Californian, Palomino and White satin rabbits. Radhakrishnan (1992) estimated significant effect of breed on litter weight at weaning. While Mukundan *et al.* (1993) could find no significant breed differences for litter weight at weaning among various

broiler breeds. Ohiosimuan *et al.* (1996) demonstrated significant effect of breed on litter weight at weaning. According to Gurmej Singh (1998) breed differences for litter weight at weaning were not significant.

2.1.4b Sire effects

Rollins *et al.* (1963) estimated sire component of variance for total weaning weight to be less than zero. Khalil *et al.* (1988) demonstrated that dams within sires contributed substantially to the variance of weaning litter weight. While Khalil and Afifi (1991) could observe significant sire effect on litter weight at weaning. Afifi *et al.* (1992) reported that differences among dams within sires constituted significant source of variation for litter weight at weaning. Yamani *et al.* (1994) demonstrated that differences among dams within sires were not significant for litter weight at weaning. Ayyat *et al.* (1995) could observe the sire component of variance of litter weight at weaning to be significantly larger.

2.1.5 Preweaning mortality

Heavy neonatal mortality is a major limiting factor in the development of broiler rabbit industry in the humid tropics. Poor adaptability and high incidence of diseases along with tropical stresses contribute to the heavy neonatal mortality. The heavy neonatal mortality in the humid tropics may be as high as 61.6 per cent (Rajadevan *et al.*, 1987). Overall preweaning mortality reported by Khalil (1993) was 38.7 per cent compared to 32 per cent under sub temperate regions of India (Bhasin and Singh, 1995). Farghaly (1996) noticed 24.09 per cent preweaning mortality

among rabbits in Egypt. Table 2.5 documents literature on preweaning mortality among New Zealand White, Grey Giant and Soviet Chinchilla rabbits.

2.1.5a Breed effects

In the studies of Grobner *et al.* (1985) New Zealand White breed was reported to have significantly low mortality rate compared to Palomino breed. Khalil *et al.* (1988) found that breed effect was not significant on preweaning mortality among rabbits. Radhakrishnan (1992) and Farghaly (1996) could not find significant breed differences among different broiler rabbit breeds for preweaning mortality. Gurmej Singh *et al.* (1997) reported that breed type contributed substantially to the variance of preweaning mortality among broiler rabbits.

2.1.5b Sire effects

Results of analysis of Rollins and Casady (1967) showed that differences between dams within sires were substantially larger than those based on differences between sires. Rouvier *et al.* (1973) estimated the sire component of variance for preweaning mortality to be close to zero indicating the significance dam effects on preweaning mortality. Variance components estimated by Khalil (1986) indicated that the sire of the doe affected preweaning mortality significantly. Khalil and Afifi (1991), Afifi *et al.* (1992), Khalil (1993) could find no significant effect of sire on preweaning mortality. Farghaly *et al.* (1994) could not find significant contribution of sire to the variation of preweaning mortality. He observed that sires and dams within sires genetic variation for preweaning mortality was close to zero and residual

Table 2.1   Litter size at birth among New Zealand White, Grey Giant and Soviet
Chinchilla rabbits

Author	Litter size at birth		
	New Zealand White	Grey Giant	Soviet Chinchilla
Gugushvili (1981)	8.0	7.6	8.0
Gogeliya *et al.* (1982)	9.91	9.54	-
Nunes and Moura (1985)	5.92	-	-
Mach (1986)	6.6	-	-
Rahamathulla *et al.* (1986)	5.9	-	-
El-Maghwry *et al.* (1988)	7.05	-	-
Lee *et al.* (1988)	7.61	-	-
Ziemmermann *et al.* (1988)	8.63	-	-
Bhasin *et al.* (1989)	6.06	6.28	6.04
Mishra (1990)	5.34	-	-
Radhakrishnan (1992)	4.36	5.29	4.28
Mukundan *et al.* (1993)	4.61	-	5.7
Ohiosimuan *et al* (1996)	6.80	-	3.94
Gurmej Singh (1998)	6.2	7.4	7.4
Nandakumar and Thomas (1998)	4.54	5.75	4.85

Table 2.2 Litter weight at birth among New Zealand White, Grey Giant and Soviet Chinchilla rabbits

Author	Litter weight at birth (g)		
	New Zealand White	Grey Giant	Soviet Chinchilla
Mukundan *et al.* (1993)	365.36	-	377.45
Gurmej Singh (1998)	384.5	390.9	395.2

Table 2.3 Litter size at weaning among New Zealand White, Grey Giant and Soviet Chinchilla rabbits

Author	Litter size at weaning		
	New Zealand White	Grey Giant	Soviet Chinchilla
Mach *et al.* (1986)	6.4	-	-
Lee *et al.* (1988)	6.45	-	-
El-Maghwry (1988)	6.70	-	-
Bhasin *et al.* (1989)	4.57	4.39	4.51
Misra (1990)	2.56	-	-
Radhakrishnan (1992)	3.55	4.14	3.0
Mukundan *et al.* (1993)	3.0	-	4.0
Khalil *et al.* (1995)	4.4	-	-
Ohiosimuan (1996)	3.7	-	3.4
Gurmej Singh (1998)	5.3	5.3	4.8

Table 2.4 Litter weight at weaning among New Zealand White, Grey Giant and Soviet Chinchilla rabbits

Author	Litter weight at weaning (g)		
	New Zealand White	Grey Giant	Soviet Chinchilla
Niedzwiadek et al. (1983)	2460 - 3443	-	-
El-Maghwry et al. (1988)	3484.61	-	-
Bhasin et al. (1989)	2280	3030	190
Radhakrishnan (1992)	1835	2544	2079
Mukundan et al. (1993)	1804.29	-	2098.57
Ohiosimuan et al. (1996)	6900	-	8500
Gurmej Singh (1998)	3499.4	3278.7	3309.7

Table 2.5 Preweaning mortality among New Zealand White, Grey Giant and Soviet Chinchilla rabbits

Author	Preweaning mortality (%)		
	New Zealand White	Grey Giant	Soviet Chinchilla
Damodar and Jatkar (1985)	54.8	26.19	-
Radhakrishnan (1992)	19.64	21.04	27.41
Mukundan et al. (1993)	33.46	-	51.36
Gurmej Singh et al. (1997)	23.32	24.98	24.18
Nandakumar and Thomas (1998b)	33.5	38.6	35.02

environmental variance for mortality were higher. Yamani *et al.* (1994) reported that difference between dams within sires significant for progeny survival rate. Farghaly (1996) demonstrated that residual environmental variance were high for preweaning mortality. According to him, high within environmental variation indicated that genetic improvement for preweaning survivability by selection could be difficult.

2.1.6a Phenotypic correlations among litter traits

The phenotypic correlation between litter size at birth and litter size at weaning was consistently estimated to be significantly positive and high. It was reported that direct selection for litter size at birth would be more effective than indirect selection using litter size at weaning (Afifi *et al.*, 1980; Lahiri and Mahajan, 1982; Lukefahr *et al.*, 1983; Khalil, 1986; Khalil *et al.*, 1987; Khalil *et al.*, 1988; Afifi *et al.*, 1992; EL-Sayiad *et al.*, 1993; EL-Sheikh and EL-Bayoni, 1994; Gurmej Singh, 1998).

The phenotypic correlation between litter size at birth and litter weight at birth and at weaning were positive and significantly high (Afifi *et al.*, 1980). Lahiri and Mahajan (1982) reported significant phenotypic correlation, among these traits. Lukefahr *et al.* (1983), Khalil (1986), Khalil *et al.* (1987a); Krogmeier and Dzapro (1991); Afifi *et al.* (1992); EL-Sayiad *et al.* (1993); EL-Sheikh and EL-Bayoni (1994). Gurmej Singh (1998) and Nandakumar and Thomas (1998b) estimated significantly high and positive correlation among litter size at birth and litter weight traits.

The association among litter weight traits was reported to be high (Afifi *et al.*, 1980). Lahiri and Mahajan (1982) estimated low phenotypic correlation among these traits. Later, Lukefahr *et al.* (1983); Khalil (1986); Khalil *et al.* (1987a), Krogmeier and Dzapro (1991); Afifi *et al.* (1992); EL-Sayiad *et al.* (1993); EL-Sheikh and EL-Bayoni (1994) and Gurmej Singh (1998) observed significantly high positive correlation among litter weight traits.

The correlation between litter size and mortality rate did not show any consistent trend. Rouvier *et al.* (1973) estimated significantly moderate positive correlation among litter size at birth and preweaning mortality and negative correlation between litter size at weaning and preweaning mortality. Khalil *et al.* (1988) demonstrated negative phenotypic correlation between litter size traits and preweaning mortality. Phenotypic correlation between litter size at birth and preweaning mortality was reported to be positive and of low to moderate magnitude (Afifi *et al.*, 1992). EL-Sayiad *et al.* (1993) revealed that litter size traits and preweaning mortality were negatively correlated. Farghaly *et al.* (1994) observed that preweaning mortality was highly significantly affected by litter size at birth.

Rouvier *et al.* (1973) estimated negative correlation between litter weights at 21 days and 56 days and preweaning mortality. Khalil *et al.* (1987) indicated that preweaning mortality decreased insignificantly as litter weight at birth increased. EL-Sayiad *et al.* (1993) observed negative correlations among litter weight traits and preweaning mortality. Farghaly (1996) reported antagonistic quadratic regression of

preweaning mortality on litter weight at birth. Nandakumar and Thomas (1998b) observed significant negative correlation between litter weight traits and preweaning mortality.

2.1.6b Genetic correlations

Rouvier *et al.* (1973) reported genetic correlation of 0.04 between litter size at birth and litter size at 56 days among New Zealand White rabbits. Garcia *et al.* (1980) estimated it to be 0.51 ± 0.75 for New Zealand White and 0.83 ± 0.32 for Californian rabbits. Khalil (1986) reported moderate to high positive genetic correlations between these traits. Khalil *et al.* (1987); Afifi *et al.* (1992) reported high and significant positive genetic correlation among litter size traits.

Rouvier *et al.* (1973) observed genetic correlation of (-)0.05 and (-) 0.17 respectively for litter size at birth with litter weight at 21 days and litter weight at 56 days. Garcia *et al.* (1980) estimated genetic correlation among total number born and litter weight at weaning to be (-) 0.57 ± 1.39 and 0.75 ± 0.40 respectively for New Zealand White and Californian breeds. Genetic correlation between litter size and weight traits was reported to be positive and significant. (Lahiri and Mahajan (1982), Khalil (1986), Khalil *et al.* (1987a) and Afifi *et al.* (1992).

Rouvier *et al.* (1973) reported significantly high genetic correlation among litter weight traits. Lahiri and Mahajan found genetic correlation of (-)0.013 for litter weight traits among New Zealand White rabbits. Khalil (1986) stated that genetic

correlation of 0.19±0.33 and 0.99±0.64 among bauscat and Giza white rabbits for litter weight traits. Afifi *et al.* (1992) demonstrated relatively high and positive genetic correlation among litter weight traits.

Rouvier *et al.* (1973) reported significantly high and positive genetic correlation between litter size traits and preweaning mortality. They observed significantly high negative genetic correlation between litter weight traits and preweaning mortality. Khalil *et al.* (1988) found negative genetic correlations between litter size and litter weight traits and preweaning mortality.

2.2.1 Body weight at weaning

Several factors influence body weight at weaning among broiler rabbits. Maternal and litter influences were reported to be more important than additive genetic effects for body weight at weaning (Khalil *et al.*, 1987b; Ferraz *et al.*, 1992; Lukefahr *et al.*, 1993).

Lui *et al.* (1987) observed weaning weight of 498.47 g to 530.94 g among different breeds of broiler rabbits under temperate climate. Rajadevan *et al.* (1987) documented weaning body weight of 308.19 g among crossbred rabbits in Sri Lankan tropics. Gurmej Singh and Prasad (1997) reported weaning weight of 364 g among rabbits from semi-arid tropics of India.

Mgheni *et al.* (1982) reported that weaning weight for New Zealand White rabbits at six weeks was 551±121 g. Patras (1985) reported that average body weight

at 21 days of D'champagne rabbits was 450 g. Ahmed *et al.* (1986) found the weaning weight of Baladi and Flemish rabbits to be 308±7.7 g and 362±7.6 g respectively. In a study of Californian and New Zealand White rabbits body weight at weaning was reported to be 594 g and 680 g respectively by Mach *et al.* (1986). Ahmed *et al.* (1986) documented body weight at weaning of 308 g and 362 g respectively for Baladi and Flemish rabbits. Khalil *et al.* (1987b) observed body weight at weaning among Bauscat and Gizza White rabbits to be 516.8 g and 546.59 g respectively. Slawinski and Asias (1988) reported that 42 days body weight for Californian and Chinchilla was 1051.29 g and 1009.10 g respectively. Rastogi (1988) reported that average weaning weight of rabbits was 318 g in Trinidad. Radhakrishnan (1992) reported average body weight at six weeks of Grey Giant, Soviet Chinchilla and New Zealand White rabbits to be 614.1±13.2 g, 679.1±12.8 g and 573.4±18.1 g respectively. Mukundan *et al.* (1993) observed six weeks weight of New Zealand White (625.32±91.39 g) and Soviet Chinchilla (607.62±126.88 g).

2.2.1a Breed effects

Comparative breed studies of Carregal and Lui (1984), Grobner *et al.*, 1985; Ahmed *et al.* 1986; Coudert and Brun (1989) and Ozimba and Lukefahr (1991) revealed that breed component of variance was not significant for weaning body weight among broiler rabbits. Ferraz *et al.* (1991) reported the significant contribution of breed to the weaning body weight. Radhakrishnan (1992) and Mukundan *et al.* (1993) observed significant breed differences for body weight at weaning. Roberts and Lukefahr (1992) found no significant breed differences for the

weaning body weight. Mc Nitt and Lukefahr (1993) demonstrated significant breed differences for this trait among White Satin, New Zealand White, Palomino and Californian rabbits.

2.2.1b Sire effects

Results of Mostageer *et al.* (1970) on body weight at weaning showed that dam components of variance were higher than the sire components. Mc Reynolds (1974) demonstrated that sire differences in body weight at 21 and 56 days of age were not significant, whereas dam was a highly significant source of variation for these traits. El-Amin (1974) worked out that differences in body weight due to the sire and dam effects were significant. Vrillon *et al.* (1979) observed that a comparison of sire and dam variances indicated the presence of maternal effects especially on weaning weight. Dragnev and Tsocheva (1983) reported that dam and sire contributed significantly to the body weight at weaning. Studies of Khalil (1986) on Bauscat and Giza White rabbits revealed the significant effect of both dam and sire on body weight at weaning. Luzi *et al.* (1992) reported that body weight at weaning was highly influenced by buck genotype.

2.2.2 Body weight at 12 weeks

Body weight at the marketable age is one of the major economic traits in the broiler rabbit production. Several factors have been reported to influence post weaning growth in rabbits. Body weight at 12 weeks was found to be moderately to highly heritable (Lukefahr *et al.*, 1992, 1996) suggesting that improvement in growth could be achieved by selection.

Grobner *et al.* (1985) observed body weight at 12 weeks of New Zealand White and Palomino rabbits as 2275 g and 1845 g respectively under temperate climate. Radhakrishnan (1992) reported the average body weight of 1226.2 g at 12 weeks among broiler rabbits under humid tropical climate of Kerala. Gurmej Singh and Prasad (1997) documented average body weight at 12 weeks to be 1.92 kg among rabbits in semi-arid climate of India.

Carregel and Lui (1984) found that at slaughter (70 days) body weight in Dutch, New Zealand White, Californian and Baladi Grey rabbits averaged 1930 g, 2121.50 g, 2252.52 g respectively. Kosba *et al.* (1985) observed 90 day body weight among Soviet Chinchilla, Bauscat and Baladi Yellow rabbits respectively as 1084.8±51 g, 1114.6±56.7 g, 875.3±35.5 g. Khalil *et al.* (1987) observed that the body weight at 12 weeks of Bauscat and Gizza White rabbits were 1033.6 g and 1052.2 g respectively. Granat and Zelnik (1987) reported that at 77 days, New Zealand White and Californian rabbits averaged 1715.90±22.23 g. At 10 weeks, Reodeocha and Kijparkora (1988) documented the weight of New Zealand White and Thai rabbits as 2420 g and 2300 g respectively. Opoku and Lukefahr (1990) reported that for the stock maintained at a rabbit station in Ghana, average individual body weights at 90 days averaged 1350.0±23.8 g. Radhakrishnan (1992) documented 12 weeks body weight of Grey Giant (1226.1±27.1 g), Soviet Chinchilla (1354.1±24.4 g) and New Zealand White (1005.61±29.2 g).

