ASSESSMENT OF GROWTH AND REPRODUCTIVE TRAITS IN DIALLEL CROSSING OF THREE RABBIT BREEDS

BY

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DEPARTMENT OF ANIMAL SCIENCE
FACULTY OF MEDICINE
AHMADU BELLO UNIVERSITY
ZARIA, NIGERIA

AUGUST, 2010

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BY

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B.Sc. (Maiduguri, 1994), M.Sc. (ABU, 2006)
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DEPARTMENT OF ANIMAL SCIENCE
FACULTY OF MEDINE
AHMADU BELLO UNIVERSITY
ZARIA, NIGERIA

AUGUST, 2010

DECLARATION

I declare that the work in the dissertation entitled '**Assessment of Growth and Reproductive Traits in Diallel Crossing of Three Rabbit Breeds'** has been performed by me in the Department of Animal Science, under the supervision of Professor G.N. Akpa, Dr. B.I. Nwagu and Professor I.A. Adeyinka.

The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another higher degree or diploma at any university.

……..	……	……
Name of student	Signature	Date

CERTIFICATION

This dissertation entitled "**ASSESSMENT OF GROWTH AND REPRODUCTIVE TRAITS IN DIALLEL CROSSING OF THREE RABBIT BREEDS**", by Kabir Mohammed meets the regulations governing the award of the degree of Doctor of Philosophy (Ph.D) of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This dissertation is dedicated to The **Almighty Allah** the Creator of Heavens and Earth; to my dearly-loved aged Mum Hajiya Maryam Ibrahim (Inna), in grateful recognition of her love, care, and prayers at all times; and to the memory of my late Father (Malam Mohammad Kyari), who passed away before the realization of this dream; May **Allah** grant him eternal rest in Al-Jannatul-Firdaus, Amen.

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ABSTRACT

A study was conducted to assess the growth and reproductive performance of three breeds of rabbit in a full diallel crossing scheme. Data generated from 162 purebred kits born in 36 litters and 408 crossbred kits from 72 litters were used. The purebred kits comprised 38 Chinchilla (CHC), 54 New Zealand White (NZW) and 70 California White (CAW) kits. The crossbred groups comprised 217 'main cross' kits and 191 'reciprocal cross' kits. Birth and weaning traits considered included gestation length, litter size at birth and weaning, litter weight at birth and weaning, preweaning mortality and weaning sex ratio while growth traits included weekly body weight (BW) and body linear measurements: ear length (EL), body length (BL), nose to shoulder (NTS), shoulder to tail-drop (STT), heart girth (HG), tail length (TL), length of front leg (LFL) and length of back leg (LBL). Results of litter size at birth for CHC, NZW and CAW breeds were 6.05, 6.89 and 7.33, respectively. The litter sizes at 21 and 35 days of age were 4.61, 5.5 and 5.94, and 4.58, 5.39 and 5.86 for CHC, NZW and CAW breeds, respectively. Results for Litter weight for CHC, NZW and CAW breeds were 163.68g, 149.25g and 155.94g at birth, 952.13g, 1041.02g and 1067.29g at 21 days of age and 1596.93g, 1764.05g and 1838.40g at 35 days of age, respectively. The respective birth weights for individual kits for CHC, NZW and CAW breeds were 27.05g, 21.66g and 21.27g while the values at 21 and 35 days of age were 206.53g, 189.27g and 179.68g, and 348.67g, 327.28g and 313.72g for CHC, NZW and CAW breeds, respectively. The above results revealed that the CHC breed produced kits that were individually heavier at birth and at weaning than the kits from NZW and CAW breeds. The relatively high performing ability of the CHC breed was confirmed by the results of the general combining ability (GCA) on growth traits which indicated that CHC breed showed significantly ($P<0.05$) high superiority over NZW and CAW breeds for 8 traits (BW, EL, BL, TL, NTS, STT, LFL and LBL).

Nevertheless, heritability estimates for litter size from birth to weaning were high (0.49–0.64) in the CHC breed, while the estimates for litter weight were moderate to high (0.34–0.52). In the NZW and CAW breeds moderate to high estimates of heritability for litter size and litter weight (0.33–0.46 and 0.28–0.41, and 0.31–0.42 and 0.32–0.41, respectively) were observed from birth to weaning. In the crosses however, the results of specific combining ability (SCA) indicated that the CHC x NZW cross was the best combination regarding the use of sire and dam breed to exploit non-additive genetic variance in 6 of the 9 examined body measurement traits. It was observed also that the CHC breed performed generally well in crosses with either NZW or CAW. Cross performance was however low for NZW x CAW cross, implying poor manifestation of non-additive gene action. Moderate to high coefficients of genetic correlation in the CHC breed for growth traits (0.43±0.03–0.88±0.24; 0.27±0.04–0.85±0.15; 0.20±0.02–0.83±0.14) at 6, 8 and 10 weeks of age respectively, were observed. Positive and significantly high association for HG, BL, NTS, STT and BW indicated that absolute height and frame size were complementary. Beside, selection for increased measurement for any trait and in any of the breeds studied herein, would mean positive and significant influence on the others and therefore, increased skeletal stature with concormitant increase in other absolute body measurements. It was concluded that rabbit farmers in the Guinea Savannah zone of Nigeria would operate more profitably if they keep Chinchilla does with optimal feeding levels especially after weaning so as to attain faster growth and market weight. The progeny from CHC x NZW combination proved the best among the crossbreds, probably due to high exploitation of heterosis from both parents.

CHAPTER ONE

1.0 INTRODUCTION

While human population growth in the developed countries is stabilizing, populations are still increasing rapidly in virtually all developing countries in Africa, Asia and the Americas. Most of the world's population is fed by the output of small farms in developing countries (Gallardo, 1984), which continues to get smaller as the human population pressures increase, and will serve as the primary source of food for the millions of people in developing countries. The recent Nigerian population figure of over 140 million (NPC, 2006) is a pointer to the fact that urgent action needs to be taken in order to meet the food production, availability as well as the protein requirement of the entire populace.

Rapid human growth and low protein intake are some of the problems facing developing countries. According to Fayeye and Ayorinde (2007), an average Nigerian consumes 7.5g of animal protein per day as against 28g per day consumed by an average Briton, despite the recommendation made by the British Medical Association of a minimum daily intake of 34.4g of animal protein per caput.

Nigeria, like many developing countries, has for long been plagued with the problem of worsening situation of inadequate consumption of animal protein. With the continuous rise in the cost of beef, mutton, chevon and chicken, there is need for a greater emphasis on the development of other less common, but potentially sustainable sources of animal protein for the populace (Togun *et al.*, 2009). A panacea for the protein shortage is to target prolific livestock species that for one reason or another have not played a major role in animal agriculture (Fayeye and Ayorinde, 2003; Das and Bujarbarua, 2005). Small livestock, such as rabbits, have many qualities that might benefit the small holder, subsistence-type integrated

farming and food production systems in developing countries (Aduku and Olukosi, 1990; Taiwo *et al*., 2005). Vietmeyer (1985) had coined the term "microlivestock" to describe these animals. He aptly stated, "Livestock for use in developing countries should, like the computers, be getting smaller and more 'personal'. Mainframes, such as cattle, cannot solve the widespread shortage of meat because they require too much space for the landless and the poor. Miniframes, such as sheep, goats and the pigs, could play an increasing role if not for the attachments of certain cultural and religious taboos. But the tiny, 'user-friendly' species for home use show the most promise and they are being overlooked". Among the microlivestock that Vietmeyer suggested were the rabbits, guinea pigs, grass-cutter, bush rats, the blue duiker (which is a small antelope), dwarf Asian deer, iguana and the capybara (a large South American rodent).

The 3rd World Rabbit Congress held in 1984, recommended that Governments give high priority to the development of rabbit projects in their national development and budget plans. Governments of certain developing countries have formally established national rabbit programmes to support self-help, small-scale rabbit production (Lukefahr and Cheeke, 1990). Rabbit projects supported through such national policies in developing countries include those in Brazil, Cameroon, the Caribbean, China, Egypt, Ghana, Guatemala, India, Indonesia, Kenya, the Republic of Korea, Mexico, Mozambique, the Philippines and Zambia. Perhaps the most internationally recognized rabbit programme in Africa is the National Rabbit Project of Ghana.

Following an effective promotion campaign, there was a strong awareness among Ghanaians of the self-reliant benefits in raising rabbits, which has been socially accepted on the basis of its low space requirements; the animal's high reproductive rate and lack of competition with humans for the same foods; minimal zoonotic health hazards and the minor

capital investment involved (Lukefahr *et al.,* 1992). In addition, there are no social taboos regarding the consumption of rabbit meat and the diminishing supply of bush-meat has been a strong impetus to small-scale rabbit farming.

The world's domestic rabbit population estimated to be 709 million (Lukefahr, 1985), was comparable to 764 million swine (FAO, 2003). About 82% of the world's population of rabbit meat comes from the developed nations (Lebas *et al.,* 1986), meaning that approximately only 18% of the total rabbit meat production occurred in the developing countries. The cost of other conventional animal products like milk, fish and egg has also gone beyond the reach of the common man due to their staggering and intimidating prices (Onyimonyi and Ene, 2003). Rabbits are such wonderful animals that possess a number of characteristics which made them particularly suitable as meat producing small livestock in developing nations. Among these characteristics are small body size, rapid growth, short generation interval and high reproductive potential, utilization of non-competitive feeds, potentials for genetic improvement and production of high quality meat and useful by-products.

In most tropical countries there are "local breeds" of rabbits which have been raised in the local environment for many years. Typically, the local breeds are small and slow growing, but are presumably more adapted to the environment than imported breeds. The use of local breeds in crossbreeding programs with imported breeds to improve productivity, while maintaining adaptation to the environment, has been practiced. Falconer (1989) showed that a cross between two base populations would show heterosis if they differ in the frequency of genes affecting a given trait. According to Ahmed (2003), crossing does not only take advantage of traits with considerable non-additive genetic variations (i.e. dominance and

epistatic), but also exploits differences in additive effects (i.e. differences in average performance between populations as a deviation from the overall mean) between populations.

For many years, the aim of genetic selection in rabbit dam lines has been to increase the number of young born alive or still alive at weaning and successfully raised to market weight (Larzul and Gondret, 2005). However, it is necessary to distinguish according to the specialization of the lines, paternal or maternal. Paternal lines are commonly selected for postweaning daily gain (Estany *et al.*, 1992; Gomez *et al.*, 2002) or for a weight at a given age (Lukefahr *et al.*, 1996; Larzul and Gondret, 2005).