2.2.2a Breed effects

Breed comparison studies conducted in the United States involving medium sized New Zealand White, Californian, Champagne D'Argent and Palomino breeds have demonstrated insignificant differences for post-weaning growth traits (Lukefahr et al., 1983b). In contrast, Grobner et al. (1985) observed significant difference among Palomino and New Zealand White breeds for body weight at 12 weeks. Ahmed et al. (1986); Ozimba and Lukefahr (1991) and Roberts and Lukefahr (1992) documented insignificant breed difference for body weight at marketable age. Gupta et al. (1992) and Radhakrishnan (1992) demonstrated significant effect of breed on body weight at 12 weeks.

2.2.2b Sire effects

High dam component of variance for 12 weeks body weight was reported by Mostageer et al. (1970) and they attributed it to maternal effect on the body weight. EL-Amin (1974) investigated the genetic variance components for 60 day body weight and found that differences in body weight due to sire and dam effects were significant. Mgheni et al. (1982) reported that, although maternal effects decrease in relative importance after weaning, they were still present at sexual maturity. Khalil et al. (1986) reported the significantly higher sire component of variance on mature body weight in Bauscat and Gizza White rabbits. They concluded that dam effects were more important for the growth traits from birth to weaning though they were still present at later stages. Lui et al. (1987) and Khalil et al. (1987b) reported the significant sire component of variance influencing the adult body weights of

broiler rabbits. Radhakrishnan (1992) demonstrated significant effect of sire on body weight at 12 weeks.

2.3 Immune Response

Immune system is a powerful tool in mammalian and avian homeostasis. Basically immune system serves to adapt individual animals and population to the environment and is the major component in specific disease resistance. The main characteristic of immune system is to detect and resist antigenic invasions by maintaining the antigenic integrity against bacteria, viruses, parasites or transformed malignant cells.

Immune responses can be basically grouped in to humoral and cell mediated immunity. The production of antibody in humoral immune response depends on the interaction of B-cells, T-cells and macrophages (Bach *et al.*, 1974; Unanue, 1984), while cellular immunity is a function of many types of leucocytes including T-cells, macrophages, NK cells and LAK cells. In addition to cells of immune system, a variety of cell mediators modulate the immune response. The primary molecules of antibodies synthesised by B-cells, complement system, interferons, interleukins and other lymphokines and monokines also play a major role in immune response (Adams and Hamilton, 1984; Smith, 1984; Herberman *et al.*, 1986).

According to Cheng and Lamount (1988) immune response consists of three major facets, as phagocytosis, cell mediated immunity and humoral immunity,

performed respectively by macrophages, T-lymphocytes and B-lymphocytes. They postulated that both humoral and cell mediated immunities are under independent genetic control and there exists an inverse relationship between genetic regulations of antibody responsiveness and macrophage activity. The role of immune system in disease resistance is well established and the role of both nonspecific and immunologic specific defense systems contribute to it substantially. Nonspecific innate immune mechanism operate through phagocytic leucocytes (neutrophils and macrophages), soluble mediators like lactoferins, lactoperoxidases, thiocyanate system, hydrogen peroxidase system, lysozymes, cationic proteins and complement proteins. The specific adaptive immune system consists of leucocytes and antibodies (Brian and Harp, 1989). Three sets of genes are reported to modulate the response of vertebrate hosts to infections, namely those controlling innate immunity, those determining the specificity of acquired immune responses and those which affect the quality of acquired immunity (Doenhoff and Davis, 1991).

The overall complex and dynamic interaction between host immune response and its pathogens are controlled by many genes. The strains developed for a particular response, either in respect of resistance to one pathogen species (Windon and Dineen, 1984) or for a more general enhanced immune response for high antibody production (Biozzi et al., 1975) are not resistant to all pathogens.

Direct selection by challenging the breeding stock, sibs or progeny would be costly and adverse to production. Direct challenge requires the standardisation of

level of challenge exposure to a particular disease and maintanence of isolation facilities for this type of selection. It is likely that selection difficulties would arise if negative correlations exist between disease resistance and production traits. This would be augmented in multiple selection for several diseases. An index approach would be useful requiring all genetic correlations between disease resistance and production traits.

Table 2.6 Direct approaches to selection for disease resistance

SI. No.	Method of selection	Effects on production traits	Expression of disease resistance	cost
1.	Observe breeding stock	None	Questionable	None
2.	Challenge breeding stock	Negative	Good	Low
3.	Challenge sibs or progeny of breeding stock	None	Good	High
4.	Challenge clones	None	Excellent	High

(Modified from Gavora and Spencer, 1983)

Indirect selection for disease resistance have been proposed as a most viable approach for selection for disease resistance. Immune responsiveness has been suggested as one of the best indicators of disease resistance (Biozzi et al., 1980; Gavora and Spencer, 1983; Buschman et al., 1985; Warner et al., 1987).

Biozzi *et al.* (1980) conducted genetic studies in mice for the antibody response to sheep RBC and found that genetic control of antibody response to sheep erythrocytes was moderately heritable and selection for immune response to one antigen might improve humoral immune response to other antigens as well. But selection for immune response to sheep RBC did not improve cell mediated immunity (Parmentier *et al.*, 1994).

Table 2.7 Indirect approaches to selection for genetic resistance to diseases

Sl. No.	Method of selection	Effects in production of breeding stock	Expression of disease resistance	cost
1.	Vaccine challenge	None	Good	Low
2.	*In vitro* tests	None	Good	Low
3.	Genetic markers	None	Good	Low
4.	Molecular genetics	None	Good	High
5.	Construct resistant genotype	None	Good	High

(Gavora and Spencer, 1983; Rothschild, 1985)

Genetic variations in immune responsiveness to a variety of antigens including sheep erythrocytes have been reported in mice (Biozzi, 1980) in sheep (Nguyen, 1983), in Swine (Meeker *et al.*, 1987) and in cattle (Burton *et al.*, 1989). According to Nonnecke and Harp (1989) immune system is the most important system controlling disease resistance. Lamont (1994) have postulated that selection for

enhanced immune responsiveness and disease resistance can make permanent improvement in fitness and enhance response to vaccine in livestock and poultry.

Earlier, Biozzi *et al.* (1975) have attributed the general immune responsiveness as a polygenic trait determined by a group of about 10 individual loci. Immune response to an antigen is influenced by several factors - antigen presentation, site of entry, response of antigen binding cells and regulation of response (Tizzard, 1979). The declining humoral immune response with advancing age has been reported in mice, rats, man, pigs, poultry and sheep (Munns and Lamont, 1991; Watson and Gill, 1991).

Thermal stress was found to have a depressant effect on the humoral immune response (Thaxton and Siegel, 1970). Earlier Siegel (1985) had postulated that immunological responses reflect the bird's response to environmental stress and it might be modified by interactions between specific and nonspecific responses to that environment. Leitner *et al.* (1992) reported that environmental stress had an immuno suppressant effect.

When an antigen is introduced into animal body, antibody production follow the characteristic fashion of lag phase, logarithmic phase, plato and phase of decline. Initial production of antibodies after first immunisation is markedly different from that of antibody production from second immunisation. Former is known as primary immunisation and second is the secondary anamnestic response. Primary response is

sluggish, short lived and comprised of mainly 19S IgM. Secondary response is swift, prolonged and comprised mainly 7S IgG. correlation between primary and secondary immune responses to complex antigen were highly significant.

Divergent selection experiments conducted in poultry for the persistence of antibody responses revealed additive genetic variation (Siegel and Gross, 1980). Kreukniet and Van der Zijpp (1990) studied the kinetics of primary humoral immune response in chicken lines selected for high and low antibody production to sheep erythrocytes and they could find that peak titres were reached earlier in high responder lines. Lamont and Dietert (1991) proposed that early immunocompetence is important in the disease control especially during the vulnerable neonatal period.

2.3.1 Antibody response

Hylgaard-Jensen (1979) observed that peak antibody titres to bovine and human serum albumin were obtained two to three weeks after primary immunisation in pigs and primary antibody responses were influenced by dose of antigen and adjuvant used. Siegel and Gross (1980) reported that additive genetic variance was noticed for high and low antibody titres five days after sheep RBC inoculation. Van der Zijpp and Leenstra (1983) found that mean total antibody titre to sheep RBC was highest on seventh day after primary immunisation. According to Van der Zijpp *et al.* (1983) on day three and seven post injection of chicken following primary immunisation, random size effects was not significantly different from zero. Selection for primary antibody response could be based on total antibody titres at five days post injection.

According to Burton *et al.* (1989) peak antibody response was observed in calves by seven to fourteen days following human erythrocyte inoculation. Miller *et al.* (1991) found that peak antibody titres to sheep RBC occurred on day six or seven in chicken following primary immunisation. Pinard *et al.* (1992) reported a selection experiment which generated high and low response line to sheep erythrocytes in chicken. The mean post primary antibody titre was 4.73 (log2) in the base population. After nine generations of selection antibody titre was 10.6 (log2) in high responder line and 1.92 (log2) in low responder lines.

2.3.1a Effect of breed

Van der Zijpp (1978) observed significant breed and strain differences for humoral immune response of poultry to sheep RBC. Banyard and Morris (1980) in a comparative study involving *Bos taurus* and *Bos indicus* observed that *Bos indicus* had a high antibody response to key hole limpet haemocyanin (KLH). Lamont and Smith (1984) reported that breeds significantly differed in their antibody producing capacity against sheep RBC and *Brucella abortus* antigens. Rothschild *et al.* (1984) found significant breed differences in the humoral immune response of pigs to inactivated *Bordetella bronchiseptica* antigen. Ubosi *et al.* (1985) found significant population difference in response of chicken to sheep erythrocytes. The peak response to sheep erythrocytes occurred at the same time in all lines of population. Bushman (1986) found significant differences among various breeds of swine for their antibody response to different antigens. Muggli *et al.* (1987) reported no breed differences among Hereford and Red pole calves for their humoral immune response to

Infectious bovine rhino tracheitis virus 60 days post vaccination. Petrosky *et al.* (1988) found significant breed differences among White leghorn, Rhode island red and Rhode island white birds of poultry in their humoral immune response to *Brucella abortus* vaccine and sheep erythrocytes. Buschman and Meyer (1990) found that immune response of swine to tetanus toxoid was significantly influenced by breed. Benda *et al.* (1990) found significant breed effect on humoral immune response to sheep RBC in poultry. Dunnington *et al.* (1992) reported that among high and low antibody producing lines to sheep erythrocytes in White leghorn and White plymoth rock chicken, antibody response to New castle disease virus was consistently higher in high responding lines. In a study on pekin ducks, Wanka *et al.* (1993) could observe significant line difference in antibody response to sheep RBC and tetanus toxoid in Pekin duck. Haddad *et al.* (1994) studied immune response of Arakanese progressive and regressive chicken lines for their antibody response to sheep RBC and *Salmonella pullorum* antigen at seven weeks of age and found that significant differences existed between lines in their antibody response to these antigens. Sacco *et al.* (1994) in their studies on antibody response of two turkey lines to New Castle disease virus and *Pasteurella multocida* vaccines, observed significant difference in their antibody response among the two lines. Leitner *et al.* (1994) reported that high and low antibody responder lines to sheep erythrocytes differed significantly in the early immune response to *Escherichia coli* and New Castle disease virus vaccination. Al-Murrani *et al.* (1995) while studying the genetic resistance of native Iraqi and White leghorn chicken to *Salmonella typhimurium*, found high antibody titre and wattle thickness in native Iraqi chicken in comparison with White leghorn. High

within-breed variability was noticed for this trait and they concluded that superior performance of local Iraqi chicks was attributable to accumulation of resistance genes through natural selection. Nandakumar (1995) could find no significant breed differences in the humoral immune response to bovine erythrocytes among broiler rabbits.

2.3.1b Sire effects

Nguyen (1983) found that antibody titres of sires varied from $4\log_2$ to $8\log_2$. The regression coefficient of sire was found to be 0.41 indicating that effect of sire was significant on the antibody response. Lie *et al.* (1983) could observe that, in cattle, sire families but not sires differed in the antibody response to human serum albumin and synthetic peptide. Rothschild *et al.* (1984) reported the non-significant effect of sires on antibody response against *Bordetella bronchiseptica* in swine. Nandakumar (1995) demonstrated that humoral immune response towards bovine erythrocytes was not significantly influenced by sire. Newman *et al.* (1996) studied the antibody responses to *Brucella abortus* strain 19 vaccine in cattle and found that sire effects and individual BOLA types were significant on the antibody response. This indicated that at least two separate genes/genetic systems contribute to the regulation of bovine antibody response to *Brucella abortus*.

2.3.1c Sex effects

Nguyen (1983) studied the effect of sex on humoral immune response to chicken erythrocytes in sheep and observed that mean HA titres of young females

were higher than young males, though the difference was not significant. No sex related difference could be observed for antibody response to sheep erythrocytes, *Brucella abortus* or rabbit erythrocytes in chicken (Mc Corkle and Glick, 1980 and Van Der Zijpp *et al.*, 1986). Leitner *et al.* (1989) demonstrated that females had high antibody response to sheep erythrocytes contributing to increased survival of females. Hameda and EL-Ficky (1993) reported strong immune response in females in comparison with males against sheep RBC in Japanese quails. Nandakumar (1995) could not find significant sex differences for humoral immune response against bovine RBC in rabbits. Raadsma *et al.* (1996) studied the antibody response to commercial multivalent vaccines of *Clostridium tetani* and *Clostridium chauvoei* in sheep and found that sex of the lamb had no significant effect on clostridium antibody titre.

2.3.2 Heritability estimates of immune response

The heritability estimates of primary immune response to sheep RBC was found to vary considerably. Claringbold *et al.* (1957) estimated the heritability of 0.43 for the primary immune response, while Biozzi *et al.* (1970) estimated it to be 0.36 in mice. The heritability of humoral immune response of sheep to chicken RBC was worked out to be 0.82 (Nguyen, 1983). While Van Der Zijpp (1983) worked out heritability of antibody response to sheep RBC in poultry to be 0.39. Muggli *et al.* (1987) found heritability of 0.21 ± 0.20 for antibody response to *Infectious bovine rhinotracheitis* virus among beef cattle. Knyaazev *et al.* (1991) estimated heritability of 0.76 for antibody titres to sheep erythrocytes in pigs. Pinard *et al.* (1992) reckoned heritability of immune response to sheep RBC in poultry to be

0.31 compared with 0.38 ± 0.70 for antibody response to New Castle disease virus and 0.296 ± 0.063 for *Pasteurella multocida* vaccines among turkeys (Sacco *et al.*, 1994). Heritability estimates of antibody response to bovine erythrocytes during first, second and third weeks postprimary immunisation were 0.922, 0.940 and 0.907 respectively (Nandakumar, 1995). Raadsma *et al.* (1996) worked out the heritability to be 0.12 ± 0.04 and 0.24 ± 0.07 respectively for antibody response towards *Clostridium tetani* and *Clostridium chauvoei* in sheep.

2.3.3a Association among immune response traits

Biozzi *et al.* (1975) could find no significant association between immune response to sheep RBC and T-cell response to phytohaemagglutinin. However total IgG level was found to be associated with immune response to sheep RBC. Muggli *et al.* (1987) observed a significant correlation between IgG1 levels post vaccination titre to *Infectious bovine rhino tracheites* virus vaccine. Cheng and Lamont (1988) reported a significant negative correlation between phagocytic index and T-cell response to phytohaemagglutinin, especially among female chicken. Mouton *et al.* (1988) found that the vaccine response in high responder lines to sheep RBC might be as high as 200 times compared to low responder line. They postulated that innate resistance to intracellular pathogens were low in low responder line owing to the difference in macrophage activity in two lines, antigen catabolism being faster in low responder lines. Cheng *et al.* (1991) estimated the genetic correlation between immune response to *Pasteurella multocida* and *Mycobacterium gallisepticum*. T-cell responses as measured by PHA tests were negative. Pollock *et al.* (1991) recorded

significant positive correlation between IgG_1, IgG_2 and IgA levels and cutaneons response to key hole limpet haemocyanin. Heller *et al.* (1992) documented that high responder line to *Escherichia coli* had increased antibody response to New Castle disease virus vaccine and sheep erythrocytes and increased phagocytic activity and increased proliferative response.

Parmentier *et al.* (1994) observed that peripheral blood leucocytes obtained from high responder line of chicken to sheep erythrocytes exhibited lower proliferative responses to concanavalin A than that from control and low responder lines indicating that selection for an enhanced immune response to one antigen may not necessarily implicate improvement of immunity to another antigen.

Sacco *et al.* (1994) estimated the genetic correlation of 0.292 between immune response to New Castle disease virus and *Pasteurella multocida* vaccines. Scott *et al.* (1994) identified the higher antibody response of chicken lines to *Brucella abortus* with high antibody response to sheep RBC. Raadsma *et al.* (1996) estimated a high genetic correlation of (-)0.08 to (-)0.41 between clostridial antibodies and *Dichaelobacter nodosus* vaccine and 0.50 for *Clostridium tetani* and *Clostridium chauvoei* antibody titres. Parmentier *et al.* (1997) demonstrated that humoral response to bovine serum albumin was significantly higher in high immune responder line of chicken to sheep RBC than low responder and control lines.

2.3.3b Association of immune response with diseases and mortality

Biozzi *et al.* (1975) found that higher responder lines of mice to sheep RBC were more susceptible to *Salmonella typhi* infection and *Yersinia pestis* infection. There was a quicker distribution of T4 bacteriophages and slower growth rates of *Listeria monocytogenus* in low responder group. Gross *et al.* (1980) reported that high responder chicken lines to sheep RBC showed stronger antibody response to New Castle disease virus vaccine and were more resistant to *Mycoplasma gallisepticum, Eimeria nicatrix,* Spleenomegali virus and feather mites. But they were less resistant to *Escherichia coli* and *Staphylococcus aureus* infections. Lines of chickens selected for nonpersistence of antibody response to sheep erythrocytes were susceptible to all infectious agents. Dunnington *et al.* (1986) selected chicken for high and low antibody titre to sheep RBC. Low responder lines were more susceptible to Marek's disease. Covelli *et al.* (1989) showed that mice selected for high antibody response to sheep erythrocytes and salmonella flagellar antigens had a lower incidence of lymphomas. Burton *et al.* (1989) found that diarrhoea prevalence among calves were negatively correlated with high primary antibody response to human erythrocytes. Laasgaard (1990) noticed impaired health status in goats selected for high immune response. Gill *et al.* (1993) demonstrated that primary antibody response to ovalbumin was greater in haemonchosis resistant sheep. In contrast, antibody responses to T-cell independent antigen, *Brucella abortus* lipopolysaccharide did not differ among resistant and random bred lines. Al-Murrani *et al.* (1995) attributed superior performance and disease resistance of native Iraqi chicken compared to White leghorn to higher humoral and cell mediated immune responses

to *Salmonella typhimurium.* Pernthaner *et al.* (1995) documented that antibody titres in gastrointestinal nematode resistant Romney sheep decreased sooner after primary and secondary immunisation with human RBC and Ovalbumin than that in susceptible lambs.

As early as 1983, Van Der Zijpp demonstrated that chicken lines with high antibody response to sheep erythrocytes had a lower mortality rate. Takahashi *et al.* (1984) observed no difference in survival rate among high and low immune responder lines of turkey to New Castle disease virus vaccine. Covelli *et al.* (1989) found that mice with high antibody response to sheep erythrocytes had higher life span. Leitner *et al.* (1992) reported that birds with high antibody response to *Escherichia coli* vaccination had lowest morbidity and mortality rate when challenged with pathogenic *Escherichia coli.* Pinard and Van Der Zijpp (1992) observed higher mortality rate on challenging with virulent Marek's disease virus among low immune response groups to sheep RBC, however the high responder line was not significantly more resistant than control line, suggesting that divergent selection in the immune response to sheep RBC produced correlated response in resistance to Marek's disease using downward selection but not using upward selection.

2.3.3c Association with growth and litter traits

Han and Smyth (1972) found that increased growth rate in broilers could be associated with an increased susceptibility to Marek's disease. Siegel and Gross (1980) showed that lines selected for low antibody response to sheep RBC had

significantly higher four week body weight than high antibody responder lines or unselected controls. Van Der Zijpp (1983) showed negative correlation between live weight and haemagglutination titre to sheep RBC. In beef cattle no association could be detected between immune response and growth traits (Muggli *et al.*, 1987). Knyaazev *et al.* (1991) stated that body weight was slightly higher in piglets that reacted weakly to erythrocyte and salmonella antigens than that of strongly reacting pigs. The persistence of antibodies to sheep RBC was reported to be lower in Japanese quail line selected for high body weight than control line (Miller *et al.* 1992a). Miller *et al.* (1992b) demonstrated that high body weight and low body weight lines of chicken initially reacted similarly to sheep RBC and thereafter low weight line maintained a high antibody level than the other line. Sacco *et al.* (1994) could observe no phenotypic and genetic correlations among antibody responses to New Castle disease virus and *Pasteurella multocida* vaccines and 16-week body weight in turkeys. Parmentier *et al.* (1997) observed that body weight of high responder line remained significantly lower than those of the control line and low responder line of chickens. Mashaly *et al.* (1997) documented that feed consumption and bodyweight of chicken lines selected for high antibody production to sheep erythrocytes was significantly lower than both low antibody producing and control lines. They attributed low feed consumption to higher IL-1 production which was presumed to be increased in high antibody producing animals.

Materials and Methods

MATERIALS AND METHODS

Three temperate broiler breeds of rabbits maintained at Rabbit Research Station, Centre for Advanced Studies in Animal Genetics and Breeding, Kerala Agricultural University formed the animals for study. The breeds included in the experiment were New Zealand White, Grey Giant and Soviet Chinchilla. Animals were maintained under identical conditions of feeding and management. A total of 172 kindlings from 54 New Zealand White, 47 Grey Giant and 71 Soviet Chinchilla obtained during the period between October 1997 to June 1998 were utilised for the study.

Ten bucks from each breed were used for the implementation of pure breeding experiment. Breeding animals were selected on the basis of breed characteristics and body conformation. Selected animals had a minimum adult body weight of 3 kg. Matings were planned in such a way as to minimise the occurrence of inbreeding.

According to the breeding plan, the does in heat were transferred to buck's cage for mating and were returned after a day. Prior to kindling, a nest box was placed in the pregnant doe's cage by about 28 days of pregnancy. Litters produced were examined for the litter size and weight at birth. Bunnies were weaned at six weeks of age. Litter size and weight at weaning along with individual body weight at weaning were recorded. Preweaning and post weaning mortality along with individual body weight at 12 weeks were also documented. Mortality percentages were subjected to $\sin^{-1}$ transformation.

Immune response

From a total of 172 kindlings, one hundred and thirteen bunnies, one from each litter were randomly chosen at 8 to 10 weeks of age to study the antibody response to chicken erythrocytes.

Chicken erythrocytes were used as the test antigen. Approximately 20 ml of chicken RBC was collected in Alsever's solution and washed thrice in normal saline by repetitive centrifugation and pelleting at 1500 rpm for 10 minutes and resuspended in fresh normal saline to a final concentration of 20% v/v. Rabbits were immunised by single intravenous injection of chicken RBC at the rate of 1 ml/kg body weight.

Serology

Blood samples were collected just prior to immunisation and at 7, 14 and 21 days post-immunisation. The antibody titres in the serum were measured by direct haemagglutination test (Hines, 1985). The test was performed in microtitre plates using 2% v/v of chicken RBC as the test antigen on serial doubling dilution of serum starting with plain serum. The reagents were incubated after thorough mixing at 37°C for two hours. The antibody titres were recorded as the highest dilution at which a visible positive haemagglutination occurred. The antibody titres were transformed to $1 + \log_e$ for obtaining normal distribution.

Statistical analysis

Least squares analysis using the LSM-LMW package (Harvey, 1985) was performed to assess the effect of breed and sire on the litter traits, growth and viability using the mathematical model,

$$Y_{ijk} = \mu + b_i + S_{ij} + I_{ijk}$$

where,

Y_{ijk}	=	observation of kth rabbit of jth sire in i^{th} breed
μ	=	overall population mean
b_i	=	effect of ith breed
S_{ij}	=	effect of jth sire in i^{th} breed
e_{ijk}	=	random deviation of kth member of jth sire in i^{th} breed, including all the effects not described in the model

The effect of breed, sire and sex on antibody response to chicken RBC were estimated using the statistical model,

$$Y_{ijk} = \mu + b_i + S_j + Se_k + e_{ijkl}$$

where,

Y_{ijkl}	=	observation of lth rabbit of kth sex of jth sire in i^{th} breed
μ	=	overall population mean
b_i	=	effect of ith breed
S_j	=	effect of jth sire
Se_k	=	effect of kth sex
e_{ijkl}	=	random error

Heritability of immune responses was estimated by paternal half-sib analysis using the statistical model (Becker, 1975),

$$Y_{ij} = \mu + S_i + I_{ij}$$

where,

Y_{ij}	=	observation of jth progeny of ith sire
μ	=	overall mean

S_i =   effect of ith sire assumed to be random with mean zero and variance ^2s

I_{ij} =   random error of each observation

Analysis of variance

Source	df	MSS	EMS
Between sires	S - 1	MS_s	$^2e + k\ ^2s$
Progeny within sires	N - S	MS_e	^2e

where, $K = \dfrac{1}{S-1} \left(N - \dfrac{\Sigma ni^2}{N}\right)$

K   =   Average number of progeny per sire

S   =   Number of sires

n_i =   Number of progeny with in i[th] sire

N   =   Total number of progeny

^2s =   Sire component of variance

^2e =   Variance among progeny within sire

MS_s =   Mean sum of squares due to sire

MS_e =   Mean sum of squares due to progeny

^2s = $\dfrac{MS_s - MS_e}{K}$

t   =   intraclass correlation between half sibs

t   = $\dfrac{^2S}{^2s + ^2e}$

Heritability (h^2) = 4t

The standard error of heritability was estimated by the method described by Swiger *et al.* (1964).

$$SE(h^2) = 4 \sqrt{\frac{2(N-1)(1-t^2)(1+[k-1]t^2}{k^2(N-s)(s-1)}}$$

For the estimation of correlations, the analysis of covariance models and procedures for X and Y (two characters considered at one time) are the same as given for the estimation of heritability. The variance component ^2s (x), $^2s(y)$, ^2e (x) and ^2e (y) were obtained as before.

Analaysis of Co-variance

Source	df	MSS	EMS
Between sires	S - 1	MCP_s	Cove + KCov$_s$
Progeny within sires	N - S	MCP_e	Cove

K was estimated as in the case of analysis of variance.

Cov$_s$	=	Sire component of covariance
Cove	=	Covariance among progeny within sires
MCP$_s$	=	Mean cross product due to sire
MCP$_e$	=	Mean cross product due to progeny

Phenotypic correlation (r_p)

$$r_p \ (xy) \ = \ \frac{Cov_e \ (xy) \ + \ Cov_s \ (xy)}{\sqrt{[\sigma^2 e \ (x) \ + \ \sigma^2 s \ (x)] \ [\sigma^2 e(y) \ + \ 3\sigma^2 s(y)]}}$$

where,

$$Cov_e \ = \ MCP_e$$

$$Cov_s \ = \ \frac{MCP_s \ - \ MCP_e}{k}$$

Genetic correlation ($r_g \ (xy)$)

$$r_g \ (xy) \ = \ \frac{Cov_s \ (xy)}{\sqrt{\sigma^2 s(x) \ \sigma^2 s \ (y)}}$$

Environmental correlation

$$r_e(xy) \ = \ \frac{Cov_e \ - \ 3Cov_s}{\sqrt{[\sigma^2 e(x) \ - \ 3 \ \sigma^2 s(x)][\sigma^2 e(y) \ - \ 3 \ \sigma^2 s(y)]}}$$

Results

RESULTS

4.1 Litter traits

4.1.1 Litter size at birth

The overall mean and range of litter size at birth among broiler rabbits are documented in Table 4.1. Litter size at birth ranged between one to nine with an average of 4.37±0.15.

4.1.1a Breed effects

Least-squares analysis of variance for the effect of breed on litter size at birth are presented in Table 4.2. Effect of breed was not significant on the litter size at birth. Breed wise least-squares means of litter size at birth are presented in Table 4.3. Grey Giant had highest litter size at birth of 4.55±0.31 followed by Soviet Chinchilla (4.35±0.26) and New Zealand White (4.24±0.29). Litter size at birth among New Zealand White, Grey Giant and Soviet Chinchilla is presented in Figure 4.1.

4.1.1b Sire effects

Least-squares analysis of variance for the effect of sires within breed on litter size at birth are summarised in Table 4.2. sire effects were not significant on litter size at birth. Least-squares means of litter size at birth for the different sires are detailed in Table 4.3. Soviet Chinchilla sire, S17 had largest litters with a mean of 5.78 followed by N237 (5.63), a New Zealand White sire. Least litter size at birth was observed for sire N220 (2.00) followed by 2.67 in sires S100 and S101.

4.1.2 Litter weight at birth

Table 4.1 summarises range and mean of litter weight at birth. Litter weight at birth averaged 227.36 ± 6.81 g ranging between 30 g to 405 g.

4.1.2a Breed effects

Variance components for the breed effects on litter weight at birth are presented in Table 4.2. Breed differences for the litter weight at birth were not significant. Least-squares means of litter weight at birth for different breeds are given in Table 4.3. Grey Giant rabbits tended to have higher litter weight at birth with a least-square mean of 236.70 ± 14.74 g compared to Soviet Chinchilla (226.06 ± 12.87 g) and New Zealand White (220.93 ± 14.36 g). Litter weight at birth among New Zealand White, Grey Giant and Soviet Chinchilla is graphically represented in Figure 4.2.

4.1.2b Sire effects

Least-squares analysis of variance for the sire effect on litter weight at birth are detailed in Table 4.2. Sire component of variance for litter weight at birth was not significant. Table 4.3 presents least-squares means of litter weight at birth for the different sires. Highest birth weight was observed for litters sired by S17 with an average weight of 282.22 g followed by N237 with 281.88 g. The least litter weight at birth was observed in the litters of N220 (105 g) followed by 122.5 g in N12.

4.1.3 Litter size at weaning

Data on litter size at weaning among broiler rabbits are documented in Table 4.1. Overall mean of litter size at weaning was 1.61±0.14.

4.1.3a Breed effects

Table 4.2 details least-squares analysis of variance for the breed effects on litter size at weaning. Three breeds differed significantly ($P \leq 0.05$) for the litter size at weaning. Table 4.3 presents least-squares means of litter size at weaning for the various breeds. Grey Giant had largest weaning litters (1.96±0.25). New Zealand White had larger litter size at weaning of 1.87±0.24, when compared to the litters of Soviet Chinchilla (1.18±0.21). Litter size at waning among New Zealand White, Grey Giant and Soviet Chinchilla is presented in Figure 4.3.

4.1.3b Sire effects

Sire component of variance for litter size at weaning is documented in Table 4.2. Sires had no significant effect on this trait. sire wise least-squares means of litter size at weaning are summarised Table 4.3. Largest weaning litters (4.0±1.0) were sired by Grey Giant buck R60.

4.1.4 Litter weight at weaning

The overall mean and range of litter weight at weaning are summarised in Table 4.1. Highest litter weight at weaning was 4340 g and it averaged 925.64±77.17 g among broiler rabbits.

4.1.4a Breed effects

Least-squares analysis of variance for the breed effects on litter weight at weaning are presented in Table 4.2. Breed had a significant ($P \leq 0.05$) effect on litter weight at weaning. Least-squares means of litter weight at weaning for different breed groups are documented in Table 4.3. Grey Giant had heaviest weaning litters of 1084.15±148.45 g followed by New Zealand White (1073.88±138.50 g) and Soviet Chinchilla (707.96±120.78 g). Figure 4.4 presents the litter weight at weaning among New Zealand White, Grey Giant and Soviet Chinchilla rabbits.