Diallel cross is a very important tool used to evaluate the performance of breeds and/or strains in their various combinations. In addition, analysis of diallel crosses enables the breeder to partition total genetic variation into additive and non-additive genetic variance (Nagpure *et al.*, 1991). Genes could impart additive and non-additive effects on traits. While additive gene action is transmissible from parents to their offspring, non-additive gene action (dominance and epistasis) is not. Diallel crossing further entails taking advantage of the combining ability of both parents (male and female) involved in the cross.

Diversity generated among breeds may result in greater non-additive genetic activity in crosses originating from breeds selected for different criteria. Non-additive genetic effect is an important factor in carcass production, due to opportunities to combine stocks that complement each other or interact favourably. This allows development of mating combinations for rapid growth and other important economic traits (Marks, 1995). Heterosis or hybrid vigour for certain traits exists when the average performance of crossbred progeny is superior to the average performance of the two parents. This means that the magnitude of non-additive (mainly dominance) is comparatively substantial. The amount of heterosis can vary practically, depending on the environment and on the populations being crossed.

Theoretically, the magnitude of heterosis is inversely related to the degree of genetic resemblance between parental populations (Willham and Pollak, 1985) and it is expected to be proportional to the degree of heterozygousity of the crosses (Sheridan, 1981). The main purpose of crossing is to improve carcass characteristics and to combine different traits which are advantageous in the crossed breeds (i.e complementarities) (Willham and Pollak, 1985).

JUSTIFICATION:

Knowledge of the type of gene action operating in a population enables the breeder to formulate breeding plans for genetic improvement of characters. For the fact that not much breeding work has been done with rabbits in Nigeria, it is important to provide such baseline information which could serve as basis for future research. There is little or no published information on the assessment of reproductive and growth traits of rabbits in Nigeria, using the diallel crossing technique. This therefore necessitated this work.

OBJECTIVES:

The study is aimed at assessing the growth and reproductive characteristics in a diallel crossing of three rabbit breeds; specifically to:

1. Evaluate the growth performance and carcass characteristics of the crossbred kits.
2. Evaluate the reproductive performance and productivity of the purebred does.
3. Estimate the maternal heterosis and reciprocal effects for litter traits among the three breeds of rabbits.
4. Estimate the additive and non-additive differences in postweaning growth and carcass characteristics of the pure and crossbreds
5. Estimate the genetic parameters of the traits considered in the purebreds.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 HISTORICAL ORIGIN OF THE RABBIT

An interesting account of the history of Rabbit (*Orictolagus cuniculs*), from antiquity to the second half of the 20th century, was given by Zeuner (1963) as cited by Janusz and Josef (1982). He relates that rabbit originated in the Iberian Peninsula, where they were confined until the end of the last period of glaciations, after which they were freed to migrate. It is a descendant of the European wild rabbit including many other species like the Cottontail, Pikas and the Hares which made up the Order Lagomorpha. According to Lebas *et al.*(1986), man's relationship with the European 'true' rabbit was first recorded by the Phoenicians over 1,000 years B.C. when they termed the Iberian Peninsula 'i-shephan-im' (literally, 'the land of the rabbit'), which the Romans converted to the Latin form, Hispania, and hence the modern word Spain.

The Romans kept rabbits in walled enclosures ('leporaria') and there was evidence that they brought them to Britain, but they did not survive there. In Europe, especially France, the domestication process was well under way by the 5th Century. In the 12th Century, the Normans brought them to Britain where they became established and remained both as domestic and wild animals.

The first breeding experiment took place in France Monasteries between the 6th and 10th Centuries A.D, when colonies of breeding stock were maintained. In the 16th Century, black, white, piebald (i.e black and white) and other colour variants were mentioned by Agricola. By the 17th Century, white domestic does were being crossed with wild bucks, whose dominant coat colour was more acceptable to the consumer. By the turn of the 19th

Century, Britain was said to be the stud farm of the world for breeding stock, exporting to nearly all countries where rabbits were known to be bred (Lebas *et al.,* 1986). The main emphasis at that time was on the pelt, with the carcass as a byproduct. As a source of meat, the commercial production of domestic rabbit began seriously in the late 1920s, with pelt as byproduct. This change in trend influenced genetic selection and placed the emphasis on a strain of rabbit whose progeny would reach a table weight of 2Kg live weight while growth rate and feed conversion were still maximal. In 1995, 61 breeds and 351 varieties of rabbit were recognized in the United Kingdom and more are continuously evolving by selective breeding and mutation (Lukefahr *et al.*, 1996).

2.2 ANATOMICAL AND BIOLOGICAL DESCRIPTION OF THE RABBIT

Thakur *et al.* (1988) stated that rabbit belongs to the Phylum Chordata, Subphylum Craniata, Class Mammalia, Subclass Eutheria, Order Lagomorpha, Family Leporidae, Genus Oryctolagus, Species cuniculus. They are social burrowing herbivores that are natural prey for majority of carnivores. As a prey species, the rabbit have evolved to be constantly vigilant, lightweight and fast-moving, with a highly efficient digestive system that enables them to spend the minimum time possible above ground and in danger of capture. For the same reason of attracting predator attention, rabbit behaviour is not florid and overt and relies heavily on scent. The life expectancy of the rabbit is 5 – 8 years, but some individuals live up to 10 years or more (Janusz and Josef, 1982).

2.2.1 Musculoskeletal system

The rabbit skeleton is light, making up only 7–8% of its bodyweight (Johansson and Rendel, 1978). Skeleton of dermal origin forms the frame work of the body and is called endoskeleton. The exoskeleton is derived from the integuments and lies either above or within the limit of the skin. According to Thakur *et al.* (1988), the cartilage and bones together with

other forms of connective tissues are the structural elements of the endoskeleton. The forelimbs are short, fine and consist of upper arm, forearm and hand, with 5 digits each ending in curved horny claw (Thakur *et al.* 1988). The hind limbs which are longer and more powerful are divided into thigh, shank, ankle and foot, which has only 4 clawed digits (Thakur *et al.,* 1988). The plantar surface of the hind limb from the tarsus distally is in contact with the ground at rest. Body conformation varies greatly depending on the breed, from 1kg to 10kg and from the squat or "cobby" shape of the dwarf breeds to the lithe and lean "racy" Belgian Hare. Skull morphology can lead to disease in some breeds, especially dental problems. The forelimb has five digits and the hind limb four. The vertebral formula of the rabbit is C7T12L7S4C16 (i.e 7 cervical, 12 thoracic, 7 lumber, 4 sacral and 16 caudal vertebrae) (Johansson and Rendel, 1978). However, thirteen thoracic vertebrae are seen in some breeds (Lebas *et al.,* 1986). Rabbit muscle is light pink in colour.

2.2.2 The Oral cavity and Rabbit's Dentition

The upper lip of the rabbit is cleft. The dental formula is 2/1,0/0,3/2,3/3; i.e two upper incisors and one lower, no canine teeth in both upper and lower jaw, three upper and two lower premolars and then three molars each for upper and lower jaw (Johansson and Rendel, 1978). The incisors are used for grazing and food is then passed to the back of the mouth for grinding. The incisors have enamel layer only on the surface, which wears more slowly than the posterior surface, thereby maintaining a chisel shape for cutting herbage. The vestigial second pair of upper incisors is located directly behind the first pair and are known as "peg teeth" (Janusz and Josef, 1982). Rabbit teeth are open rooted, long-crowned and grow continuously. The cheek teeth are wider apart on the maxilla than on the mandible and the lower teeth grow faster than the upper. The oral commissure is small and the oral cavity long and curved. Cheek folds across the diastema make visualization of the cheek teeth difficult in

the conscious animal. The tongue is large and has a mobile rostral portion and a relatively fixed thicker caudal portion. According to Janusz and Josef, (1982) there are four pairs of salivary glands: parotid, submaxillary, sublingual and the zygomatic.

2.2.3 The Rabbit Skin

Female rabbits possess a large fold of skin under the chin known as the dewlap, from which they pull hair to line the nest before kindling. The toes and metatarsal areas are completely covered with hair and there are no footpads. Scent glands are located on the underside of the chin, either side of the perineum (inguinal glands) and at the anus (anal gland). The inguinal glands are large and pouch-like and often contain a yellow/brown oily deposit. According to Lasley (1978), hair coat depends on breed and the normal coat consists of a short soft undercoat protected by longer guard hairs. The only hairless areas are the tip of the nose, part of the scrotum and the inguinal folds. In the Rex breed, the guard hairs are shortened, which do not protrude above the level of the undercoat. Satin breeds have an altered hair fibre structure that gives the coat a characteristic sheen. Angora rabbits have very long undercoat and guard hairs that are harvested for spinning into wool and needs regular grooming to prevent matting (Lasley, 1978). The guard hairs are the first to emerge in the new-born kits, followed by the undercoat. By few days, the soft ‘baby’ coat is well developed and it persists until about five to six weeks of age. An intermediate or pre-adult coat then replaces this, followed by the adult coat by about six to eight months of age.

Thereafter most rabbits moult approximately twice a year, but this can vary. Moulting starts at the head and proceeds caudally. Pregnant or pseudo-pregnant does undergo a loosening of the hairs on the belly, thighs and chest, which are then easily plucked to line the nest and expose nipples. Tactile vibrissae are present on the muzzle, which are used to help

locate food and when underground. Female rabbits possess four to five pairs of nipples on the ventrum. Nipples are absent in the male (Lebas *et al.,* 1986).

2.2.4 Ears and Eyes

Rabbit's eyes are large and located laterally with a blind spot in the area beneath the mouth for food detection by the sensitive lips and vibrissae. The lens is large and almost spherical, and the ciliary body is poorly developed therefore accommodation is limited. The retina is merangiotic, with optic disc lying above the midline of the eye and retinal vessels spreading horizontally out from it (Lebas *et al.,* 1986). The optic disc has a natural depression or cup. A third eyelid is present in the rabbit and the harderian gland is located just behind it. This gland has two lobes; the upper being white and the lower larger and pink in colour. Lebas *et al.,* (1986) further explained that the gland is larger in males especially during the breeding season. The rabbit ears are highly vascularized and are involved in heat regulation, containing large arterio-venous shunts. Ear size varies between breed and those that hang down are refereed to as "lops".

2.2.5 The Digestive tract

Rabbits are hind-gut fermenters adapted to digest a low quality, high fibre diet containing mainly of grass (Aduku and Olukosi, 1990). However, unlike other hind-gut fermenters, for example the horse, rabbit has a very rapid gut transit time and eliminates fibre from the digestive tract as soon as possible. This permits body size and weight to remain low, which is advantageous in a prey species. In the wild, feeding takes place mainly in the early morning, evening and at night (Aduku and Olukosi, 1990).