4.1.4b Sire effects

Sire component of variance of litter weight at weaning are summarised in Table 4.2. Sires within breed had no significant effect on litter weight at weaning. Sire wise least-squares means of litter weight at weaning are detailed in Table 4.3. Grey Giant sire, R60 had heaviest weaning litters (2327.50 g) followed by N178 with an average litter weight of 1811.25 g. The least weaning weight was observed in litters of S100 (245 g) followed by 327.5 g in litters of N12.

4.1.5 Preweaning mortality

Table 4.1 documents the mean and range of preweaning mortality among broiler rabbits. Preweaning mortality averaged 76.2±2.15 per cent among the whole population.

4.1.5a Breed effects

Least-squares analysis of variance for the effect of breed on preweaning mortality are presented in Table 4.2. Preweaning mortality differed significantly ($P \leq 0.05$) among the three breeds studied. Table 4.3 details breed wise least-squares means of preweaning mortality. New Zealand White had least preweaning mortality losses of 67.7 ± 3.8 per cent compared to Grey Giant ($70.9 \pm 4.1\%$) and Soviet Chinchilla ($84.9 \pm 3.3\%$). Preweaning mortality among New Zealand White, Grey Giant and Soviet Chinchilla breeds is represented graphically in Figure 4.5.

4.1.5b Sire effects

Sire component of variance for pre-weaning mortality is listed on Table 4.2. The effect of sires on preweaning mortality was not significant. Least-squares means of preweaning mortality for different sire groups are documented in Table 4.3. Litters sired by N220, R60 and N211 showed minimum preweaning losses of 20.72, 24.56 and 27.06 per cent respectively and maximum losses was from the litters of S124 (90.05%).

4.1.6a Phenotypic correlations among litter traits

The phenotypic correlations among litter size and weight, at birth, litter size and weight at weaning and preweaning mortality are presented in Table 4.4. Litter size at birth had a highly significant ($P \leq 0.01$) positive correlation of 0.901 and 0.382 with litter weight at birth and at weaning respectively. Association among litter size at birth and at weaning was highly significant ($P \leq 0.01$) and positive. Litter weight
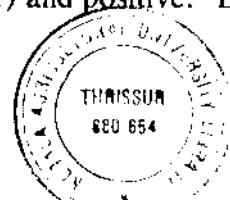
at birth had a highly significant (P ≤ 0.01) positive correlation of 0.438 with litter weight at weaning. Phenotypic correlation between litter weight at birth and litter size at weaning (0.500) was highly significant (P ≤ 0.01) and positive.

Associations between litter traits and preweaning mortality were negative. Preweaning mortality had a highly significant (P ≤ 0.01) negative correlation of (-)0.274 and (-)0.847 respectively with litter weight at birth and at weaning. Phenotypic correlation among preweaning mortality and litter size at weaning [(-)0.817] was highly significant (P ≤ 0.01) and negative. Association of preweaning mortality with litter size at birth [(-)0.167] was significant (P ≤ 0.05) and negative.

4.1.6b Genetic correlations among litter traits

Genetic correlations among litter traits are documented in Table 4.5. Litter size at birth was found to have highly significant (P ≤ 0.01) positive genetic correlation with litter weight at birth. Litter size at birth and litter size at weaning were correlated positively and highly significantly (P ≤ 0.01). Litter weight at birth had a highly significant (P ≤ 0.01) positive genetic correlation of 0.8446 with litter size at weaning.

4.2.1 Body weight at weaning

Data on body weight at weaning are documented in Table 4.6. Body weight at weaning varied between 305 - 960 g with a population mean of 611.73 ± 12.15 g.

4.2.1a Breed effects

Least-squares analysis of variance for the effect of breed on body weight at weaning are presented in Table 4.7. Breed differences for body weight at weaning among rabbits were not significant. Least-squares means of body weight at weaning for different breed groups are summarised in Table 4.8. Least-square means of body weight at weaning in grams for Soviet Chinchilla, New Zealand White and Grey Giant were 564.36 ± 23.95, 614.32 ± 14.30 and 641.92 ± 25.39 respectively. Figure 4.6 presents body weight at weaning among New Zealand White, Grey giant and Soviet Chinchilla rabbits.

4.2.1b Sire effects

Sire component of variance for body weight at weaning is presented in Table 4.7. sires within breed had no significant effect on body weight at weaning. Sire wise least-squares means are listed in Table 4.8. Bunnies sired by New Zealand buck N11 had heaviest body weight at weaning of 795 g.

4.2.2 Body weight at twelve weeks

Table 4.6 details the mean and range of body weight at 12 weeks among broiler rabbits. Body weight at 12 weeks averaged 1168.41 ± 19.13 g and ranged between 765-1805 g.

4.2.2a Breed effects

Least-squares analysis of variance for the effect of breed on body weight 12 weeks is presented in Table 4.7. Breed effects were not significant on body weight

at 12 weeks among broiler rabbits. Breed-wise least squares means of body weight at 12 weeks are documented in Table 4.8. Soviet Chinchilla rabbits had heaviest body weight at 12 weeks (1237.66±44.90 g) followed by New Zealand White (1132.97±41.82 g) and Grey Giant (1121.19±44.85 g). Body weight at 12 weeks among New Zealand White, Grey Giant and Soviet Chinchilla rabbits is presented in Figure 4.7.

4.2.2b Sire effects

Least-squares analysis of variance for the effect of sire on body weight at 12 weeks is summarised in Table 4.7. sire contributed significantly ($P \leq 0.05$) to the variance of body weight at 12 weeks. Least-squares means of body weight at 12 weeks for different sire groups are detailed on Table 4.8. Rabbits sired by N220 had heaviest body weight at 12 weeks (1652.50 g) and that of R22 had the least body weight at 12 weeks (992.50 g).

4.3.1 Humoral immune responses against chicken erythrocytes

Over all mean and range of Forssman antibody titre and post immunisation haemagglutinin levels (1 + $\log_e$) against chicken erythrocytes at 7, 14 and 21 days are documented in Table 4.9. Forssman antibody levels to chicken RBC averaged 0.106±0.036 with a range of 0 to 2 among broiler rabbits.

Humoral immune responses against chicken RBC peaked on 7 days post immunisation. Antibody titres to chicken RBC averaged 4.208±0.116 with a range

of 1.693 to 8.625 on 7 days post immunisation. Haemagglutinin levels to chicken RBC were declined to a mean value of 3.454 (range 1.693 to 5.852) on 14 days post immunisation. Humoral immune responses towards chicken erythrocytes showed again a downward trend on 21 days post immunisation. Mean and range of persistent haemagglutinin levels to chicken erythrocytes were respectively 2.932±0.084 and 1 to 5.159 on 21 days post immunisation. Kinetics of humoral immune response to chicken RBC among rabbits are presented in Figure 4.8.

4.3.1a Breed effects

Estimates of breed component of variance for the Forssman antibody levels and post immunisation haemagglutinin levels against chicken RBC on 7, 14 and 21 days are presented in Table 4.10. Effect of breed was not significant on Forssman antibody titre and 7 and 14 days post immunisation humoral immune responses towards chicken RBC. Breed differences were significant ($P \leq 0.05$) for the antibody titres on 21 days post immunisation against chicken erythrocytes.

Breed-wise least-squares means of Forssman antibody titre and haemagglutinin titres on 7, 14 and 21 days post immunisation against chicken RBC are detailed in Table 4.11. Forssman antibody titres towards chicken RBC were maximum among New Zealand White rabbits followed by Soviet Chinchilla and Grey giant with titres of 0.1452±0.0608, 0.1289±0.0681 and 0.0052±0.0762 respectively.

At day seven of post immunisation antibody levels towards chicken RBC was highest among Soviet chinchilla rabbits (4.375±0.2470) compared to Grey giant (4.2779±0.2483) and New Zealand White (3.8939±0.2296). On 14 day post immunisation, haemagglutinin levels to chicken erythrocytes were maximum among Soviet Chinchilla rabbits followed by Grey Giant and New Zealand White. Antibody titres were 3.6320±0.2182, 3.6052±0.2160 and 3.079±0.2037 among the respective breeds. Breed differences for humoral immune responses against chicken erythrocytes were more apparent on 21 days post immunisation. Breed rankings on the basis of humoral immunes responses on 21 days post immunisation against chicken RBC remained same as before. Least-square means of antibody titres against chicken RBC on 21st day, among Soviet Chinchilla, New Zealand White and Grey Giant rabbits were 3.2903±0.2131, 2.9245±0.2069 and 2.6150±0.2003 respectively. Breed differences for humoral immune response to chicken RBC among rabbits are presented in Figure 4.9.

4.3.1b Sire effects

Least-squares analysis of variance for the effect of sire on Forssman antibody titres and humoral immune response against chicken erythrocytes on 7, 14 and 21 days post immunisation are summarised in Table 4.10. Sires within breed had no significant effect on Forssman antibody levels against chicken RBC. Sires had significant effect (P≤0.05) on day seven and fourteen of post immunisation haemagglutinin levels. Effect of sire on 21 days post immunisation haemagglutinin titres was highly significant (P≤0.01). Sire-wise least squares means of Forssman

antibody titres and 7, 14 and 21 days post immunisation chicken RBC antibody titres are listed in Table 4.11.

4.3.1c Sex effects

Least-squares analysis of variance for the effect of sex on Forssman antibody levels and humoral immune response at 7, 14 and 21 days post immunisation against chicken RBC are presented in Table 4.10. Effect of sex was not significant on Forssman antibody levels and 7, 14 and 21 days post immunisation agglutinin titres.

Least-squares means for the effect of sex on Forssman antibody levels and post immunisation antibody titres at 7, 14 and 21 days post immunisation are presented in Table 4.11. Though not significant, males had higher Forssman antibody titre of 0.111 and haemagglutinin levels of 4.3096, 3.5315 and 2.9906 respectively on 7, 14 and 21 days post immunisation, compared to the corresponding values of 0.06807, 4.0527, 3.3406 and 2.8960 among female rabbits. Sex differences for humoral immune responses to chicken RBC among rabbits are presented in Figure 4.10.

4.3.2 Heritability estimates

Estimates of heritability for humoral immune responses on 7, 14 and 21 days post immunisation by paternal half-sib analysis are presented in Table 4.12. The heritability estimates were 0.589 ± 0.390, 0.727 ± 0.399 and 0.953 ± 0.410 respectively for humoral immune responses at 7, 14 and 21 days post immunisation against chicken erythrocytes.

4.3.3 Association among immune response traits

Phenotypic correlations between Forssman antibody titres, haemagglutinin levels on 7, 14 and 21 days post immunisation against chicken RBC are documented in Table 4.13. Associations of Forssman antibody titre with 7, 14 and 21 days post immunisation haemagglutinin levels were not significant. Phenotypic correlations among post immunisation antibody titres against chicken RBC were highly significant (P ≤ 0.01) and positive. Humoral immune response at 7 days had a highly significant (P ≤ 0.01) positive correlation of 0.662 and 0.650 respectively with antibody response at 14 and 21 days post immunisation against chicken RBC. Association between 14 and 21 days post immunisation anti chicken RBC haemagglutinin titres (0.734) were highly significant (P ≤ 0.01) and positive.

4.3.4 Association between immune response traits and economic traits

Phenotypic correlation between immune response traits with litter traits, preweaning mortality and body weight traits are detailed in Table 4.14. Association among humoral immune response traits litter sizes and litter weights at birth and at weaning, preweaning mortality were not significant. Body weight at weaning had significant (P ≤ 0.05) negative correlation of (-)0.180 and (-)0.189 respectively with 14 and 21 days post immunisation antibody titres whereas body weight at 12 weeks had no significant correlations with 14 and 21 days post immunisation haemagglutinin levels.

Table 4.1   Mean, standard error and range of litter traits and preweaning mortality
              among broiler rabbits

Trait	Number	Mean + SE	Range
Litter size at birth	172	4.372±0.148	1 - 9
Litter weight at birth (g)	172	227.355±6.870	30 - 405
Litter size at weaning	172	1.610±0.135	0 - 9
Litter weight at weaning (g)	172	925.640±77.170	0 - 4340
Preweaning mortality(%)	172	76.20±2.158	0 - 100

Table 4.2   Least-squares analysis of variance for the effect of breed and sires within breed on litter traits and preweaning mortality among broiler rabbits

Source	df	Litter size at birth MSS	Litter weight at birth MSS	Litter size at weaning MSS	Litter weight at weaning MSS	Preweaning mortality MSS
Breed	2	1.2507^{NS}	3229.0291^{NS}	$11.1370*$	$2866025.7436*$	$2519.7411*$
Sire within breed	29	4.4197^{NS}	10343.0154^{NS}	2.9875^{NS}	841732.6915^{NS}	690.9951^{NS}
Error	140	3.6537	7545.8276	3.0428	1035788.0722	798.9665

* Significant at 5% level   NS - Not significant

Table 4.3   Least-squares means for the effect of breed and sires within breed on litter traits and preweaning mortality among broiler rabbits

Classes Overall mean	n	Litter size at birth Mean + SE	Litter weight at birth Mean + SE	Litter size at weaning Mean + SE	Litter weight at weaning Mean + SE	Preweaning mortality Mean + SE
Overall mean Breed	172	4.38±0.16 (P=0.7556)[NS]	227.89±8.16 (P=0.7343)[NS]	1.67±0.13 (P=0.0362)*	955.33±78.74 (P=0.0470)*	59.97±2.18 (P=0.0387)*
New Zealand White	54	4.24±0.29	220.92±14.36	1.87±0.23	1073.88±138.49	67.70±3.84
Grey Giant	47	4.55±0.30	236.70±14.93	1.95±0.25	1084.14±148.45	70.90±4.12
Soviet Chinchilla	71	4.35±0.26	226.05±12.87	1.18±0.20	707.95±120.78	84.90±3.35
Sires N12	2	4.00±0.99	122.50±12.50	0.50±0.50	327.50±327.49	72.40±17.64
N27	1	4.00±0.00	160.00±00.00	3.00±0.00	1480.00±000.00	30.01±0.00
N70	7	3.85±0.82	197.85±43.05	1.28±0.56	927.14±402.43	64.55±9.32
N151	10	3.80±0.46	215.50±23.65	1.30±0.44	822.50±280.99	61.30±10.09
N178	4	4.75±1.03	216.25±55.99	3.00±1.08	1811.25±665.66	42.96±16.48
N205	6	3.83±0.83	218.33±45.17	2.50±1.17	1483.33±619.9	49.87±14.64
N211	2	3.50±2.50	185.00±135.02	3.00±2.00	1525.00±870.00	27.06±2.95
N220	1	2.00±0.00	105.00±000.00	2.00±0.00	1490.00±0.00	20.71±00.00
N232	5	1.41±0.63	230.00±39.30	2.60±0.74	1490.00±411.76	42.15±13.22
N237	8	5.62±0.69	281.87±22.35	2.00±0.56	1051.25±297.17	56.27±8.39
N309	8	4.50±0.70	241.25±29.63	1.37±0.53	574.35±285.27	67.74±8.94

Table 4.3 contd....

R1	6	5.50±0.22	275.00±19.62	0.83±0.54	641.66±413.15	76.66±8.55
R3	4	5.00±1.08	265.00±46.95	1.75±0.75	986.25±420.37	58.10±12.88
R11	6	4.83±0.30	253.33±28.80	1.33±0.55	900.00±385.59	59.55±11.99
R12	4	4.50±1.66	203.75±67.52	3.00±2.04	1720.00±954.11	48.86±16.47
R22	5	5.00±1.14	263.00±52.28	3.00±1.18	1543.00±523.50	48.58±12.29
R30	5	3.20±0.85	174.00±41.36	0.80±0.80	376.00±375.99	79.09±10.95
R32	6	4.33±1.05	206.66±30.56	1.50±0.49	882.50±291.33	53.55±12.77
R60	2	5.00±2.00	280.00±80.01	4.00±0.99	2327.50±542.99	24.55±7.77
R77	4	4.00±1.41	221.25±49.09	3.25±1.25	1342.50±856.03	52.16±21.89
R80	5	4.20±0.49	242.00±35.79	2.20±0.66	1193.00±408.93	46.99±12.67
S2	6	4.83±0.47	265.83±14.56	0.83±0.47	613.33±343.78	72.64±8.23
S17	9	5.77±0.64	282.22±25.76	1.77±0.54	1045.00±349.92	57.88±9.59
S20	11	5.36±0.49	275.45±20.79	1.90±0.53	1048.63±330.22	64.07±8.13
S100	6	2.66±0.55	139.16±26.89	0.50±0.49	245.00±244.99	77.83±12.21
S101	3	2.66±1.66	163.33±75.95	1.00±0.99	696.66±696.68	75.03±15.00
S109	8	3.87±0.81	218.15±40.03	1.50±0.65	930.62±396.70	64.54±10.33
S124	1	4.00±0.00	160.00±0.00	0.00±0.00	0.00±0.00	90.04±0.00
S216	9	5.22±0.57	254.44±23.91	0.77±0.27	511.66±175.45	68.67±5.68
S220	10	3.80±0.71	201.00±26.66	1.10±0.43	643.50±224.00	60.43±10.26
S221	8	3.12±0.54	169.37±25.22	0.75±0.49	450.00±328.15	73.38±10.97

* Significant at 5% level   NS - Not significant

Table 4.4   Phenotypic correlation among litter traits and preweaning mortality in broiler rabbits

Variable	Litter size at birth	Litter wieght at birth	Litter size at weaning	Litter weight at weaning	Preweaning mortality
Littter size at birth	1.0000	0.901*	0.446**	0.382**	-0.167*
Litter weight at birth		1.0000	0.500**	0.438**	-0.274**
Litter size at weaning			1.0000	0.907**	-0.817**
Litter weight at weaning				1.000	-0.847**
Pre-weaning mortality					1.0000

** Significant at 1% level   * Significant at 5% level   NS - Not significant

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Table 4.5   Genetic correlations among litter traits in rabbits

Characters	Genetic correlation
Litter size and litter weight at birth	1.0632
Litter size at birth and litter size at weaning	1.0873
Litter weight at birth and litter size at weaning	0.8446

Correlation estimates more than one may be taken as one

Table 4.6   Mean, standard error and range of body weight traits in broiler rabbits

Trait	Number	Mean + SE	Range
Weaning body weight (g)	113	611.726±12.152	305 - 960
Body weight at 12 weeks (g)	113	1168.407±19.132	765 - 1805

Table 4.7   Least-squares analysis of variance for the effect of breed, sire and sex on body weight traits among broiler rabbits

Source	Degrees of freedom	Body weight at weaning MSS	Body weight at twleve weks MSS
Breed	2	52219.6278[NS]	150007.8902[NS]
Sire within breed	26	18497.9659[NS]	57788.0055*
Sex	1	38234.1262[NS]	17842.6755[NS]
Error	83	15083.4353	33794.7315

* Significant at 5% level   NS - Not significant

Table 4.8   Least-squares means for the effect of breed, sire and sex on body weight traits among broiler rabbits

Classes	n	Body weight atweaning Mean + SE	Body weight at twelve weeks Mean + SE
Overall means	113	607.03±14.29	1163.94±26.69
Breed	1	(P=0.0777)^{NS}	(P=0.0938)^{NS}
New Zealand White	46	614.32±14.29	1132.97±41.82
Grey Giant	30	641.92±25.39	1121.19±44.85
Soviet Chinchilla	37	564.35±23.94	1237.66±44.90
Sex		(P=0.1152)^{ns}	(P=0.4695)^{NS}
Male	73	628.50±17.22	1178.61±30.32
Female	40	585.56±21.81	1149.27±36.33
Sire		(P=0.2403)^{NS}	(P=0.0353)*
N232	8	628.12±63.26	1124.37±79.48
N178	7	551.42±47.45	1035.71±82.9897
N12	1	655.00±00.00	925.00±00.00
N11	1	795.00±00.00	1425.00±00.00
N70	4	665.00±55.34	1155.00±72.22
N205	12	622.08±19.75	1135.41±47.05
N237	5	606.00±30.30	1104.00±80.96
N309	3	570.00±62.51	1030.00±125.03
N27	1	515.00±00.00	1060.00±00.00
N220	2	745.00±35.00	1652.50±152.50
R22	2	652.50±87.49	992.50±67.50
R60	4	582.50±35.15	1020.00±43.78
R1	1	720.00±00.00	1135.00±00.00
R32	2	645.00±4.99	1157.50±17.50
R11	6	684.16±25.21	1285.83±61.15

Table 4.8 contd....

R3	4	678.75±16.33	1263.75±94.35
R77	3	663.33±18.66	1035.00±90.73
R12	2	560.30±30.00	1100.00±4.99
R80	4	720.00±109.56	1057.50±68.57
R30	2	522.50±12.50	997.50±102.50
S17	10	534.00±34.22	1263.00±48.52
S220	5	569.00±124.82	1325.00±133.10
S214	5	583.00±68.62	1153.00±65.70
S221	3	345.00±35.12	1110.00±80.20
S216	4	647.50±47.89	1241.25±98.47
S20	6	645.00±51.60	1154.16±92.00
S21	2	665.00±25.00	1380.00±125.00
S109	2	605.00±9.99	1477.50±127.49
S151	2	642.50±52.50	1222.50±102.50

* Significant at 5% level   NS - Not significant

68

Table 4.9   Mean, standard error and range of antibody titres to chicken RBC at 0, 7, 14 and 21 days postimmunisation in rabbits

Trait	Number	Mean + SE	Range
Antibody response			
0 day	113	0.106±0.149	0.000-2.000
7th day	113	4.208±0.116	1.693-8.625
14th day	113	3.454±0.088	1.693-5.852
21st dya	113	2.932±0.084	1.000-5.159

Table 4.10   Least-squares analysis of variance for the effect of breed, sex and sire on antibody response to chicken RBC at 0, 7, 14 and 21 days post-immunisation in broiler rabbits

Source	Degrees of freedom	Antibody response to chicken RBC			
		0 day MSS	7th day MSS	14th day MSS	21st day MSS
Breed	2	0.2273[NS]	2.6526[NS]	4.1012[NS]	4.6700*
Sires within breed	26	0.0936[NS]	1.7714*	1.3413*	1.2302**
Sex	1	0.0384[NS]	1.3682[NS]	0.7560[NS]	0.1584[NS]
Remainder	83	0.1664	1.0827	0.7376	0.5714

** Significant at 1% level   * Significant at 5% level   NS - Not significant

Table 4.11 Least-squares means for the effect of breed, sires within breed and sex on antibody response to chicken RBC at 0, 7, 14 and 21st day post-immunisation

Classes	n	IR0	IR7	IR14	IR21
Overall mean (ō)	113	0.0896±0.0408	4.1811±0.1469	3.4360±0.1296	2.9433±0.1264
Breed		(P=0.1080)[NS]	(P=0.2424)[NS]	(P=0.0642)[NS]	(P=0.0358)*
New Zealand White	46	0.1452±0.0608	3.8939±0.2296	3.0709±0.2037	2.6150±0.2003
Grey Giant	30	0.0052±0.07624	2.779±0.2483	3.6052±0.2160	2.9245±0.2069
Societ Chinchilla	37	0.1289±0.0681	4.3715±0.2470	3.6320±0.2182	3.2903±0.2131
Sex		(P=0.6230)[NS]	(P=0.2643)[NS]	(P=0.3143)[NS]	(P0.5705)[NS]
Male	73	0.1111±0.0518	4.3096±0.1680	3.5315±0.1460	2.9906±0.1396
Female	40	0.0680±0.0683	4.0527±0.2026	3.3406±0.1734	2.8960±0.1621
Sire		(P=0.9507)[NS]	(P=0.0486)*	(P=0.0218)*	(P=0.0047)**
N232	8	0.125±0.1238	3.686±0.4031	3.079±0.3465	2.473±0.3819
N178	7	0.286±0.2872	4.466±0.3704	3.277±0.1965	2.980±0.2343
N12	1	0.000±0.0000	2.386±0.000	2.386±0.000	1.0000±0.000
N511	1	1.000±0.000	3.079±0.0000	3.079±0.000	2.386±0.000
N70	4	0.000±0.000	3.773±0.4000	3.079±0.4000	2.559±0.3333
N205	12	0.083±0.0837	4.177±0.3118	3.137±0.1588	2.675±0.1039
N237	5	0.400±0.3980	3.773±0.3086	2.941±0.3399	2.525±0.1386
N309	3	0.000±0.0000	3.773±0.0000	3.542±0.2300	3.079±0.000
N27	1	0.000±0.000	3.773±0.0000	1.693±0.0000	1.693±0.000

N220	2	0.000±0.000	3.773±0.6930	3.079±0.6930	2.386±0.6930
R22	3	0.000±0.0000	4.119±1.7320	3.426±1.0395	3.079±0.6930
R60	4	0.000±0.0000	5.332±0.1755	4.639±0.1750	3.777±0.4000
R1	1	0.000±0.0000	5.852±0.0000	4.466±0.0000	4.466±0.0000
R32	2	0.000±0.0000	4.119±1.0395	3.426±1.0395	2.733±1.0394
R11	6	0.000±0.0000	5.390±0.2327	4.466±0.4384	3.542±0.3430
R3	4	0.000±0.0000	3.946±0.4350	3.773±0.4000	2.039±0.3450
R77	3	0.000±0.0000	2.848±0.4619	2.617±0.6120	2.155±0.4619
R12	2	0.000±0.0000	3.773±0.6930	3.773±0.0000	2.732±0.3465
R80	4	0.000±0.0000	4.639±1.3955	3.600±0.435	3.253±0.3333
R30	2	0.000±0.0000	2.039±0.3465	2.039±0.3465	1.346±0.3465
S17	10	0.200±0.1992	4.743±0.4301	3.981±0.3574	3.426±0.3321
S220	5	0.000±0.0000	4.882±0.4965	4.327±0.4025	4.050±0.1700
S214	5	0.000±0.0000	4.327±0.7379	3.079±0.4383	2.802±0.3533
S221	3	0.000±0.0000	4.235±0.2309	4.004±0.4619	4.004±0.4619
S216	4	0.000±0.0000	4.466±1.0650	3.600±0.1450	3.600±0.175
S20	6	0.3333±0.2123	3.7773±0.4737	3.195±0.4532	2.133±0.2981
S21	2	0.000±0.0000	4.466±0.6930	3.426±0.3465	2.732±0.3465
S109	2	0.5000±0.5020	4.466±1.3860	3.079±0.6930	2.732±0.3465
S151	2	0.000±0.0000	3.773±0.6930	3.079±0.6930	3.079±0.6930

** Significant at 1% level   * Significant at 5% level   NS - Not significant
IR0, IR7, IR14, IR21   =   Post-immunisation antibody responses against chickne RBC at 0, 7, 14 and 21 days

Table 4.12 Heritability estimates of immune response traits in rabbits

Trait	Heritability estimate (SE)
Antibody response	
7th day	0.589±0.390
14th day	0.727±0.399
21st day	0.953±0.410

Table 4.13 Phenotypic correlations among immune response traits in rabbits

Antibody response	0 day MSS	7th day MSS	14th day MSS	21st day MSS
0 - day	1.0000	0.037[NS]	0.056[NS]	0.097[NS]
7th day		1.0000	0.662**	0.650**
14th day			1.0000	0.734**
21st day				1.0000

** Significant at 1% level   NS - Not significant

Table 4.14 Phenotypic correlations among immune response and economic traits in rabbits

Variable	Litter size at birth	Litter wieght at birth	Litter weight at weaning	Litter weight at weaning	Preweaning mortality	Body weight at weaning	Body weight at 12 weeks
Antibody response to chicken RBC							
0 day	-0.143^{NS}	0.104^{NS}	0.092^{NS}	0.162^{NS}	0.046^{NS}	0.097^{NS}	0.085^{NS}
7th day	-0.165^{NS}	-0.101^{NS}	0.043^{NS}	0.077^{NS}	-0.171^{NS}	-0.059^{NS}	0.053^{NS}
14th day	-0.062^{NS}	-0.020^{NS}	0.004^{NS}	-0.022^{NS}	-0.046^{NS}	-0.180*	0.044^{NS}
21st day	-0.095^{NS}	-0.021^{NS}	0.001^{NS}	-0.008^{NS}	-0.020^{NS}	-0.189*	-0.050^{NS}

* Significant at 5% level   NS - Not significant

Fig.4.1   LITTER SIZE AT BIRTH AMONG BROILER'RABBITS
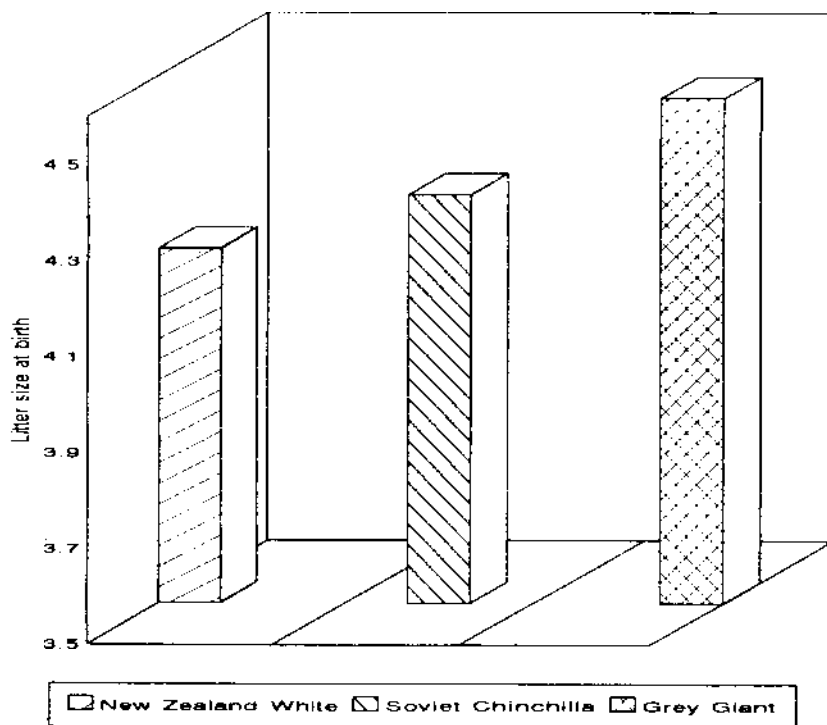
Fig.4.2   LITTER WEIGHT AT BIRTH AMONG BROILER RABBITS
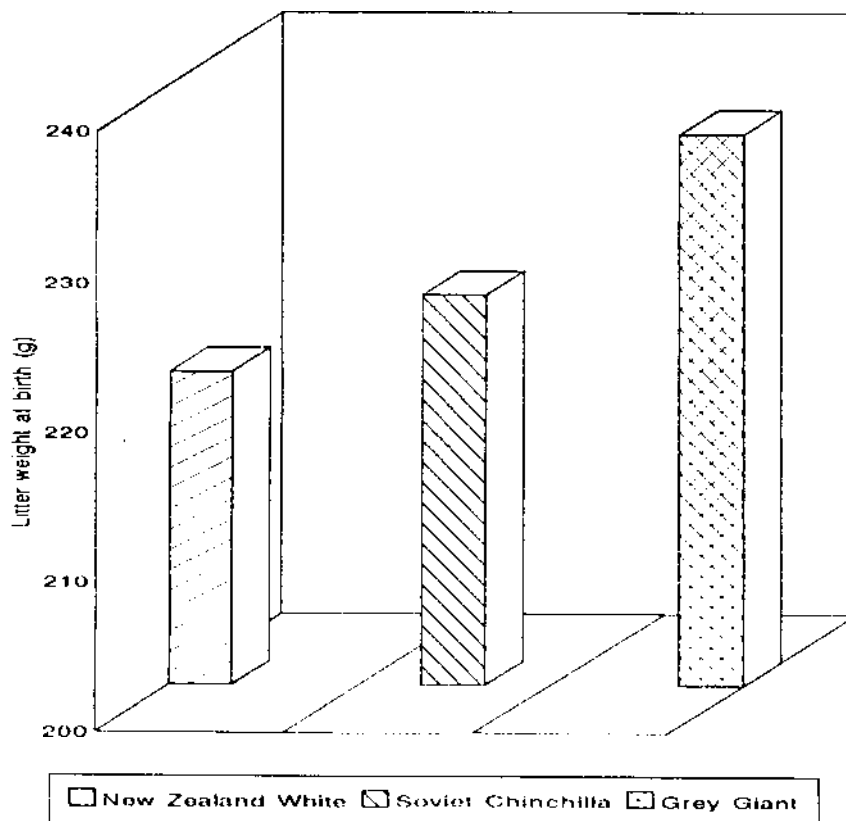
Fig.4.3   LITTER SIZE AT WEANING AMONG BROILER RABBITS
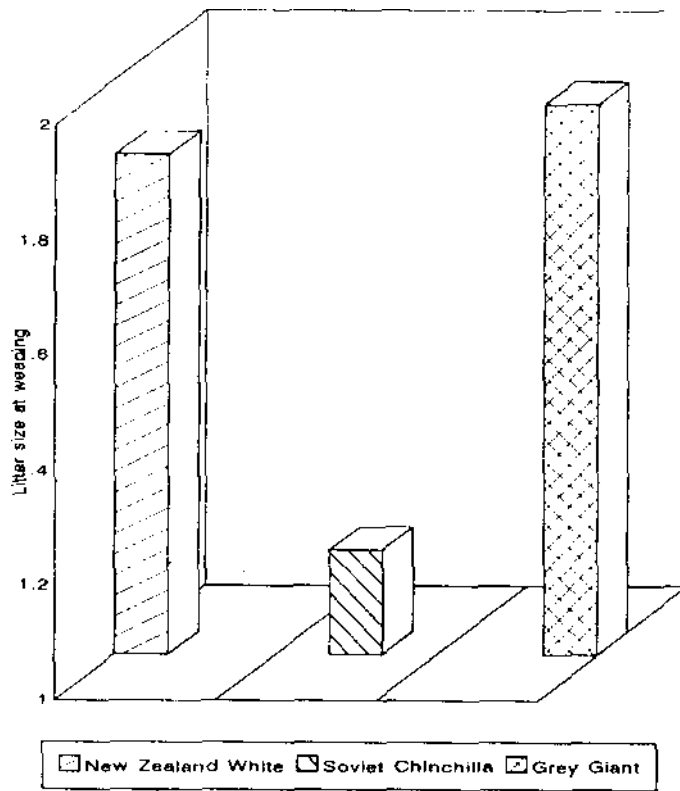
New Zealand White   Soviet Chinchilla   Grey Giant