The gastrointestinal tract makes up 10 – 20% of body weight (Lasley, 1978). The stomach is thin-walled and poorly distensible with a well-developed cardia and pylorus.

Vomiting is not possible in the rabbit because food and caecal pellets are always present in the stomach. The duodenum and jejunum are narrow and at the end of the ileum there is the sacculus rotundus, rich in lymphoid follicles and also known as ampulla ilei or ileocaecal tonsil. According to Lasley (1978), the caecum is very large, thin walled and coiled, and has many sacculations. It terminates in the vermiform appendix which is also rich in lymphatic tissue. The caecum lies on the right side of the abdomen and its contents are normally semifluid.

The colon, as Lasley (1978) further explained, is sacculated and banded. Colonic contractions separate fibrous from non-fibrous particles, and fibre moves rapidly through for excretion as hard faecal pellets. Antiperistaltic waves move fluid and non-fibrous particles back into the caecum for fermentation. Three to eight hours after eating, and thus mainly at night, soft, mucus-covered caecal pellets are expelled and eaten directly from the anus (a process known as caecotrophy, coprophagy, refection or pseudorumination). Arrival of the caecotrophs at the anus triggers a reflex licking of the anus and ingestion of the caecotrophs, which are swallowed whole and not chewed (Lasley, 1978). A muscular band of richly innervated tissue with a thickened mucosa, the fusis coli, lies at the end of the transverse colon and acts to regulate colonic contraction and controls production of the two types of pellets. The mucus covering protects the caecal pellet bacteria from the low pH of the stomach.

Caecotrophs remain in the stomach for up to six hours with continued bacterial synthesis, and eventually the mucus layer dissolves and the bacteria are killed (Johansson and Rendel, 1978). This process of caecotrophy allows absorption of nutrients and bacterial fermentation of products (amino acids, volatile fatty acids and vitamins B and K) and the redigestion of previously undigested feed. A feed item can thus pass twice through the

digestive tract in 24 hours (Lasley, 1978). The pancreas is diffused and located in a pocket formed by the transverse colon, stomach and duodenum. A gall bladder is present and rabbits secrete mainly biliverdin in the bile rather than bilirubin. The pancreatic duct and the bile duct are separate. The spleen is flat and elongated and lies on the dorsolateral surface of the greater curvature of the stomach (Johansson and Rendel, 1978).

Composition of faeces and caecotrophs

	Dry matter	*Crude protein*	*Crude fibre*
Faeces	*53%*	*15%*	*30%*
Caecotrophs	*39%*	*34%*	*18%*

Source: Lebas *et al.* (1986)

2.2.6 The Liver

The liver is the largest gland in the body of the rabbit. Its anterior surface is convex and is in contact with the posterior surface of the diaphragm, and posterior surface is concave fitting against the stomach. The liver is divided into 5 lobes by a series of fissures (Thakur *et al.,* 1988).The right and left central lobes lie on either side of the median vertical fold of peritoneum which attaches the liver to the diaphragm. The liver is richly supplied with blood vessels. Its large size makes it possible to contain as much as fifth of all the blood and to act as blood reservoir. Thus, the liver is called the "busiest port on the whole river of life" (Thakur *et al.,* 1988). This close relation of the liver through the circulatory system to all other parts of the body is due to the fact that the liver cells are involved in the most complicated catabolic and anabolic reactions, which occur in the rabbit's body. The liver probably originated as an ordinary digestive gland but in modern vertebrates it is the main metabolic "factory" of the animal (Thakur *et al.,* 1988).

2.2.7 The Respiratory system

Rabbits are nose-breathers (mouth breathing is a very poor prognostic sign). The nose moves up and down in a normal rabbit (called 'twitching') 20–120 x per minute (Johansson

and Rendel, 1978). This usually stops when the rabbit is very relaxed or anaesthetised. Thakur *et al.* (1988) stated that the rabbit, as a terrestrial animal, has lungs as the only respiratory organs. The respiratory system thus includes external nares, nasal passages, internal nares, pharynx, glottis, larynx, trachea, bronchi and lungs (Thakur *et al.*, 1988). The glottis is small and visually obscured by the back of the tongue. The thoracic cavity is small and breathing is mainly diaphragmatic. The lungs have three lobes and the cranial lung lobes are small (left smaller than right). The thymus remains large in the adult rabbit and lies ventral to the heart extending into the thoracic inlet (Lasley, 1978).

2.2.8 Cardiovascular system

The blood vascular system consists of the heart, blood vessels and blood (Thakur *et al.* 1988). The heart is the pumping organ of the blood vascular system and it is enclosed in thin double-walled pericardium. According to Thakur *et al.*, (1988), the heart is a hollow conical muscular organ lying ventrally in the anterior part of the mediastinal cavity of the thorax. Its base is directed forward and apex backwards and slightly to the left. The heart of the rabbit has only four chambers–the right and left auricles and right and left ventricles. Veins of the heart differ from arteries in that some are provided with semilunar valves which prevent backward flow of blood in them. The blood in the arteries flows away from the heart whiles those in the veins flows toward the heart. The arteries carry oxygenated blood except pulmonary arteries while veins carry deoxygenated blood except pulmonary veins (Thakur *et al.* 1988). The right atrioventricular valve has only two cusps (Johansson and Rendel, 1978). The rabbit's aorta has neurogenic rhythmic contractions.

2.2.9 The Excretory/Urinary system

The excretory system is responsible for the elimination of metabolic waste products from the body. These materials include nitrogenous compounds like urea, uric acid, ammonia

and various inorganic salts, pigments and excess water, and are all eliminated in the form of aqueous solution known as urine. The organs of excretion in the rabbit are a pair of kidneys, a pair of ureters, urinary bladder, urinogenital canal and the urinogenital aperture. The excretory system is similar in both sexes of the rabbit (Thakur *et al.,* 1988). Rabbit kidneys are metanephric and they lie in the anterior part of the abdominal cavity on either side of the vertebral column. They are dark-red in colour and roughly bean shaped measuring 20-25mm (Lebas *et al.,* 1986). The outer border is convex and the inner surface is concave. This depression in knows as hilus (Thakur *et al.,* 1988), through which renal artery enters the kidney while renal vein and ureter come out.

Urine is the major route of excretion for calcium. Serum calcium levels in rabbit are not maintained within a narrow range, but are dependent largely on dietary intake, with excess excreted via the kidney. According to Lebas *et al.* (1986), the urine of the rabbit is often thick and creamy due to the presence of calcium carbonate crystals. It can also vary in colour from pale creamy yellow through dark red (often mistaken for haematuria by owners), due to the presence of porphyrin pigments thought to be derived from the diet (Lasley, 1978).

2.2.10 The Reproductive system

The reproductive tract of the female rabbit is unusual compared to dog or cat. The uterus is biconuate and each uterine horn possesses a cervix, no uterine body and the two separate uterine horns and two cervices open into the vagina (Wu *et al.,* 1987). The vagina is large and flaccid. The mesometrium is a major site of fat deposition. The placenta is haemochorial. The blood supply to each implantation site is reduced when the number of fetuses increases (Eze *et al.,* 2009). It is a common finding in rabbits that the heaviest fetuses are located at the ovarian end of the uterine horn while the lightest fetuses are those that develop in the intermediate uterine position (Wirth-Dzieciololoska, 1987). Bucks have two

hairless scrotal sacs on either side, and situated cranial to the penis. The hairless, slightly depressed patch of skin between the anus and the penis or vulva is called the perineum in which open the ducts of perineal glands (Thakur *et al.,* 1988). The secretion of these glands has a strong and characteristics odour.

2.3 ATTRIBUTES OF RABBITS:

Small body size: There are a number of advantages of small animals in developing countries. They require small amounts of feed and use inexpensive, easily constructed housing. The small body size provides a small carcass that can be consumed by a family in one meal, eliminating the need for meat storage and refrigeration, especially in Nigeria where there is erratic, insufficient and rampant power failure. Thakur *et al.,* (1988) stated that the rabbit meat is stored on the live animal until needed. Hence, Rabbits are 'biological refrigerators'. Many households in Northern Guinea Savannah zone of Nigeria kept an average of 10.6 rabbits due to their small body size (Jokthan *et al.,* 1996), and the dominant mixed breeds kept are in the following order New Zealand White, Chinchilla, Dutch and Simonaire.

Rapid growth: In American and European rabbit production, market weight of fryers (i.e 2kg) is reached in 8 to 9 weeks of age, but the growth rate is usually lower in developing countries; 1.8kg at 12 weeks for Nigeria (Omole, 1982), 1.7kg for Ghana (Owen, 1978), 1.6kg for Kenya (Owiro, 1981) and 1.3kg for Sudan (El Amin, 1978). Rabbits reach market or consumable size much faster than larger livestocks. Iyeghe-Erakpotobor (2009) reported that the slow growth of rabbits under tropical conditions has made it impossible to produce fryers by 9 weeks as obtained under temperate conditions. Hence fryer rabbits are sold between 20–25 weeks old in most tropical countries. However, nutritional studies are conducted during the weaner phase (4–10 weeks) when growth is high in rabbits and do not take into consideration the slow growth of rabbits between the ages of 12–25 weeks in the

tropics (Iyeghe-Erakpotobor *et al.,* 2001). This period according to the authors, coincides with the growing, pubertal and adult phases of rabbit growth.

Short generation interval and high reproductive potential: The reproductive capacity of rabbit is legendary! However, Togun *et al.* (2009) had implicated factors like genetic, nutrition and environment as determinants of growth, development and efficient functioning of the reproductive organs of the rabbit. Rabbits are induced ovulators, and will breed within 24 hours of parturition. Thus, it is theoretically possible to produce about 10 litters per year (Cheeke, 1986). This intensive type of production could not be obtained in developing countries, but it is quite feasible to produce four to six litters per year or about 25 offspring per doe per year. It had been suggested that with good feeding and early rebreeding, 9 or more litters a year are possible (NRC, 1991 as cited by Akpa and Jokthan, 1996). With only three does and a buck, a breeding program can be set up so that a slaughtered rabbit is available for consumption by the family at least once per week. The potential for year-round production is another advantage of rabbits.

Utilization of non-competitive feeds: Like ruminants, rabbits can be raised successfully on grain-free diets, based on forages and by-products. Acceptable growth performance can be obtained using greens such as weeds, tree leaves, tropical legumes and grass forage, vegetable tops, waste fruits and vegetables with supplements of table scraps and by-products such as rice bran and maize offal (Aduku and Olukosi, 1990).