Fig.4.4   LITTER WEIGHT AT WEANING AMONG BROILER RABBITS

New Zealand White   Soviet Chinchilla   Grey Giant

Fig.4.5 PRE-WEANING MORTALITY (%) AMONG BROILER RABBITS

Pre-weaning mortality (%)

90

80

70

60

50

☐ New Zealand White ◪ Soviet Chinchilla ☐ Grey Giant

Fig.4.6   BODY WEIGHT AT WEANING AMONG BROILER RABBIT BREEDS

New Zealand White   Soviet Chinchilla   Grey Giant

Fig.4.7   BODY WEIGHT AT 12-WEEKS AMONG BROILER RABBIT BREEDS

New Zealand White   Soviet Chinchilla   Grey Giant
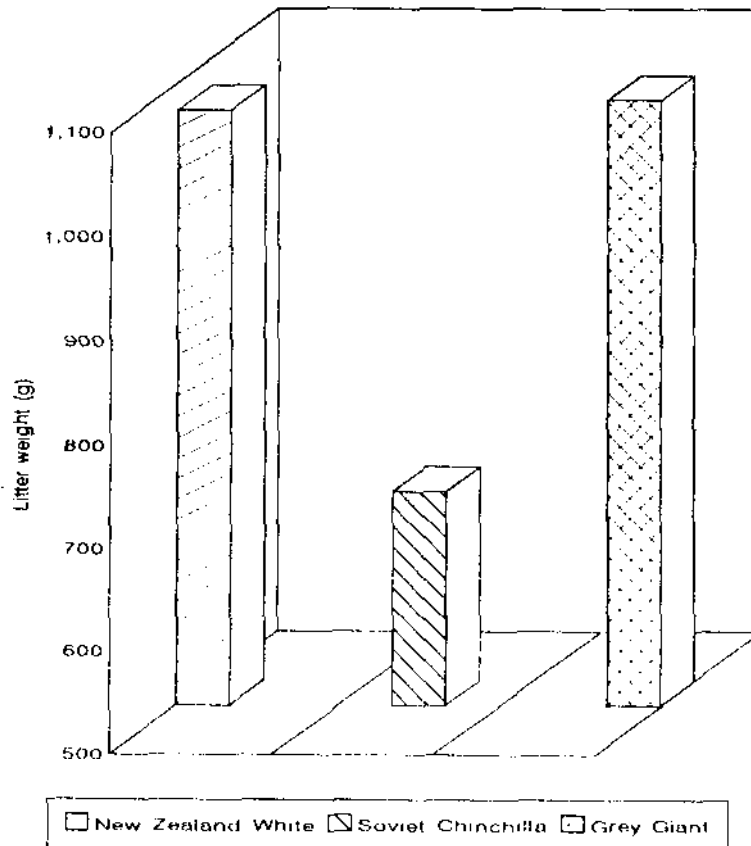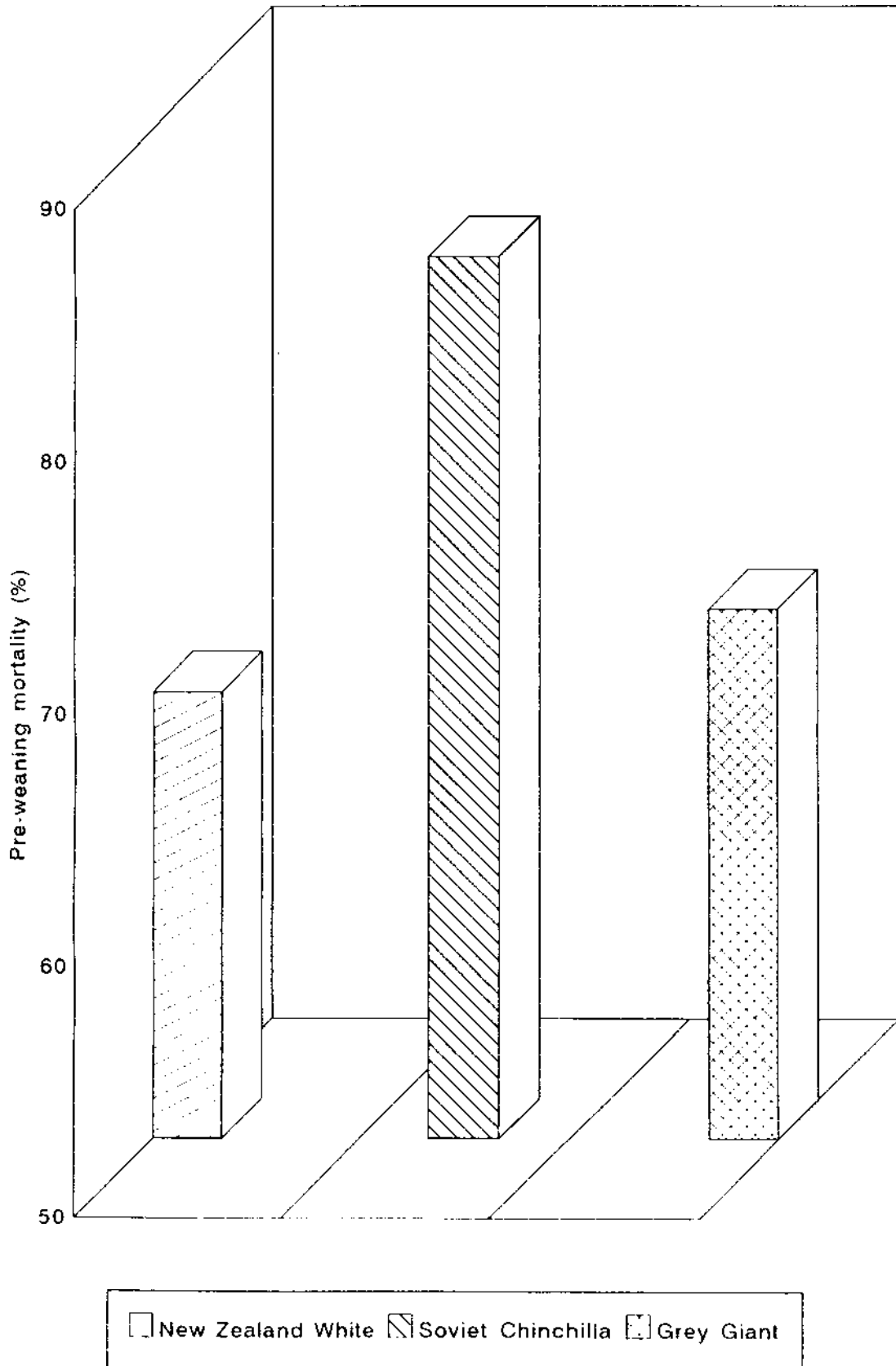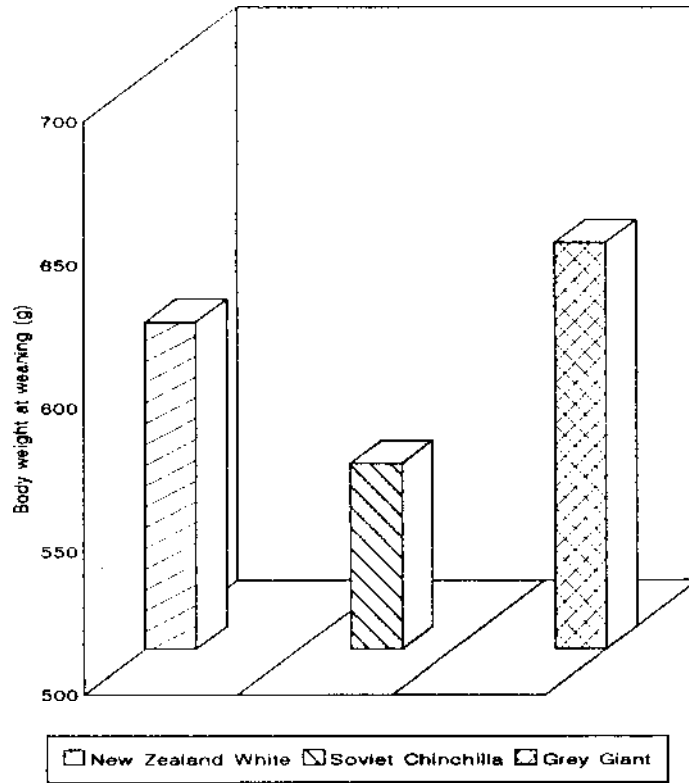
Fig.4.8   KINETICS OF HUMORAL IMMUNE RESPONSE TO CHICKEN RBC
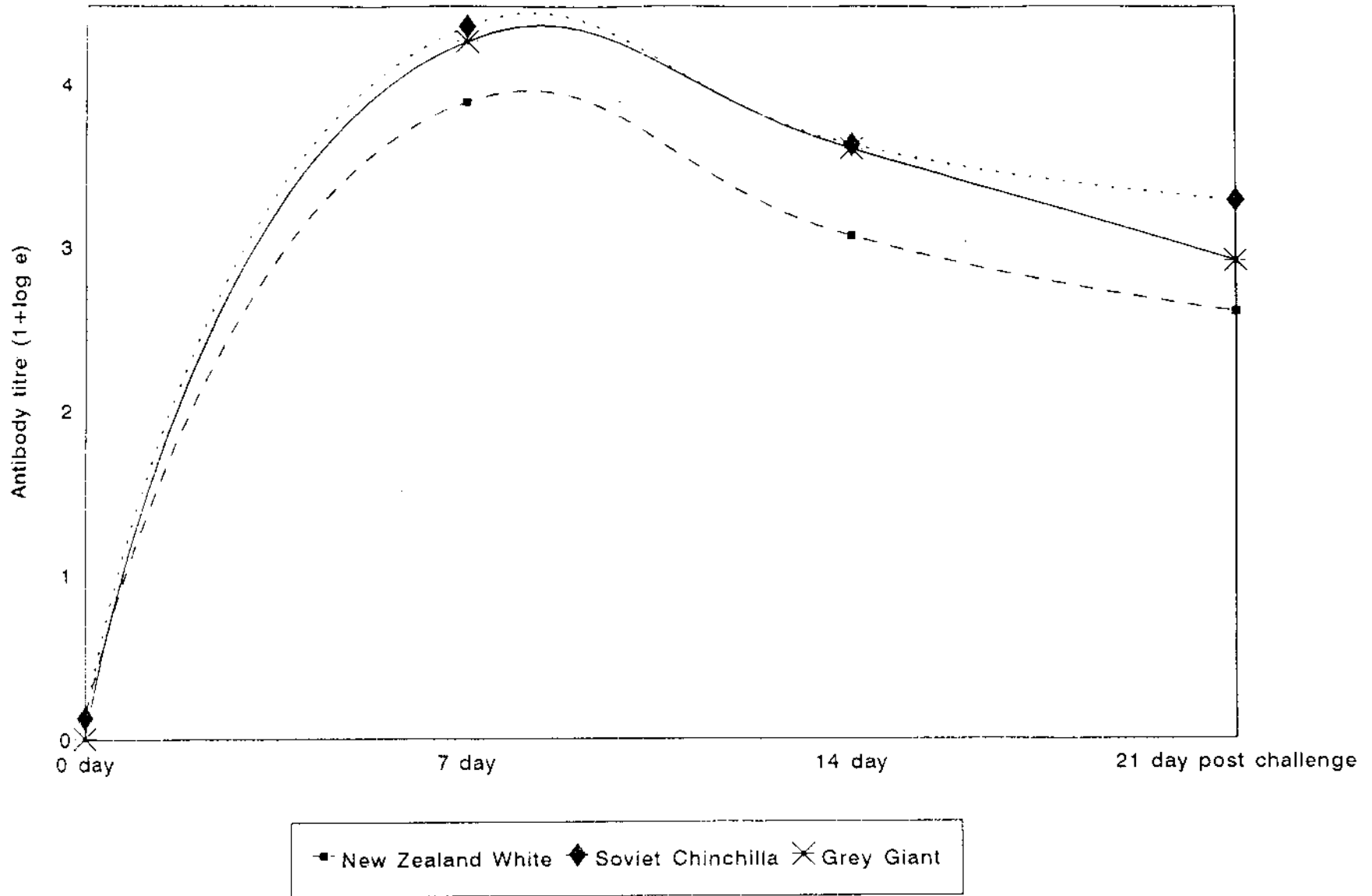
Fig.4.9 BREED COMPARISON OF HUMORAL IMMUNE RESPONSE TO CHICKEN RBC
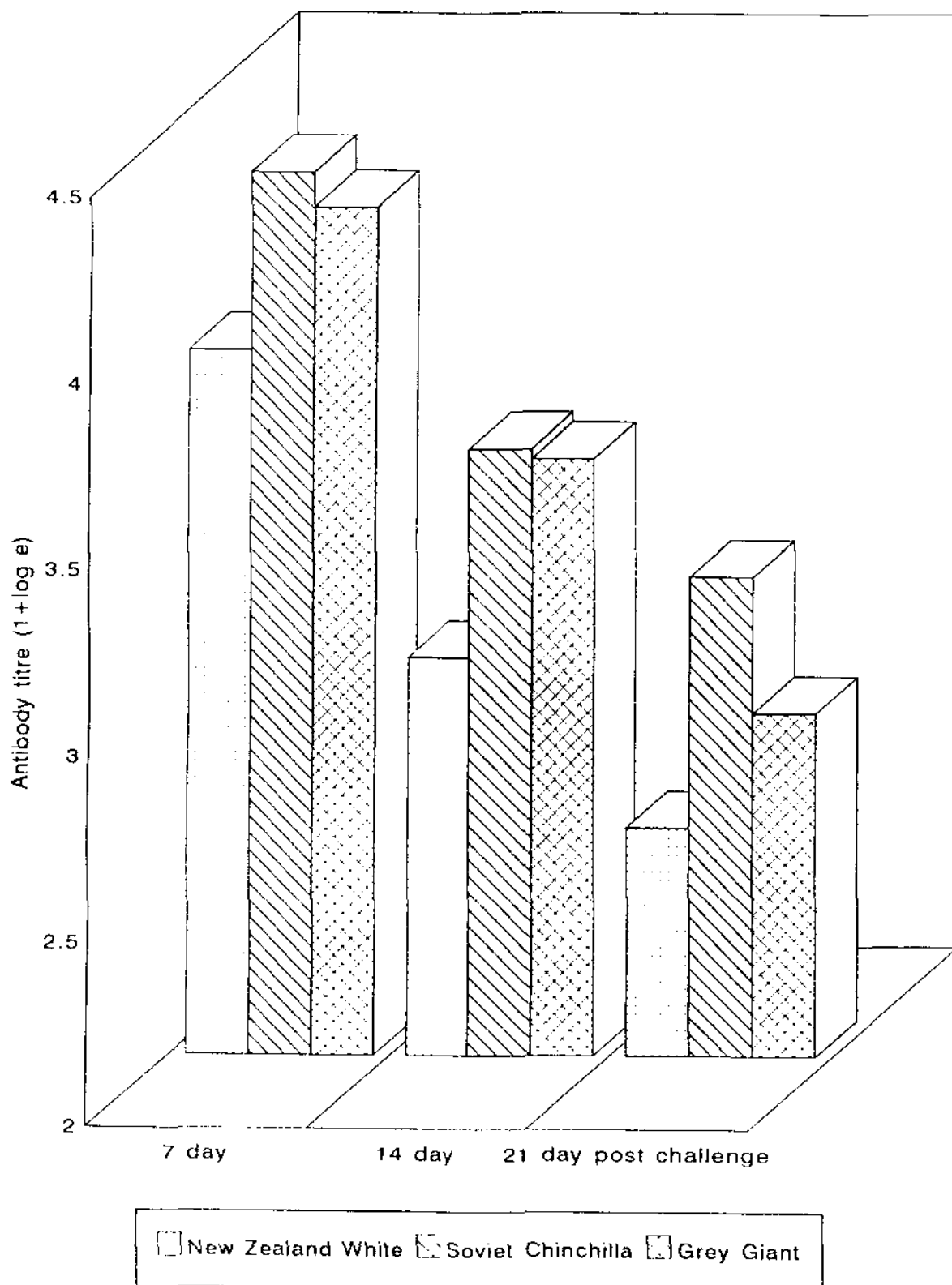
Fig.4.10   EFFECT OF SEX ON HUMORAL IMMUNE RESPONSE TO CHICKEN RBC
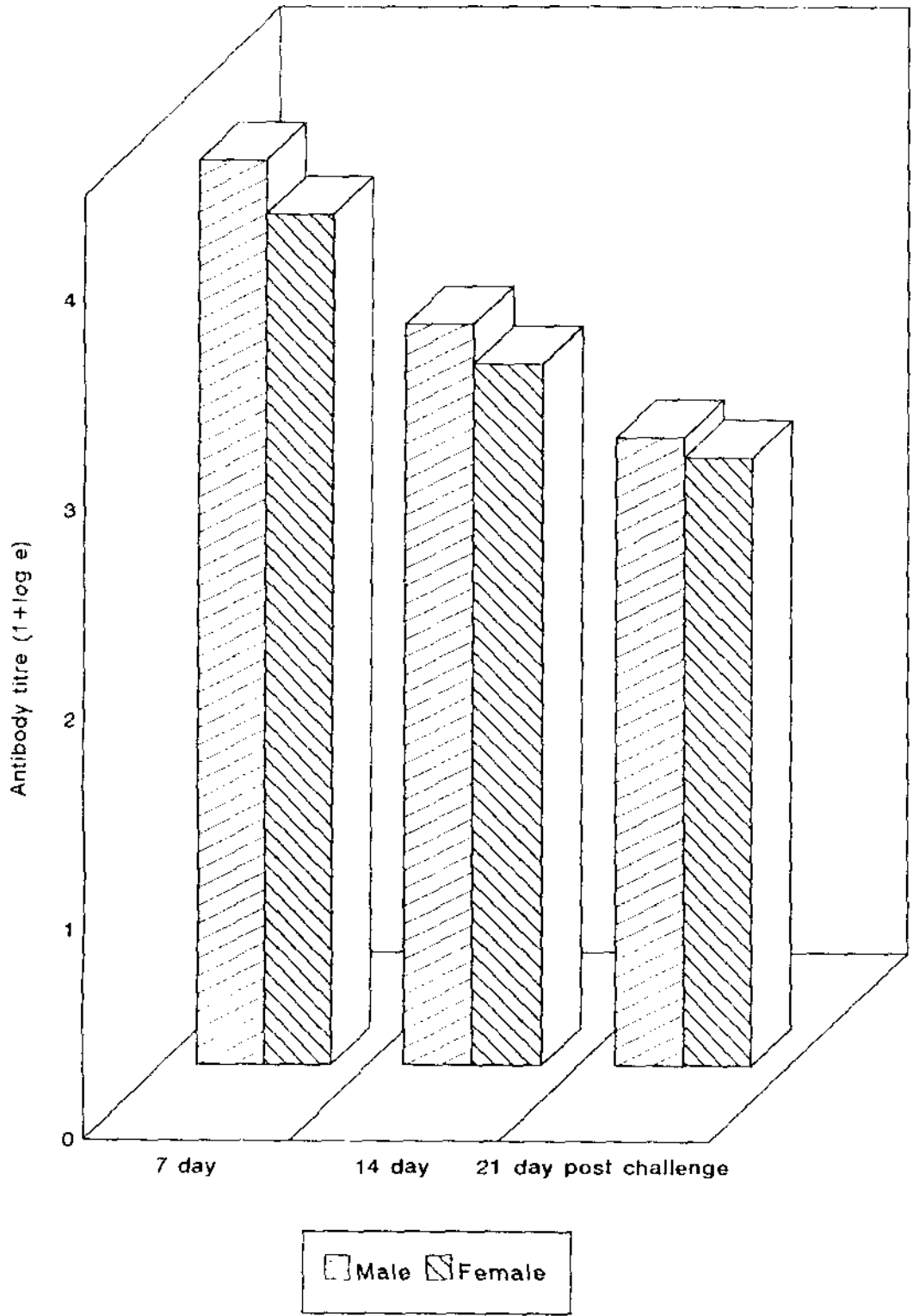
Discussion