Potential for genetic improvement: There is a high degree of diversity in the rabbit genetic resource pool and thus, the productive performance of rabbits is a function of the breed or strain (Cheeke, 1986; Ayorinde, 1997). Mature body weight ranges from <1kg to >10kg, while there is much variability in traits such as maternal ability, fecundity, resistance to heat stress, etc. Thus, it is possible, by selection, to make rapid improvement in animal

performance (Iyeghe-Erakpotobor *et al.,* 1996a). The maternal effect of doe size, body weight, age, gestation gain and parity on some economically important traits has been reported (Khalil and Mansour 1987; Afifi *et al.,* 1989; Odubote and Akinokun 1991).

Production of high quality meat and useful by-products: Rabbit meat is high in protein and low in fat (Holmes *et al.,* 1984), particularly when the animals are raised on high forage, low energy diet. Holmes *et al.* (1984) reported that the fat content of cooked rabbit meat ranged from 4.2 to 4.8%. Pote *et al.* (1980) noted the meat fat level (as a percentage of dry weight) to be 4.9% in rabbits fed low energy diet of fresh forage, and 14.1% in animals fed pelleted commercial diet. Das and Bujarbarua, (2005) reported that rabbit meat has high (21%) crude protein and low (5.4%) crude fat content. When compared with meat obtained from other sources of livestock, the fat in rabbit meat contains less stearic and oleic acids but high proportions of the essential polyunsaturated linolenic and fatty acids (Das and Bujarbarua, 2005). The crude fat in rabbit meat is lowest (8%) when compared with beef (35%), mutton (31%), pork (29.5%) and chicken (12%) (Lebas *et al.,* 1986).

Rabbit meat is recommended for cardiovascular patients and those prone to arteriosclerosis (Togun *et al.,* 2009). According to Cheeke (1986) a small rabbitry unit of about 3–6 does and a buck is sufficient to meet the animal protein requirement of an individual family. According to Jokthan *et al.,* (1996) more rabbits are kept for both meat and sales than for hobby. Rabbit skin can be used in the production of toys, craftwork and garments, and can be used in cottage industries for such purposes (Leach and Barrett, 1984). Rabbit manure is a useful fertilizer for crops and gardens. Thus rabbit production can be well-integrated into small farming systems (Iyeghe-Erakpotobor *et al.,* 2001).

2.4 RABBIT BREEDS

According to Lebas *et al.* (1986) breed is a collection of individuals within a species which share certain morphological characters which are passed on to their progeny as long as they breed among themselves. Johansson and Rendel (1978) defined breed as a population of animals which differ from those in other populations within the same species in respect of definite genetically determined traits. According to Lebas *et al.* (1986), the book of the Societe Centrale D'aviculture de France (SCAF) on standards for rabbits described 44 breeds which have been bred from rabbits of local and regional populations, or by crossing breeds, or using mutants for changing coat colour or structure.

2.4.1 The New Zealand Breed

Sandford (1986) reported that there are about four different strains of the New Zealand breed which include; New Zealand White, New Zealand Blue, New Zealand Red and the New Zealand Black, respectively. The New Zealand Red strain was first developed in California with a system of selection very similar to that used in France on the Burgundy Fawn strain (Lebas, 1983). The genetic constitution of the New Zealand Red strain include the gene for the elimination of all black pigment from the Agouti colouring, thus giving it a complete extension of the yellow colour (Sandford, 1986). Thereafter, a number of modifying genes to produce the bright reddish buff colour was introduced. The New Zealand Red belongs to the medium class of rabbits based on weight with an average adult weight of 3.62kg (Aduku and Olukosi, 1990). The New Zealand White strain, although very similar to the Red, Blue and the Black strains, differs considerably in that, it is heavier and larger, weighing up to 4.07kg (Sandford, 1986; Lebas *et al.,* 1986). It is the albino offspring of coloured rabbits, which was bred selectively in large meat production units, especially in the San Diego Area of Southern California. In addition, the New Zealand White becomes the

most popular strain for young meat production in America and indeed in most other countries including the United Kingdom. Its spread throughout the world has greatly exceeded that of any other strain or breed. The New Zealand White strain has very rapid growth characteristics and can reach 1.81–2.04kg at 8 weeks of age (Lebas *et al.,* 1986), although the feed for this production must be very good. The breed is an excellent meat type with considerable fleshing of the hindquarters and back, (Lebas *et al.,* 1986). They also reported that the New Zealand White is known for its high breeding qualities which include prolificacy, maternal performance, fast growth rate and precocious body development which make it ready for slaughter at 56 days; the objective being a light carcass. According to Aduku and Olukosi (1990) the New Zealand White breed can reach adult weight of 4.1 to 5.4kg.

2.4.2 The California Breed

The Californian is a synthetic American breed, which was presented for the first time in 1928 in California by its breeder, whose objective was a meat animal that has very good fur (Lebas *et al.,* 1986). According to Sandford (1986), the Californian breed was developed by crosses of New Zealand White and Himalayan with further introduction of the Chinchilla gene but the breed, according to the author, did not become well known in America for some 15 years after its original development. Lebas *et al.* (1986) stated that the Californian breed is today possibly the second most popular meat producing rabbit. The adult Californian weighs between 3.6–5.0kg (Lebas *et al.,* 1986; Aduku and Olukosi, 1990).

2.4.3 The Chinchilla Breed

The Chinchilla rabbit falls under both the medium and small class breeds. The Chinchilla Giganta, also called Grand Chinchilla, weighs between 4.10 and 5kg, while the small Chinchilla weighs between 2.5 and 3.4kg (Lebas *et al.,* 1986; Sandford, 1986; Aduku and Olukosi, 1990). Sandford (1986) reported that the intention in the production of the

Chinchilla Giganta in the early 1920s by Chris Wren was to produce a large, graceful rabbit, with good meat qualities and good pelt with the Chinchilla colouring. The advantage of the small breed, according to Lebas *et al.* (1986), is that they usually develop very quickly and make excellent mothers. They eat less than the medium and large breeds and could be crossed or used pure in developing countries to produce light, meaty carcass of 1 to 1.2kg.

2.5 INBREEDING/LINEBREEDING AND ITS GENETIC EFFECTS

Inbreeding is the mating system in which progeny are produced by parents that are more closely related than the average of the population from which they come from. Production records of daughters of a sire are a means of indicating his breeding ability, and sires that prove to be superior are used for breeding purposes as long as they retain the ability to reproduce (Lasley, 1978). Linebreeding on the other hand is a form of inbreeding in which an attempt is made to concentrate the inheritance of one ancestor or a line of ancestors, in the inbred individual. The ancestor is usually a male rather than a female, because a male generally produces more offspring than a female, and this allows greater opportunity to prove his merit by means of a progeny-test.

Among the genetic effects of linebreeding are that it tends to make pairs of genes carried in the heterozygous condition in the ancestor more homozygous in the linebred offspring (Johansson and Rendel, 1978). In addition, linebreeding increases the probability that the linebred offspring will possess the same genes as the ancestor to which the linebreeding is directed. If the ancestor possessed many desirable genes, the offspring are more likely to inherit them. This therefore, emphasizes the need for breeders to use an ancestor that is generally superior and carries less detrimental recessive genes, for linebreeding. The authors concluded that, accurate and adequate progeny-tests help to identify such individuals.

Lasley (1978) stated that a line is meant to indicate a collection of animals, which as a result of inbreeding, are more closely related to each other than to the other individuals in the same strain or breed. He further explained that, if an inbreeding coefficient of at least 0.375 is reached, corresponding to two generations of fullsib mating, then such a line is called an inbred line. In crosses between inbred lines originating from the same base population, no gene combination can occur (apart from mutation effect) that could not have been produced in the original population.

How similar or variable the progeny of a line cross are, depends on the degree of inbreeding of the lines. If the lines to be crossed with each other are 100% inbred, there is no variation in the F_1 generation; which means that additive genetic variation will be low, while non-additive genetic variation will be high (Obasi and Ibe, 2008). The more inbred the lines, the greater will be the portion of the variation between the line crosses caused by non-additive genetic variation.

Uses of inbreeding/linebreeding

a) Inbreeding could be used in a practical way to select against a recessive gene which is of economic importance. Since inbreeding brings out the hidden recessive genes, the homozygous recessive individuals as well as many other heterozygous could be identified and culled.

b) Inbreeding may be used to determine the actual genetic worth of an individual (Lasley, 1978). This is possible if a sire can be mated to a large number (say 23–35) of his own daughters, which can allow for testing of all recessive genes the sire may be carrying as well as give some indication of the desirable genes he may possess.

c) Inbreeding may be used to form or create distinct families or lines within a breed, especially if selection is practiced along side. Selection between such inbred families for traits of low heritability would be more effective than selection based on individuality alone (Lasley, 1978; Obasi and Ibe, 2008), especially if there were distinct or definite family differences. Family selection is more effective than individual selection because it tends to reduce some of the environmental variations that breeders often mistake for those of a genetic nature (Obasi and Ibe, 2008).

d) Inbreeding is used for the production of 'seed stock' or rather for the development of lines that can be used for crossing purposes. The most practical use of inbreeding is to use inbred sires in three-line rotation cross on crossbred females for commercial production.

e) From the research point of view, inbreeding is of value to determine the type or types of gene action that affects the various economic traits. If inbreeding effects are very great, the trait is affected by non-additive gene action, but if inbreeding effects are very small or absent, then the trait is affected mostly by additive gene action (Obasi and Ibe, 2008).

2.6 CROSSBREEDING AND HETEROSIS

Crossbreeding is the mating of two or more different breeds. It increases heterozygousity in the genes for which the parents possess different alleles. Crossbred animals are less likely to breed true than are inbred animals due to heterozygousity and are less likely to transmit the same genes to all of their offspring (Johansson and Rendel, 1978). Heterosis or hybrid vigour is the name given to increased vigour of the offspring over that of the parents when unrelated individuals are mated. Heterosis influences more than just hardiness, it includes greater viability, faster growth rate and greater milk production. Crossing ability is improved when parents who are crossed are superior for the additive or highly heritable traits as well as for increased heterosis. Possibly, some lines, strains or breeds

when crossed give more hybrid vigour than others for traits that show hybrid vigour. Total performance of the crossbreds however, includes both heterosis and superiority due to additive gene action. According to Johansson and Rendel (1978), crossbreeding has two genetic advantages; it tends to average the phenotypic merit of all parent breeds used in the cross and it results in hybrid vigour for some traits.

2.7 NON–ADDITIVE GENE ACTION

An understanding of the phenotypic expression of genes is the fundamental basis upon which the importance of livestock through breeding is founded (Ibe, 1995). In general, genes express themselves phenotypically in two ways; non-additive gene action and additive gene action. In non-additive gene action, there is no straight line phenotypic progression from one extreme to the other. Non-additive gene action tends to lower the heritability and increase the expression of hybrid vigour (Akanno and Ibe, 2005).

Selection on the basis of individuality for such traits is usually less effective than for highly heritable traits. The superior individual for such trait is often highly heterozygous (due to overdominance) and does not breed true. The offspring of heterozygous parents tend to regress towards the mean of the population because on the average the offspring are less heterozygous than the parent. Superior parents for such traits may also be superior because of environment, which is another factor responsible for their offspring regressing toward the mean of the population. Selection for non-additive gene action involves selection among lines, strains or breeds, to find those that combine the best on the basis of the performance of their F_1 progeny (Ibe, 1995).

2.7.1 Lack of Dominance

A case of lack of dominance or incomplete dominance is a situation where a gene does not completely suppress its allelemorphic form and as a result leads to intermediate expression (Janusz and Josef, 1982). Lasley (1978) gave example of three different coat colours that appear in the Shorthorn breed: red (RR), roan (Rr) and white (rr). He explained that when a roan bull (Rr) is mated to a group of roan cows (Rr), the offspring will be coloured in the ratio of one red (RR) to two roan (Rr) to one white (rr). The heterozygote in this case expresses itself phenotypically in a different manner from either homozygotes, and the genotypic and phenotypic ratios are the same, 1:2:1. This type of gene action is called lack of dominance (Lasley, 1978).

2.7.2 Overdominance

This is another kind of gene action that is of importance in animal breeding. It is the interaction between genes that are alleles and results in the heterozygous offspring being superior phenotypically to either of their homozygous parents. Lasley (1978) stated that a case of overdominance is a situation whereby the heterozygous condition (Aa) gives a better phenotypic performance than either of the homozygous parent (AA) or (aa). An important fact concerning selection when no dominance exists is that the genotype can be determined by inspection of the phenotype, then individuals with undesirable genes can be eliminated from the herd by culling all heterozygotes.

2.7.3 Epistasis

Epistasis is another form of non-additive gene action which is involved in some coat colours in animals and in some genetic defects. Lasley (1978) defined epistasis as the masking effect due to gene interaction and not due to true dominance. The importance of this kind of phenotypic expression of genes in causing variation in economic traits determined by

many pairs of genes, such as rate of gain, efficiency of gain and carcass quality, has been documented (Johansson and Rendel 1978; Lasley, 1978). Epistasis involves two or more pairs of genes which are not alleles. In overdominance, the action between two genes of a particular pair will give different phenotypic expressions than when these genes were in homozygous pairs. In epistasis the action is between two entirely different pairs of genes and not between members of the same gene pair. The two or more different pairs of genes may be on the same chromosomes or on different chromosomes (Lasley, 1978).

Selection among families, lines or strains to find those that would give superior progeny would be the desired way of selecting for epistatic gene action. It may be possible to cross two different breeds of livestock and produce a genetic defect in their offspring seldom or never observed in the pure breeds because of the epistatic action of two or more pairs of genes. Baselga *et al.* (2003) explained that in sire lines, selection for high growth rate has largely been practiced, but genetic selection on growth rate has been shown to modify the whole pattern of growth, feed efficiency and tissue composition, thus affecting the rabbit carcass and meat quality traits.

Baselga *et al.* (2003) reported that intensive meat production in rabbits is based on a three-way crossbreeding scheme. A first cross involves two maternal lines generating crossbred does. A second cross consists of mating males of a third line, commonly selected for growth rate or weight at a given age, with the cross bred does to produce the rabbits to be slaughtered for meat. They further elaborated that, the aim of the cross between the maternal lines is to take advantage of the expected positive heterosis in reproductive traits, the eventual complementarity among the lines and the dissipation of the inbreeding accumulated within the lines. Because the usual methods of improving the lines are based on within-line selection, it is expected that the initial heterosis expressed in the cross will be maintained along the

generations of selection and that the genetic progress obtained by selecting the maternal lines will be capitalized on top of the heterosis and expressed in the crossbred does (Baselga *et al.*, 2003).

2.8 ADDITIVE GENE ACTION

Additive gene action affects many important traits in farm animals (polygenic traits) such as growth rate, milk production, egg production, body conformation, carcass quality, carcass quantity (Janusz and Josef, 1978). Polygenic traits mostly determined by additive genes will be medium to highly heritable and will be affected very little by crossbreeding or inbreeding. Traits affected mostly by non-additive gene action will usually be lowly heritable, will be improved by crossbreeding and will show a decline when inbreeding is practiced. If a trait, on the other hand, is low to medium in its degree of heritability and shows improvement when crossbreeding is practiced, then it is an indication that the trait is probably affected by both additive and non-additive gene actions (Obasi and Ibe, 2008).

To select for additive gene action, the environment should be standardized as much as possible for all individuals to reduce phenotypic variations due to environment. The best for the trait should then be mated with the best meaning that selection should be on the basis of individual merit (Obasi and Ibe, 2008).

2.9 RECIPROCAL RECURRENT SELECTION

Lasley (1978) stated that reciprocal recurrent selection is a system for increasing the combining ability of two or more lines, strains or breeds. He further explained that, the procedure in practicing this kind of selection involves testing many inbred lines in crosses to identify those that produce the superior crossbred offspring. Then two or more of these lines could be selected for superior combining ability by making reciprocal crosses between them;

that is, by crossing sires of one line with dams of the other line, and vice versa, so that the sires and dams of each line could demonstrate their crossing ability based on the performance of their crossbred progeny. The sires and dams from each line that demonstrated their ability to produce superior crossbred offspring could then be used to produce the pure line in the next generation. Several generations of such selection might improve the overall crossing ability of the two lines (Ndjon and Nwakalor, 1998).

The idea of recurrent selection for specific combining ability was first proposed by Hull (1945) and later expanded to reciprocal recurrent selection by Comstock *et al.* (1949). The reciprocal recurrent selection is essentially a recurrent programme to mate selected males of line A with females of line B, then the B-line males with A-line females to produce test crosses. This is then followed by switch mating to produce pure-line AxA and BxB half-sibs of the test crosses (Wei and Vander Steen, 1991). According to Bell and Moore (1972) and Orozco (1974), reciprocal recurrent selection exploits both additive and non-additive variances for economic traits. Ajay *et al.* (2001) stated that the magnitude of additive genetic variance as the proportion of phenotypic variance helps in making decision regarding the choice of selection method to be applied for the most rapid improvement.

In reciprocal recurrent selection, the selection of purebred animals is based on the performance of AxB and BxA hybrids and the segregating populations (A and B) are utilized on both sides of the cross (Wei and Vander Steen, 1991). This method of selection increases the frequency of both additive and non-additive genes, hence improves pure-line as well as cross-line performances. The main reason for this is that crossbreds often exhibit heterosis, which indicates the existence of non-additive effects. The two populations under reciprocal recurrent selection do not have identical gene frequencies which cause the covariance between them to be small or negative. The selection response largely depends on additive

genetic variation whereas non-additive genetic variation is responsible for heterosis in the crosses from diverse genetic groups (Falconer, 1989). Some modified reciprocal recurrent selection methods were developed to shorten the generation interval using purebred performance in addition to the crossbred performance as a criterion of selection of purebred by reproducing both purebreds and crossbreds simultaneously (Sellier, 1982 as cited by Yahaya *et al.*, 2009a).

Johansson and Rendel (1978) reported that in linebreeding and crossing, it is usual to distinguish between general and specific combining ability of the lines. A measure of the general combining ability (GCA) is the average of the progeny when a particular line is crossed with several other lines selected at random. They further stated that the general combining ability is caused mainly by additive gene effects, whereas the specific combining ability (SCA) is due to mainly non-additive gene effects. Of the variance between line crosses, the part which is caused by the line's general combining ability is for the most part, directly proportional to the degree of inbreeding of the lines. The variance component due to specific combining ability increases as the square or higher powers of the inbreeding coefficient. If therefore, the specific combining ability is to be utilized in breeding, it is necessary to work relatively with highly inbred lines (Obasi and Ibe, 2008).

Selection for specific combining ability means that selection is practiced to take advantage of hybrid vigour when non-additive gene action is important for the trait under consideration. Selection on the basis of individuality, otherwise called mass selection, usually is not the most efficient method of selection for traits affected largely by non-additive gene action. Increased merit in such traits usually depends upon heterozygousity through crossbreeding resulting in the expression of hybrid vigour (Obasi and Ibe, 2008).

However, if dominance is important, selection on individual basis will be effective in improving traits within the line, strain or breed. But if epistasis and overdominance are important, it is less effective. Heterozygousity therefore depends upon the parents being homozygous in opposite ways (AA) and (aa) or for different alleles. In quantitative inheritance where many genes may affect the same trait, it is not possible to determine from the phenotype, which animals are homozygous in opposite ways. The method most often used in this case is to form several different inbred lines by embarking on close inbreeding, which increases the homozygousity of all pairs of genes that the individuals in the inbred line possess, regardless of the phenotypic expression of those genes (Lasley, 1978; Johansson and Rendel, 1978). Next is to test them in crosses to determine which lines combine to produce the best linecross progeny. Generally, the two inbred lines producing the most superior progeny when crossed are the ones that are homozygous in opposite ways for many pairs of genes, giving greater heterozygousity in the progeny (Lasley, 1978).

2.10 GROWTH TRAITS IN RABBIT

2.10.1 Pre-weaning growth

Growth is defined as production of new cells but since growth is measured as increase in mass (Prudhon and Selme, 1973), it includes not only cell multiplication (hyperplasia) but also cell enlargement (hypertrophy) and incorporation of specific components from environment (e.g fat deposition). The young rabbit has extremely high growth rate which starts prior to birth and continues exponentially until the animal is about ten weeks old (Lang, 1981). The weight of the fetus increases from 1g at day 16 of gestation to a birth weight of 60g, after 31 days of pregnancy (Prudhon and Selme, 1973). After birth, the young rabbit approximately doubles its weight every week until it reaches 0.45kg at three weeks of age and thereafter, the rabbit begins to eat solid food. Growth rate of the kit is 10–20g/day when milk

is the sole food, and increases to 30–50g/day between three and eight weeks of age (Rao *et al.*, 1977). The growth rates under tropical conditions are much lower and are primarily attributed to poor nutrition (Rajadevan, 1984).