DISCUSSION

5.1.1 Litter size at birth

The range and overall mean of litter size at birth of 1-9 and 4.37 respectively among New Zealand White, Grey Giant and Soviet Chinchilla were substantially lower than the reported values from temperate and subtropical climate. Litter size at birth obtained in the present study, compares well and is in agreement with the values of 4.4 reported by Rasthogi (1988) and 4.9 reported by Opoku and Lukefahr (1990) from tropical climate of West Indies and Ghanna, though substantially lower than the reported value of 9.5 by Koehl *et al.* (1994) from temperate climate. Litter s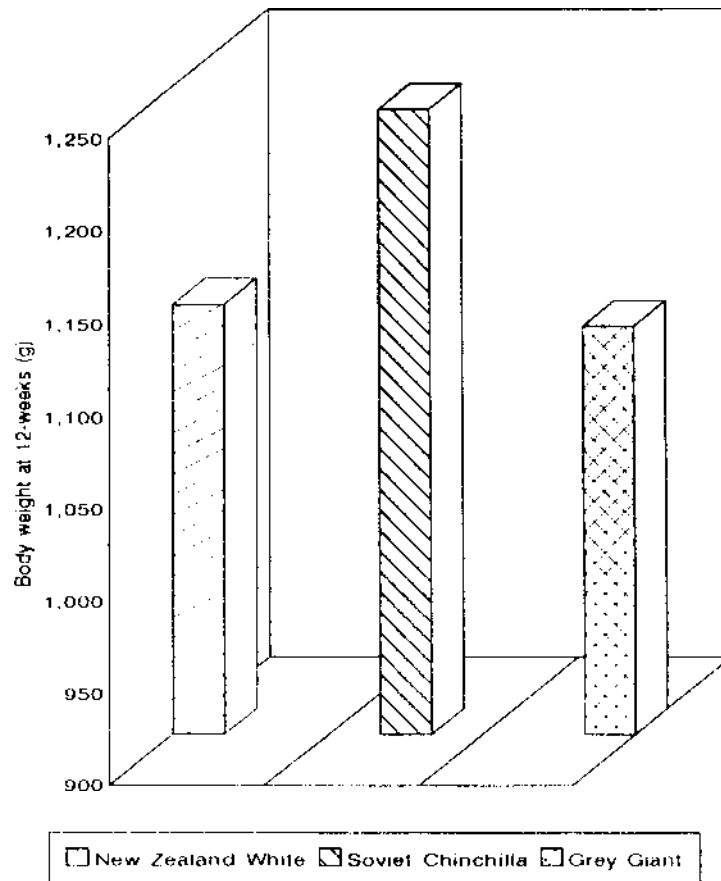ize at birth among broiler rabbits may be higher in subtemperate climate as per the reports of Misra (1990) with an average litter size at birth of 5.34. The climate in Kerala in addition to being tropical is also humid, adding up to the thermal stress.

5.1.1a Breed effects

The mean litter size at birth reported in the present study is much below the litter size reported from temperate and subtemperate areas. Gogeliya *et al.* (1982) reported from the temperate Georgian climate that litter size at birth in New Zealand White and Grey Giant were 9.91, 9.54 respectively. But it concurs with the values reported by Radhakrishnan (1992), Mukundan *et al.* (1993), Nandakumar and Thomas (1998a) from humid tropics of Kerala state.

Though the effect of breed has been reported to be significant on litter size at birth by Lee *et al.* (1988) and Afifi *et al.* (1989), the reports from India by Mukundan *et al.* (1993) and Gurmaj Singh (1998) substantiated the nonsignificance of breed on litter size at birth. This might be due to the fact that tropical climate offers substantial stress on temperate breeds and may also interfere with the prenatal survival of rabbit bunnies resulting in incomplete expression of full potential for the expression of litter size at birth.

5.1.1b Sire effects

Effect of sires within breed for litter size at birth was not significant in the present study. Reports available regarding sire effects on litter size at birth have categorically concluded that sire component exerts no substantial influence on the variation of this trait and litter size at birth has been postulated to be an attribute of the dam (Rollins *et al.* 1963; Kadry and Afifi, 1983; Khalil, 1993; Yamani *et al.*, 1994).

5.1.2 Litter weight at birth

Litter weight at birth of 227.36 g observed in the present investigation was lower than the values reported by Mukundan *et al.* (1993) with an average litter weight at birth of 370 g and Gurmej Singh (1998) with that of 390 g in the Indian tropics. The lowered litter weight at birth in the current study might probably be due to the lowered litter size at birth because of the high ambient temperature prevalent during the period of study. This is also supported by the highly significant positive

phenotypic and genotypic correlation between litter size and weight obtained in the present study.

5.1.2a Effect of breed

Grey Giant breed had a comparatively higher litter weight at birth probably due to high litter size at birth. The effect of breed on litter weight at birth was not significant and this is in confirmity with the reports from tropics (Viroji Rao, 1994; Gurmej Singh, 1998; Nandakumar and Thomas, 1998b).

5.1.2b Sire effects

Sire component of variance on the litter weight at birth was not found to be significant. This result endorses the studies of Afifi *et al.* (1992) and Yamani *et al.* (1994) who clearly stated that dams within sire contribute more to the variance than variance between sires.

5.1.3 Litter size at weaning

The litter size at weaning reported from temperate areas showed values around 7.5 whereas litter size at weaning among tropics have been reported to range from 3.2 to 5.14 from different countries (Matheron and Dolet, 1988; Radhakrishnan, 1992). However litter size at weaning in the present study is much lower than the reported values from tropics. This is mainly due to lowered litter size at birth in the present study and the extremely high ambient temperature during the period of current study which might have reduced the pre and post natal survivability among rabbit bunnies.

5.1.3a Breed effects

The effect of breed on litter size at weaning was found to be significant. Litter size at weaning among New Zealand White and Grey Giant were comparable with the mean values of 1.95 and 1.87 whereas, Soviet Chinchilla had a significantly low litter size at weaning of 1.18. This indicates the lowered preweaning survivability among Soviet Chinchilla contributing to the increased preweaning mortality and lowered litter size at weaning (Mukundan *et al.*, 1993). These findings is in full agreement with the reports of Lee *et al.* (1986); Afifi *et al.* (1989); Radhakrishnan (1992); Khalil *et al.* (1995). These findings is of significant importance in selecting breeds of rabbits suited to tropics.

5.1.3b Sire effects

The effect of sires within breed was not found to be significant on litter weight at weaning. This observation is in full agreement with the findings of Khalil *et al.* (1988), Afifi *et al.* (1992) who could also find no demonstrable effect of sires on litter weight at weaning.

5.1.4 Litter weight at weaning

The average litter weight at weaning obtained in the present study is comparitively lower than the reported values for broiler breeds of rabbits (Khalil *et al.*, 1987a; Opoku and Lukefahr, 1990). This possibly will be due to the lowered litter size at weaning obtained in the study.

5.1.4a Breed effect

Effect of breed on litter weight at weaning was found to be significant with Grey Giant having heaviest litter weight at weaning. The significant effect of breed on litter weight at weaning has been reported by Radhakrishnan (1992) and Gurmej Singh (1998) among broiler rabbits namely Grey Giant, Soviet Chinchilla and New Zealand White from India. The results of this study are in agreement with the above reports.

5.1.4b Sire effects

The effects of sires within breed was not found to be significant on litter weight at weaning among broiler rabbits. This observation is in concordance with the observations of Rollins et al. (1963), Khalil et al. (1988) and Afifi et al. (1992) who could also find no substantial effect of sires on litter weight at weaning. They postulated preweaning growth as a trait of dam.

5.1.5 Preweaning mortality

Heavy neonatal mortality has been a major stumbling block in the development of broiler rabbit production in tropics. The mean preweaning mortality in current investigation was to a tune of 76.2% and is in agreement with the reports of Rajadevan et al. (1989), which attributed 61.6% mortality among neonatal bunnies from humid Sri Lankan tropics, though the mortality pattern from the subtropical and tropical climate are comparatively less (Damodar and Jatkar, 1985; Bhasin et al., 1990 and Khalil et al., 1993).

5.1.5a Effect of breed

Present study could establish the superiority of New Zealand White and Grey Giant for preweaning survivability. The effect of breed on preweaning mortality was significant and Soviet Chinchilla had the lowest survivability. This is in accordance with the reports of Grobner *et al.* (1985), Mukundan *et al.* (1993) and Gurmej Singh *et al.* (1997).

5.1.5b Sire effects

In the present study, sire effects on preweaning mortality was not found to be significant. This finding is in confirmity with the results of Rollins and Casady (1967), Farqhaly *et al.* (1994), Farghaly (1996).

5.1.6a Phenotypic correlations among litter traits

Litter size at birth was estimated to have highly significant (P ≤ 0.01) positive correlation with litter weight at birth and litter size and weight at weaning. These findings are in accordance with the reports of Afifi *et al.* (1992), El-Sheikh and El-Bayoni (1994); Gurmej Singh (1998). These indicate the fact that direct selection for higher litter size at birth would be more effective for higher litter size and weight at weaning.

Litter weight at birth was found to have highly significant (P ≤ 0.01) positive correlation with litter size and weight at weaning and is in confirmity with the findings of Lukefahr *et al.* (1985), Afifi *et al.* (1992), El-Sayiad *et al.* (1993) and

Gurmej Singh (1998). This is indicative of a better growth and viability of litters which had a higher body weight at birth. This again confirmed by highly significant (P ≤ 0.01) association between litter size and weight at weaning in the current study, indicating a strong association between better growth and higher litter size at weaning and suggesting that a better growth rate might enhance the litter size at weaning.

In the present investigation, preweaning mortality was found to have highly significant (P ≤ 0.01) negative correlation with litter weight at birth, litter size and weight at weaning. Litter size at birth also had a significant (P ≤ 0.05) negative correlation with preweaning mortality. This finding endorses the studies of Khalil *et al.* (1988) and El-Sayiad *et al.*(1993). This association between litter size at birth and lowered preweaning mortality might be indicative of the probable association with fertility and viability which might indirectly enhance the better survival of prolific genotypes which may be biologically more successful. The highly significant (P ≤ 0.01) negative association of preweaning mortality with litter weight at birth, litter size and weight at weaning suggest the better health status and growth rate of more successful litters which survive to weaning.

5.1.6b Genetic correlations among litter traits

The genetic correlations of litter size at birth with litter weight at birth and litter size at weaning were highly significant (P ≤ 0.01) and positive. Genetic correlation between litter size and weight at birth had been reported to be highly significant (Khalil, 1986; Lahiri and Mahajan, 1982; Krogmeier and Dzapro, 1991).