Lukefahr *et al*. (1980) compared the growth rates of Flemish Giant, New Zealand White and their crosses and observed that the purebreds were inferior to their hybrid progeny. The Flemish Giant was found to be heavier than the New Zealand White kits at 21 days of age. Omole (1982) reported that the growth of the young rabbit is significantly affected by the protein level and further explained that 18% protein diet was better than 22 or 26% in supporting growth. Hafez *et al.* (1967b) reported that males have a higher growth competence before birth than females. However, males weigh relatively less than females at puberty and sexual maturity and are able to mate from about 15–30 days later than females born at the same time (Lebas, 1969).

Major environmental factors that affect prenatal growth, according to Mariana *et al*. (1988) include size, parity, nutrition and health of the mother, duration of pregnancy, litter size, position of fetus within the uterine horn, competition between one litter mate and another, relative stage of pre-implantation development of the embryo and the endometrium, placental size and ambient temperature. Campbell and Lasley (1975) stated that, a baby rabbit (kit) is born 29–30 days after conception and at birth it is naked with no hair, blind with closed eyes and it is helpless and unable to walk. However, the guinea pig on the other hand, is born 67–68 days after conception. The young are quite big at birth, they posses coat of hair, their eyes are open and they can walk and run almost immediately after birth. Muscle hyperplasia occurs primarily prenatally (Mariana *et al*., 1988), while muscle fibre numbers increase only slightly postnatally (Lebas, 1969).

2.10.2 Post-weaning growth

The potential growth of an animal, its pattern of development and to some extent, its ultimate carcass composition in terms of the proportions of muscle, bone and fat are genetically predetermined (Lebas, 1969). Growth rate and development in the rabbit is breed dependent (Lukefahr *et al.,* 1980), where some rabbits reach 2kg at eight weeks of age (Chen *et al.,* 1978) while others achieve much poorer growth (Lang, 1981). Rao *et al*. (1977) reported an average daily gain of 39.1g from four to six weeks and 36.3g from six to eight weeks. Rajadevan (1984) however, reported a lower value of 20.4g for average daily gain between four and eight weeks in a tropical environment. Average daily gain increased to a maximum between 40 and 55 days of age and then declined gradually with advancing age. The weaning weight is doubled around 40 days and tripled at about 60 days of age reaching an average body weight of 948g (Rajadevan, 1984).

2.10.3 Gestation Period

Gestation in the rabbit lasts for about 28–32 days if properly managed and the doe can produce four to five litters per year (Rajadevan *et al*., 1986). After mating, ova is transported to the middle of the oviduct within few hours of ovulation while the young embryos reach the uterine horn about 3 days after ovulation in the late morula stage (Paufler, 1985). The author reported that follicle matures in 18 days it remains for about 7 days and then regresses within about 9 days unless ovulation occurs. Release of ova is stimulated by mating or hormonal injection (Sandford, 1986).

The gestation of the rabbit is determined by the number of embryos that survive and the stage of pregnancy (Wu *et al*., 1987). If embryos are lost by the fourth day of gestation, the doe returns to normal estrus but if 1–4 embryos survive beyond day 4, then pregnancy is terminated with prolonged estrus by 6 days. If there are 4 embryos in each uterine horn by day 10 or beyond, pregnancy continues. However if there is at least 1 embryo in each uterine

horn by day 12 or more of gestation, pregnancy continues but the result is very small litter size (Hafez, 1963). The female rabbit does not appear to show any improvement in efficiency of metabolism during gestation (Rajadevan *et al.,* 1986) and reducing maternal food intake during gestation significantly depressed pup birth weight and the total hepatic glycogen content of the pups (Hafez *et al.,* 1967a). High food levels especially high energy foods are contra-indicated in early pregnancy because they may lead to increased embryonic mortality (Toplis *et al.,* 1983).

2.10.4 Lactation

In rabbits, early growth and survival are dependent in part on the intrinsic ability of the dam to provide an adequate maternal environment (Yahaya, 1993). The first three weeks of the rabbit's life, when it should feed on milk from the doe only, are very important and will affect its future growth, development and ability to thrive. The mammary glands start developing slowly in early pregnancy and rapidly in the last week of pregnancy. Milk production in the rabbit reaches its peak by the 21st day of lactation (Sandford, 1986). Growth of the young up to 22 days depends on the milk consumed. Therefore maternal influence is greatest at this point (Peinado *et al*., 1988). According to Lebas (1969) the first litter weighs less at weaning than those of subsequent litters due to the lactation curve.

A positive relationship exists between milk yield and litter weight (Lukefahr *et al*., 1981). Litter size and weight at 21 days give very good evaluation of the doe's maternal ability as the young depend solely on dam's milk to that age (Ferraz *et al*., 1992). There also exists a large variation in milk intake between litter-mates (Venge, 1963). Breed variation in milk production has also been reported (Venge, 1963) and the New Zealand White females has been reported to produce less milk in their first lactation than subsequent lactations. This has been advanced as the reason for the low weaning weights observed in the litter of first parity does (Lukefahr *et al*., 1981). Average milk yield of a medium heavy doe on *ad lib*

concentrate feed was 250g over a four week period of lactation (Paufler, 1985). Maximum daily milk yield is attained between the 18th and 23rd day after kindling and by the 42nd day it amounts to only 30–40% of maximum yield (Paufler, 1985). Partridge and Allan (1983) reported significant increase in milk production with increase in protein level when pregnant and lactating does were fed 13.5, 17.5 and 21% crude protein diets.

2.10.5 Litter size and birth weight

Litter traits are considered as character of the doe because there is a larger environmental component of variance associated with the doe during kindling and raising a litter to weaning (Khalil *et al*., 1986). The larger the number of young the doe kindles and weans, the greater is the profitability of the enterprise (Afifi and Emara, 1987). Re-mating intervals (1, 7, 14 and 21 days postpartum) did not significantly affect litter size although the 1-day re-mated group had slightly lower average litter size than the other treatment groups. Pup birth weight, 21-day litter weight and 25-day litter weight all appeared to be unaffected by the re-breeding interval after parturition (Partridge *et al*., 1984).

A wide variability exists in the litter size at birth and this is attributed to genetic and husbandry differences (Rajadevan *et al*., 1986). Rao *et al*. (1977) reported that the New Zealand White frequently had a litter size of seven. Similarly, litter size of 9.1 was obtained among New Zealand White x Dutch progeny (Scholant, 1980). According to Lukefahr *et al*. (1983a), litter sizes of 8.91 for New Zealand White, 8.04 for Californian, 10.60 for Californian x New Zealand White and 8.13 for New Zealand White x Californian doe genetic groups were obtained. Average litter size of 3.7 at first kindling (5.4 months) and 8.4 at peak production was reported by Akpa and Jokthan (1996). Commonest litter size at first kindling as reported by Jokthan *et al.* (1996) was 3 or 4, with a maximum of between 7 and 9. Mach and Safarova (1989) reported average litter sizes at birth and weaning of 6.6 and 5.2 for pure bred, 7.5 and 6.0 for 2-breed, 8.4 and 6.9 for 3-breed and 8.4 and 6.6 for 4-breed crossbred

rabbits. This is suggestive of the superiority of crossbreds to purebreds (Rajadevan *et al*., 1986). Partridge *et al*. (1981) have shown a clear effect of heterosis in increasing both litter size and the conception rate. The heritability of litter size is low therefore it can significantly be improved upon by good management (Rollins *et al*., 1963). Litter size and weight at 56 days were reported to be lower in New Zealand White compared with Californian White sired litters (Lukefahr *et al*., 1983b).

Breed type and litter size at weaning were important sources of variation in carcass traits (Rajadevan *et al*., 1986). Increased litter size at weaning was associated with decreased body length and carcass weight (Lukefahr, 1982, Lukefahr *et al.*, 1982). Ferraz *et al*. (1992) reported that breed of doe affected litter weight at weaning with California does weaning heavier litters than New Zealand White does with 3073.7 vs 2841.1g for total weaning weight and 671.11 vs 646.58g for average weaning weights. Seasonal variation on litter size was investigated by Sittmann *et al*., (1964) who reported monthly average litter sizes of 6.49 and 8.7. They further stated that total litter size and number born alive in the litter decreased from high in the month of February to low in September. The birth weight of rabbits varies and is the product of prenatal growth which is affected by genotype and the dam that furnishes the prenatal environment (Afifi *et al*., 1987). Mean kit weight was reported to range from 49.0g to 58.8g (Afifi *et al*., 1987) and from 53.4g to 66.1g (Lukefahr *et al*., 1984).

2.11 GENETIC PARAMETER ESTIMATES

2.11.1 Heritability

There are few studies on heritability estimation for growth and reproductive traits in rabbits. Patras, (1985) reported a heritability estimate for body weight at 60 days to be 54%. Khalil and Soliman (1989) reported that the heritability estimate for doe reproductive traits (number of service per conception and gestation length) was low in magnitude in Bouscat and Giza White rabbits. Chineke and Adeyemi (2001) reported 0.28, 0.99, 0.69, 0.43, 0.24 and

0.69 as heritability estimates on nose-to-shoulder, shoulder-to-tail pin bone, heart girth, withers height, length of ear and trunk length, respectively.

Akanno and Ibe (2005) reported heritability estimates (from paternal halfsibs) at 9 weeks of 0.30, 0.18, 0.45, 0.56 and 0.43 and at 12 weeks of 0.09, 0.35, 0.67, 0.06 and 0.03, for body width, body length, head-to-shoulder, shoulder-to-tail and length of leg, respectively. The indication is that, some of the body measurements are governed by genes with additive effects, while others are governed by genes with non-additive effects.

Odubote and Somade (1992) reported moderate heritability estimate for litter size at birth, litter weight and litter weaning weight as 38.0, 32.0 and 16.0%, respectively. Lukefahr *et al.* (1992) observed that productive traits relating to fertility, litter performance and those relating to health and/or survival rate are lowly heritable. This suggests that they are basically under the control of genes, which have non-additive effects. Lukefahr *et al.* (1992) estimated the heritability of body weight at 90 day of age in rabbit from tropical Ghana to be 0.42.

Chineke and Adeyemi (2001) reported low heritability estimates for withers weight (0.17) and length of ear (0.11) at 42 days of age and stated that crossbreeding might be a better option (to make use of heterosis) for the improvement of these traits since strong non-additive gene action is playing a major role. They also obtained moderate heritability estimates for nose-to-shoulder (0.28) and length of ear (0.24) at 49 days and for nose-to-shoulder (0.24), shoulder-to-tail pin bone (0.31) and trunk length (0.24) at 56 days of age. The implication of this is that these estimates would be improved by combining pedigree and individual selections. The heritability estimates at weaning age (35 days) for all the parameters measured by the authors were found to be high indicating that individual selection would improve the traits.

Ndjon and Nwakalor (1999) observed that gestation length, average daily gain at 56 days and individual weaning weight showed little or no heterosis, ranging from –1.4% for gestation length to 2.6% for average daily gain. They further explained that this is an indication of the importance of additive gene effects on these traits, and therefore, suggested that pure breeding and selection rather than crossbreeding might be the solution to the improvement of these traits. The authors finally suggested that improvement of these traits could be sought by amelioration of management techniques of the purebreds.

High heritability estimates were reported (Moura *et al.,* 1997) especially for average daily gain (0.48), indicating that mass selection could be used successfully to improve this trait. In fact, selection for average daily gain and slaughter weight has been effective in rabbits (Mgheni and Christensen, 1985; Rochambeau *et al.,* 1989; Estany *et al.,* 1992; Lukefahr *et al.*, 1996), although in some cases the response was less than expected (Estany *et al.*, 1992; Rochambeau *et al.,* 1989). Average daily gain has been indicated as the preferred trait for selection in the postweaning period, especially in an unimproved population (Moura *et al.,* 1997), because it is less affected by common litter effects than the individual weights at specific ages (Rochambeau *et al.,* 1989; Estany *et al.,* 1992; McNitt and Lukefahr, 1996).

Published estimates of heritability of postweaning gain in rabbits are variable, ranging from 0.13 to 0.48 (Rochambeau *et al.,* 1989; Estany *et al.,* 1992; Moura *et al.*, 1991; Ferraz and Eler, 1994; Krogmeier *et al*., 1994). Variability may be due to variety of breeds, environmental conditions and methodology involved in these studies (Lukefahr *et al.,* 1996; McNitt and Lukefahr, 1996). Estimates of heritability for average daily gain, specifically using animal models varied nearly as widely from 0.17 (Lukefahr *et al*., 1996) for a synthetic population to 0.35 and 0.36 (Ferraz and Eler, 1994) for purebreds, to 0.48 (Krogmeier *et al*., 1994) for crossbred rabbits. The latter estimates (0.48) based on reciprocal New Zealand

White and Helle Grossilber crossbred rabbits, was of the same magnitude (0.48) as that obtained by Moura *et al.* (1997).

2.11.2 Repeatability

The breeding value of individuals upon which selection can be based, particularly for traits that can be measured more than once in lifetime, depends on repeatability estimates of the traits (Chineke *et al*., 2001). Such estimates indicate the extent to which selection will influence future animal performance (Ibe, 1995). The improvement of lifetime record would require selecting for early records so as to exploit shortened generation intervals that can lead to increase in genetic progress (Ibe, 1995).

Moderate to high repeatability estimates were reported (Chineke *et* al., 2001) for body weights and linear body measurements at all ages except for heart girth (0.11) at 35 days and wither's height (0.13) at 49 days of age, which were low. The moderate to high repeatability values obtained implied that great reliability can be put on selection or culling of does and bucks based on 1 or 2 records. Ndjon and Nwakalor (1998) also obtained moderate to high estimates of repeatability for individual weight at weaning.

2.11.3 Maternal heterosis and reciprocal effect

In a study to estimate the heterosis and reciprocal effect for litter traits in rabbit crosses, Fayeye and Ayorinde (2000) reported that crossbreeding helped to improve the litter size in the New Zealand White x California cross. The estimate of heterosis was +24.20%, +31.63% and +22.94% at the 7^{th}, 14^{th} and 21^{st} day postpartum, respectively. It also helped to improve the pre-weaning livability, mean kit weight and rate of body weight increase in the New Zealand White x California and California x Chinchilla crosses.

According to Fayeye and Ayorinde (2000), the reciprocal effect was important for the pre-weaning litter size, livability, litter and kit weight, and rate of body weight increase as well as the weaning litter size, survival to weaning, litter and kit weight gain in the three crossbred groups and could therefore be exploited where heterosis has failed. They concluded that the most promising crossbred for the exploitation of heterotic effect was the New Zealand White x Chinchilla. It improved the litter size, litter weight, kit weight and rate of body weight increase (birth to 21 days postpartum) by 18.5%, 10.64%, 1.40% and 6.03%, respectively. Reciprocal effect is best exploited in the New Zealand White x California crossbred.

2.11.4 Genetic and phenotypic correlations among traits

Johansson and Rendel (1978) explained that high correlation between heart girth and body size has long been established in livestock. Hammond (1937) noted that there was a strong tendency for the extremities to complete their growth cycle first, followed by development of the proximal and axial parts. Significant and positive correlation between body length and body width (0.95) was reported (Tiamiyu *et al.,* 2000), which indicated that selection of medium breed that are long bodied and well rounded may be practicable, as these features are indicators of good conformation. Significant phenotypic correlation between gestation length and litter birth weight were reported by Nwagu *et al*. (2000). This was attributed to the fact that the longer the gestation the more the fetus grows, and at kindling, the higher the birth weight. The weight advantage at birth, according to the authors, was carried to later ages so that even at weaning, litters of high birth weight have superior survivability at weaning. Tiamiyu *et al.* (2000) reported that live weight in medium breed rabbits was significant and positively correlated with ear length (0.89), body width (0.97) and

body length (0.98). All the phenotypic correlations between kitten body weight at 2, 4, 6, and 8 weeks of age were positive and highly significant (Nwagu *et al*., 2000).

Genetic correlation between litter size at birth and litter size at weaning has been reported to be high and positive. Garcia *et al*. (1980) obtained a genetic correlation of 0.51 and 0.83 for New Zealand White and Californian breeds. Lahiri and Mahajan (1982) reported a high and positive genetic correlation of 0.73 in New Zealand White. In the same vein, Khalil *et al.* (1988) reported values of 0.92 and 0.43 in Bouscat and Giza White rabbits, while Odubote and Somade (1992) obtained a value of 0.67 in different breeds of rabbits.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 EXPERIMENTAL SITE

The study was conducted at the Animal Science Departmental Experimental Farm, Ahmadu Bello University, Zaria, Nigeria. Zaria is located between latitudes 11^0 and 12^0 N and on altitude of 640m above sea level. The area falls within the Northern-Guinea Savannah zone having an average annual rainfall of 1100mm which starts from late April or early May to mid October. The peak of rainy season is between June and September, followed by the harmattan period of cool and dry weather which lasts from October to January. This is then followed by hot-dry weather from February to April, otherwise called the pre-rain period (Akpa *et al.,* 2002).

The maximum temperature varies from 26 ^{0}C to 35 ^{0}C depending on the season, while the mean relative humidity during the harmattan period and the wet season are 21% and 72%. respectively. Detailed description of Zaria was given elsewhere (Kabir *et al.,* 2006; Akpa *et al.,* 2010).

3.2 EXPERIMENTAL ANIMALS AND MANAGEMENT

A complete diallel cross experiment involving three rabbit strains, namely New Zealand White (NZW), Chinchilla (CHC) and the California White (CAW) was conducted. The stock of rabbit used in this study was purchased at weaning from the National Veterinary Research Institute (NVRI), Vom, near Jos, Plateau State. They were housed in well ventilated pens according to group and small metallic ear-tags were used for their identification and proper record keeping. Feed and clean drinking water were provided *ad libitum* throughout the period of acclimatization and adaptation. They were raised on a mixed feeding regime and

fed twice daily at 8:00am and 4:00pm. Concentrates was first given in the morning and forage (*Panicum maximum* grass and/or *Centrosema pubescence* legume) in the evening to enhance intake. Composition of the experimental diet used is shown in Table 3.3.

Other routine management practices were effectively provided and were comparable for all breeding groups. Sick animals were isolated and treated whenever noticed. All healthy does and sires without apparent abnormalities were retained and used for breeding.

3.3 MATING PLAN

The design of the mating plan is presented in Tables 3.1 and 3.2. Does of each strain were divided into three groups of similar ages, and each group was further subdivided into four subgroups. Each main group was randomly assigned to one of the three breeds of the buck, and each subgroup was assigned at random to one of the four bucks within each strain of buck. All does within a strain were single-sired to obtain the pure cross first. Thereafter, does from the second and third strain were mated randomly to bucks from the first strain to obtain the crossbreeds while the bucks from the second and third strain were mated at random to does from the first strain to obtain the reciprocal cross. Thus, the arrangement is such that bucks that sired purebred kits also sired crossbred kits.

The animals were raised to sexual maturity and mating began when they were between 4–5 months of age (120–150 days). The does were mated to intact bucks in all possible combinations by introducing them to the bucks. They were allowed to remain with the bucks until mating is assured after which does were returned to their pens and observed for pregnancy. Pregnancy was monitored 14 days post coitus by palpation of the abdominal region between the thighs as well as through observation of the abdomen which gets enlarged as pregnancy progressed i.e due to the growth of the developing embryos. Ten days to kindling, weighed nesting boxes were provided and placed into individual hutches in

preparation for kindling. The kindling dates were noted, litter size and litter weight were also taken and recorded immediately kindling was discovered. Talcum powder was sprinkled on the kits and rubbed on the nose of the dam after each handling of the kits so as to avoid rejection of the kits by their dam. Weaning of kits was done at 35 days and dry does were remated within 7 days after weaning their kits.

A complete diallel cross involving three breeds will have nine possible crosses (Becker, 1992) as shown in Table 3.1.

Table 3.1: Mating plan for Diallel crossing of three rabbit breeds

	Dam strain		
Sire strain	Chinchilla (CHC)	New Zealand White (NZW)	California White (CAW)
CHC	CHC x CHC	CHC x NZW	CHC x CAW
NZW	NZW x CHC	NZW x NZW	NZW x CAW
CAW	CAW x CHC	CAW x NZW	CAW x CAW

(Becker, 1992).

Table 3.2: Complete Diallel crossing showing pure-, main- and reciprocal-crosses

Pure cross	Main cross	Reciprocal cross
CHC x CHC	CHC x NZW	NZW x CHC
NZW x NZW	NZW x CAW	CAW x NZW
CAW x CAW	CAW x CHC	CHC x CAW

3.4 DATA COLLECTION

The data generated for this study included 162 purebred kits born in 36 litters and 408 crossbred kits from 72 litters. The purebred kits comprised of 38 Chinchilla (CHC) kits, 54 New Zealand White (NZW) kits and 70 California White (CAW) kits. The crossbred groups comprised of 217 ‘main cross’ kits and 191 ‘reciprocal cross’ kits. A total of 570 offspring bred from June 2007 to May 2009 were evaluated. There were three parities.