Genetic correlation between litter size at birth and at weaning was reported to be highly significant and positive (Rouvier et al., 1973; Garcia et al., 1983; Khalil, 1986; Afifi, 1992). Results of the present study are in full agreement with the above reports. Similarly litter weight at birth and litter size at weaning had a highly significant (P ≤ 0.01) positive genetic correlation of 0.8446. Lahiri and Mahajan (1982) and Khalil (1986) could also observe similar results. These are indicative of the fact that selection for higher litter size and weight at birth may increase litter size at weaning.

5.2 Body weight at weaning

The body weight at weaning in this study averaged 611.73 g. This value concurs with the values reported by Radhakrishnan (1992) and Mukundan et al. (1993) for body weight at six weeks among broiler rabbits. However the body weights are much below the values observed for body weight at 42 days among Californian and Chinchilla breeds by Slawinski and Asias (1988) from temperate climate. This point out to the growth depressant effect of tropical climate on broiler rabbit breeds. This also necessitate the need for the development of rabbit genotypes suited to the humid tropics for better growth and survivability.

5.2.1a Breed effects

The least-squares analysis of variance for the effect of breed on body weight at weaning revealed the insignificant effect of breed on body weight at weaning. Soviet Chinchilla had lowest body weight probably indicating poor mothering ability

of the chinchilla does. The studies by Ferraz *et al.* (1991), Radhakrishnan (1992) and Mukundan *et al.* (1993) have demonstrated the effect of breed on body weight at weaning.

5.2.1b Sire effects

The effect of sire on body weight at weaning were not found to be significant. This is in agreement with the reports of Mc Reynolds (1975) and Dragnev and Tsocheva (1983). It is probable that maternal effects might have a significant influence on the weaning body weight compared to sire components.

5.2.2 Body weight at 12 weeks

The mean body weight 12 weeks were 1168.40 g. This value is in confirmity with the observations of Radhakrishnan (1992) and Mukundan *et al.* (1993). Similar reports from other parts of tropics also revealed more or less same gain in body weight (Opoku and Lukefahr, 1990).

5.2.2a Breed effects

Breed type was not found to have significant effect on body weight at 12 weeks. Contrary to higher body weight at weaning, Soviet Chinchilla had highest body weight at 12 weeks and is in agreement with the reports of Ahmed *et al.* (1986).

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5.2.2b Sire effects

The effect of sire on the body weight at 12 weeks was found to be significant. Mgheni *et al.* (1982) reported that maternal effects decrease in relative importance after weaning. And higher sire component of variance on body weight at 12 weeks was observed by Khalil *et al.* (1986) and Lui *et al.* (1987) who concluded that dam effects were more important from birth to weaning and sire effects were significant for adult body weight among broiler rabbits.

5.3.1 Immune response status

The mean antibody titres to chicken RBC at 0, 7, 14 and 21 days post immunisation were 0.106, 4.208, 3.454 and 1.693 respectively. The highest antibody titre was observed on seventh day of post immunisation. There was a decline in trend from day seven to day 21. This is in close agreement with Van Der Zijpp and Leenstra (1983), Miller *et al.* (1991), Pinard *et al.* (1992) and Nandakumar (1995).

The Forssman antibody titre to chicken RBC though negligible was observed in 20 per cent of animals. This is in contrast to presence of Forssman antibodies to sheep RBC in almost all adult rabbits (Nandakumar, 1995) and the difference possibly might be due to age difference of rabbits or due to difference in the antigen tested for Forssman antibodies.

5.3.1a Effect of breed

The breed effect was not significant on the Forssman antibody titre to chicken RBC or on the 7 and 14 days post immunisation. However breed effects on antibody

titre on 14 days post primary immunisation reached six per cent level of significance. The effect of breed on antibody titre at 21 days post immunisation was significant ($P \leq 0.05$).

Soviet chinchilla breed of rabbits had the highest antibody titre to chicken erythrocytes at 7, 14 and 21 days post primary immunisation. Whereas New Zealand White had lowest antibody titre throughout. The significance of breed effects on antibody responses had been reported in poultry by Van Der Zijpp (1978), Benda *et al.* (1990), Haddad *et al.* (1994), Leitner *et al.* (1994), in cattle by Banyard and Morris (1980) and in pigs by Rothschild *et al.* (1984), Buschman (1986). The nonsignificant effect of breed on antibody response to chicken RBC on 7 days post immunisation in this study is in accordance with Nandakumar (1995) in rabbits possibly indicating that peak antibody response in rabbit may have little association with breed. But persistency might be modulated by the breed effects.

5.3.1b Sire effects

Present experiment could clearly establish the significant effect of sires ($P \leq 0.05$) on antibody response at 7 and 14 days post immunisation. The effect of sires on persistency of antibody response on 21 days of post immunisation was highly significant ($P \leq 0.01$). These findings endorse the studies of Nguyen (1983) in sheep, Nandakumar (1995) in rabbits and Newman *et al.* (1996) in cattle.

5.3.1c Sex effects

The effect of sex on humoral immune response to chicken RBC was not found to be significant in the present investigation. The nonsignificant sex effects on antibody responses have been reported in chicken (Mc Corkle and Glick, 1980; Van Der Zijpp et al., 1986) and in sheep (Nguyen, 1983; Raadsma et al., 1996).

5.3.2 Heritability estimates

Heritability estimates of antibody responses at 7, 14 and 21 days post immunisation were 0.589, 0.727 and 0.953 respectively. Similar higher heritability estimates of 0.83 for humoral immune response in sheep (Nguyen, 1983), 0.76 in pigs (Knyazev et al., 1992), 0.922 in rabbits (Nandakumar, 1995) have been documented.

The significant sire effects and high heritability estimates of antibody response implies that antibody responses could be modified by selective breeding and strengthens the views of Ferreira et al. (1986). The antibody responses are controlled by additive effects of several individual loci.

5.3.3 Association among immune response traits

Correlation among antibody responses to chicken erythrocytes at 7, 14 and 21 days post primary immunisation were highly significant ($P \leq 0.01$). This highly significant correlation between intensity and persistency of antibody responses to a common antigen is to be expected since the genetic control for intensity and persistency of antibody response towards same antigen might be closely associated.

In the light of high correlation even among antibody responses to different antigens, this observation assumes significance (Heller *et al.*, 1992; Parmentier *et al.*, 1994; Sacco *et al.*, 1994; Parmenther *et al.*, 1997).

5.3.4 Association of immune response with economic traits

Body weight at six weeks had a significant negative correlation ($P \leq 0.05$) of (-)0.180 and (-)0.189 with antibody response at 14 and 21 days post primary immunisation. All other associations were estimated to be nonsignificant.

The negative association between antibody responses and body weight at four weeks among poultry was reported by Siegel and Gross (1980). In general growth and humoral immune response were found to be negatively associated (Van Der Zijpp, 1983; Miller *et al.*, 1992a; Parmentier *et al.*, 1997; Mashaly *et al.*, 1997). This association between fast growth and lowered antibody responses appears to suggest that increased fitness contributed by high antibody responses favour medium or lowered growth rate. In fact, Mashaly *et al.* (1997) have already established the lowered feed consumption associated with higher IL-1 production in high antibody producing animals.

Summary

SUMMARY

Rabbits possess promising prospects as an alternate source of meat for the developing humid tropics. The broiler breeds of rabbits evolved in temperate climate often failed to perform optimally in the tropical environments and as such have been found to be unsuitable for commercial exploitation in these climatic zones. This necessitates thorough evaluation on the performance of different temperate broiler breeds for litter traits, growth and viability and also to assess the factors involved in modulating viability and fitness traits. In this context, the genetics of humoral immune responses which is a major component of immunity, disease resistance and viability was assessed by the antibody response to chicken RBC. Association between immune response and production traits were also estimated to aid the commercial exploitation in intensive rabbit production systems.

Salient results of the present study are given below.

1. Litter size at birth averaged 4.37 with no breed and sire effects. This demonstrates the depressant effect of tropical stress on the litter size at birth, being much below the reported litter size at birth from temperate regions.

2. Litter weight at birth averaged 227.35 g with no significant effect of breed and sire on this trait. The litter weight at birth was lower than the values reported even from the tropical zones possibly due to the high ambient temperature prevalent during the period of study.

3. Litter size at weaning averaged 1.61 with significant effect (P ≤ 0.05) of breed on this trait. Grey Giant breed was found to have largest litter size at weaning. Sire component exerted no significant effect on litter size at weaning.

4. Average litter weight at weaning was 925.64 g. Grey Giant breed had significantly higher (P ≤ 0.05) litter weight at weaning compared to New Zealand White and Soviet Chinchilla possibly due to higher litter size at weaning. Sire effect was not evident for this trait.

5. Pre weaning mortality was confirmed to be a major impedement in broiler rabbit production using temperate breeds in the state with a pre weaning litter loss of 76.2%. Pre weaning mortality was significantly (P ≤ 0.05) influenced by breed of the rabbit with New Zealand White superiority for the pre weaning survival (32.8%) with the lowest survival rate for Soviet Chinchilla breed. Pre weaning litter mortality was not found to be influenced by the sire. This result is of value in selecting suitable breed and breed combination for the state.

6) Phenotypic correlation between litter size and litter weight traits at birth and at weaning were positive and significant. Pre weaning mortality was found to have significant negative correlation with litter size and weight traits. Higher litter size at birth tended to reduce pre weaning mortality among bunnies.

7)   Significant positive genetic correlation between litter size at birth with weaning litter traits is suggestive that direct selection for litter size at birth would improve weaning litter traits as a correlated response.

8)   Though the breed effects are not statistically significant, Grey Giant bunnies had the heaviest weaning body weight followed by New Zealand White and Soviet Chinchilla. Sire component of variance was not important for the weaning body weight.

9)   In contrast to preweaning growth, Soviet Chinchilla had the best post weaning gain with body weight at 12 weeks of 1237.66 g under the humid tropics of Kerala. Effect of sire on 12 week body weight was significant demonstrating the underlying strong genetic variation of this trait which could be exploited suitably in the broiler rabbit production.

10) Forssman antibody titre to chicken RBC was found only in 20% of animals. Humoral immune response to chicken RBC peaked on 7 day post immunisation and subsided thereafter.

11) Breed differences were not detected for humoral immune response to chicken RBC on 0, 7 and 14 day post immunisation. However, significant breed effect was evident on 21 day post challenge haemagglutinin titre. Soviet Chinchilla had consistently higher humoral immune response to chicken RBC compared to New Zealand White and Grey Giant rabbits.

12) Sire component of variance was significant for the humoral immune response to chicken RBC, on 7, 14 and 21 day post challenge. Heritability estimates of humoral immune response traits to chicken RBC were high. These results provide evidence for the importance of direct additive genetic variation for the primary antibody response of broiler rabbits to chicken erythrocytes indicating that selection for improved antibody response to chicken RBC in rabbits would be possible.

13) Correlations among antibody titres on 7, 14 and 21 day post immunisation were significant and positive, indicating strong association between intensity and persistency of antibody response.

14) Association between weaning body weight and humoral immune response to chicken RBC on 14 and 21 day post immunisation were significantly negative, revealing that the higher humoral immune response might result in lowered growth rate.

The results of the present study are suggestive of the unsuitability of temperate broiler rabbit breeds for the humid tropics of Kerala State with an average litter size at birth of 4.37, litter size at weaning of 1.61 and pre weaning mortality of 76.7%. This necessitates evolution of synthetic genotypes, utilising rabbits adapted to the humid tropics of the state like nondescript variety. Litter size at birth was found to have a strong negative association with preweaning mortality. Higher litter weight at birth and litter weight at weaning also contributed substantially to better viability. Immune responses were found to have strong genetic modulation, significant sire effects and heritability.

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IMMUNOGENETIC INFLUENCES ON LITTER TRAITS, VIABILITY AND GROWTH IN BROILER RABBITS

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ABSTRACT OF THE THESIS
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ABSTRACT

A detailed investigation into the genetic and environmental factors influencing litter traits, growth and viability among three temperate broiler breeds of rabbits namely New Zealand white, Grey Giant and Soviet Chinchilla, maintained at rabbit research station under the Centre for Advanced Studies in Animal Genetics and Breeding of Kerala Agricultural University was undertaken. The effect of breed and sire on litter traits, growth and viability were assessed. Association among these traits were estimated. In an attempt to ascertain the genetics of humoral immune response of broiler rabbits, antibody response to chicken RBC was analysed. The influence of breed, sex and sire on humoral immune response was ascertained. Heritability of humoral immune response was worked out. The interrelationship between humoral immune response, growth and viability was estimated.

Litter size at birth averaged 4.37 ± 0.15 among rabbits. The effect of breed and sires within breed was not significant on this trait. Grey Giant rabbits had highest litter size at birth.

Overall mean for litter weight at birth was 227.36 ± 6.81 g. Breed and sire effects were not significant on litter weight at birth. Grey Giant breed had highest litter weight at birth of 236.70 ± 14.74 g.

Breed differences were significant (P≤0.05) for the litter size at weaning among broiler rabbits. Grey Giant had largest weaning litter size of 1.96±0.25 followed by New Zealand White (1.87±0.24) and Soviet Chinchilla (1.18±0.21). The effect of sires on this trait was not significant.

The effect of breed on litter weight at weaning was significant (P≤0.05). Grey giant had heaviest litter weight at weaning with a mean of 1084.15 g New Zealand White and Grey Giant had weaning litter weight of 1073.88 g and 707.96 g respectively. Sire component of variance was not significant for this trait.

Pre-weaning mortality among the three breeds of broiler rabbits averaged 76.20%. The influence of breed on preweaning mortality was significant (P≤0.05). New Zealand White rabbits had least preweaning mortality and Grey Giant suffered from maximum preweaning losses. Preweaning mortality among the litters of various sire groups were not differed significantly.

Phenotypic correlation coefficient among litter size traits and litter weight traits studied were positive and highly significant (P≤0.01). Litter size traits had highly significant (P≤0.01) positive correlation with litter weight traits. Pre-weaning mortality had a highly significant (P≤0.01) negative correlations of (-)0.27, (-)0.85 and (-)0.81 respectively with litter weights at birth and at weaning and litter size at weaning. Association between litter size at birth and preweaning mortality was significant (P≤0.05) and negative.

Genetic correlations of litter size at birth with litter weight at birth and litter weight at weaning were highly significant (P≤0.01) and positive. Litter weight at birth had a highly significant (P≤0.01) genetic correlation with litter size at weaning.

Overall mean of body weight at weaning was 611.73 g among rabbits. Effect of breed and sire was not significant on this trait. Grey Giant, New Zealand White and Soviet Chinchilla respectively had weaning weight in grams of 641.92, 614.33 and 564.36.

Body weight at 12 week averaged 1168.41 g in broiler rabbits. Though the breed effect was not significant, Soviet Chinchilla had heaviest body weight at 12 week with a mean of 1237.66 g followed by New Zealand White (1132.97 g) and Grey Giant (1121.19 g). The effect of sire was significant(p≤0.05) for the variation body weight at 12 week.

Effect of breed, sire and sex on Forssman antibody titre to chicken RBC was not significant. Forssman antibody titre $(1 + \log_e)$ averaged 0.11 in the population.

Antibody response to chicken RBC peaked 7 day post immunisation with a mean of 4.208 and dwindled to a mean of 3.454 and 2.932 respectively on 14 and 21 day post immunisation.

The effect of breed was not significant on 7 and 14 day post-immunisation antibody titres to chicken RBC. However, 21 day post-immunisation antibody titres to chicken RBC was significantly (P≤0.05) influenced by the breed. Soviet chinchilla rabbits consistently had higher antibody titres with a mean of 4.3715, 3.6320 and 3.2903 at 7, 14 and 21 day post-immunisation. Though not significant, males had higher antibody titres to chicken RBC compared to females. sire had significant effect on 7th day (P=0.0486), 14th day (P=0.0218) and 21st day (P=0.0047) post-immunisation antibody titres. Heritability estimates were high for the immune response traits.

Phenotypic correlation between 7, 14 and 21 day postimmunisation antibody titres were highly significant (P≤0.01). Association of Forssman antibody titre with postimmunisation antibody titres were not significant. Body weight at weaning had significant (P≤0.05) negative correlation of (-)0.18 and (-)0.19 respectively, with 14 and 21 day postimmunisation antibody levels to chicken RBC.

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