To evaluate the general performance of the purebred and crossbred kits, measures of prolificacy, viability and growth were taken. In addition, birth, weaning and carcass traits were considered. Thus, data for the following traits were collected:

3.4.1 Litter traits at Birth

The litter birth traits measured are as follows:

1. Gestation Length (GL): Taken in days as the difference between the date of kindling and the date at which successful mating occurred.
2. Litter Size at Birth (LSB): Obtained by actual count and is commonly termed as measure of prolificacy.
3. Gestation Gain (GG): Taken in kg as the difference between doe weight at mating and its weight one-day pre-partum.
4. Kindling Loss (KL): The difference in kg between doe weight one-day pre-partum and its weight within 24 hours postpartum measured.
5. Litter Birth Weight (LBW): Obtained by subtracting the weight of the nest box from the combined weight of nest box and the kits, using a digital scale (Mettler Toledo, Top Pan Sensitive Balance, J. Liang Int. Ltd. U.K.).
6. Neonatal Mortality (NM) per litter: Number dead at the time of assessing the new born kits expressed as a ratio of the total pups in the litter.

3.4.2 Weaning traits (at 35 days post partum)

The weaning traits measured include:

1. Litter Size at Weaning (LSW): Taken by actual count of weaners alive at weaning.
2. Litter Weight at Weaning (LWW): Weight of litters taken in kg at weaning.
3. Litter Weight Gain (LWG): Difference between LWW and LBW measured in kg.
4. Weaning Sex Ratio (WSR): Proportion of males to females obtained by examination of the kits external genitalia at weaning.

5 Survival Rate to Weaning (SWR): Taken in percentage, calculated as follows:

$$\frac{\text{Litter size at weaning}}{\text{Litter size at birth}} \quad X \quad 100$$

3.4.3 Growth traits (taken at 35, 42, 49, 56, 63 and 70 days of age)

All linear body measurements were carried out using the flexible tailor's tape calibrated in centimeters (cm) while weight was in kilogram (kg) obtained using the 10kg capacity digital scale (Mettler Toledo, Top Pan Sensitive Balance, J. Liang Int. Ltd. U.K.)

1. Body weight (BW): Obtained by taking the weight of each rabbit.
2. Ear length (EL): This was measured as the distance from the point of attachment of the ear to the tip of the ear.
3. Nose to shoulder (NTS): Is the distance from the nose to the point of the shoulder.
4. Shoulder to tail-drop (STT): This is the distance from the point of the shoulder to the pin bone (otherwise called coccygeal vertebra).
5. Heart girth (HG): This refers to the body circumference and was measured just behind the fore legs.
6. Body length (BL): Is the longitudinal distance from the point of the shoulder to the tuberosity of the ischium.
7. Length of front and back leg (LFL and LBL): This is the length of front and back legs measured in centimeter.

3.4.4 Carcass traits

Two rabbits (male and female) from each breeding group (Table 4.34) were randomly chosen and slaughtered at eleven weeks of age after 24h fasting from feed only. A total of 18 rabbits were slaughtered and dissected according to the method of Blasco *et al*. (1993). Body weights before and after fasting in addition to the following parameters were considered: -

1. Carcass weight (kg): Also called hot carcass weight and is the weight of the carcass determined immediately after slaughter excluding the blood, skin, tail, distal parts of fore and hind limbs, the GIT (gastro intestinal tract) and urogenital tract.
2. Dressing percentage: Defined as the ratio between hot carcass weight and live weight of the rabbit multiplied by 100%.
3. The weights of heart, liver, kidney, lungs, full and empty stomach as well as small and large intestines were taken and expressed as percentage of live weight.

3.5 DATA ANALYSIS

3.5.1 Maternal heterosis and reciprocal effects for litter traits

Heterosis indicates the increase in fitness or productivity of crossbred offspring above the average of the parental breeds because of increased heterozygousity (Aggrawal *et al.*, 1979). Apart from heterosis, reciprocal effect or deviations between the crosses of two or three parent strains or breeds in which their roles as male or female parents are reversed, represent another feasible route to the economic exploitation of interbreed difference. For the estimation of maternal heterosis and reciprocal effects, a total of 202, 272 and 256 records for purebreds, crossbreds and reciprocal-crossbreds were used and the following parameters were considered:

- Gestation length
- Litter sizes at birth and at weaning
- Litter weight at birth and at weaning
- Weekly body weight of kits from birth to weaning
- Weaning sex ratio
- Survival rate to weaning
- Mortality from birth to weaning

Maternal heterosis and reciprocal effect was calculated using the method of linear contrasts (Dickerson, 1992) as follows:

H'_{CHC} {CHC x NZW} = {CHC x NZW + NZW x CHC} – {CHC x CHC + NZW x NZW}

H'_{NZW} {NZW x CAW} = {NZW x CAW + CAW x NZW} – {NZW x NZW + CAW x CAW}

H'_{CAW} {CAW x CHC} = {CAW x CHC + CHC x CAW} – {CAW x CAW + CHC x CHC}

The percent heterosis was computed as follows; $\frac{H' \text{ (unit)}}{\text{mean of straightbred}} \times 100$

While the reciprocal effect was calculated thus; $\frac{R' \text{ (unit)}}{\text{mean of straightbred}} \times 100$

H′ = Estimate of maternal heterosis in unit and R′ is the estimate of reciprocal differences.

Heterosis was calculated using the general formula given below;

$$\% \text{ heterosis} = \frac{\text{crossbred average} - \text{straightbred average}}{\text{straightbred average}} \times 100$$

The statistical model used in this investigation is as follows:

$$Y_{ij} = \mu + B_i + E_{ij}$$

Where; Y_{ij} = Record of j^{th} kit or litter of the i^{th} strain; B_i = effect of i^{th} strain;
μ = Random mean and E_{ij} = Error residual.

3.5.2 Estimates of Additive (General Combining Ability) and Non-additive (Specific Combining Ability) effects for litter size and weights at birth and weaning

The results obtained from reciprocal cross effects and maternal heterosis was used for the estimation of additive and non-additive effects for growth and carcass traits. The statistical analysis for this study was performed using the IML procedure of SAS (Martinez-Garza, 1983, 1991). The dependent variables were litter size at birth and at weaning and litter weight at birth and at weaning whereas the independent variables were the progenitor breeds of rabbits used.

The statistical model used for the investigation was as follows:

$$Y_{ijk} = \mu + g_i + g_j + s_{ij} + m_i + m_j + r_{ij} + \ell_{ijk}$$

Where;

Y_{ijk} = variable analysed;

μ = overall mean;

g_i = effect of the general combining ability of the $_i^{th}$ strain of rabbit;

g_j = effect of the general combining ability of the $_j^{th}$ strain of rabbit;

s_{ij} = Interaction or effect of the specific combining ability of the cross ($_{i \times j}$);

r_{ij} = reciprocal (sex-linked) effect of the cross ($_{i \times j}$);

ℓ_{ijk} = random error; assumed to be independently randomly distributed $(0, \sigma^2)$.

Statistically all effects were considered as fixed effects.

General Combining Ability (GCA) and Specific Combining Ability (SCA) were estimated using the following respective formulae:

$$GCA = \tfrac{1}{2}\, n\, (Y_{i.} + Y_{.i}) - 1/n^2\, Y$$

$$SCA = \tfrac{1}{2}\, (Y_{ij} + Y_{ji}) - \tfrac{1}{2} n\, (Y_{i.} + Y_{i} + Y_{j.} + Y_{.j}) + 1/n^2\, Y$$

Where; n is the number of records considered or number of breeds involved in the crosses; Y. is the sum of the observations $Y_1+Y_2+Y_3+\ldots+Y_n$ for respective strains (i or j) of rabbit.

3.5.3 Estimation of genetic parameters for growth and reproductive traits

3.5.3.1 Heritability estimates

For the purpose of estimating genetic parameters (heritability, repeatability, genetic and phenotypic correlations) only data on purebred kittens were considered. For heritability estimation, the following parameters were taken: body weight (BW) and body linear measurements, namely ear length (EL), body length (BL), tail length (TL), heart girth (HG), nose to shoulder (NTS), shoulder to-tail-drop (STT), length of front leg (LFL) and length of back leg (LBL). All linear body measurements were taken in centimeters with a tape rule at 35 (weaning age), 42, 49, 56, 62 and 70 days of age. The data were subjected to analysis of variance (ANOVA) using the GLM procedure of SAS (SAS 2002). The design of the experiment is of the Nested or Hierarchical type (Henderson, 1963), in which a sire was

mated to several dams with each mating producing several offspring. The model is as given below:

$$Y_{ijk} = \mu + B_i + S_{ij} + D_{ijk} + E_{ijkl}$$

Where; Y_{ijkl} = Observation on the i^{th} rabbit of the k^{th} doe mated to the j^{th} sire of the i^{th} strain; μ =

overall mean, B_i = effect of the i^{th} strain; S_{ij} = effect of the j^{th} sire of the i^{th} strain; D_{ijkl} =

effect of the k^{th} doe mated to the j^{th} sire of the i^{th} strain; E_{ijkl} = random error.

Estimates of variance components due to sire (σ^2_S) and dam (σ^2_D) were calculated by equating computed mean squared to their expectations and solving the components. Heritability was then obtained using the standard expression given by Becker (1992) as follows:

$$h^2_S = \frac{4\,\sigma^2_S}{\sigma^2_T} \quad \text{or} \quad h^2_D = \frac{4\,\sigma^2_D}{\sigma^2_T}$$

Where; h^2_S = heritability based on sire variance component;

h^2_D = heritability based on dam variance component;

$\sigma^2_T = \sigma^2_S + \sigma^2_D + \sigma^2_W$; $\quad \sigma^2_W = MS_W$;

$$\sigma^2_S = MS_S - \frac{(MS_W + K_2\sigma^2_D)}{K_3} \qquad \sigma^2_D = MS_D - \frac{MS_W}{K_2}$$

K_2 = average number of progeny per dam; K_3 = average number of progeny per sire;

$$K_2 = \frac{\left\{ \frac{n\,..\, - \sum n^2_i}{n_{i.}} \right\}}{\text{d.f (dams)}} \qquad K_3 = \frac{\left\{ \frac{n..\, - \sum n^2_{i.}}{n_{..}} \right\}}{\text{d.f (sires)}}$$

$n_{i.}$ = number of offspring of the $_i$th sire; $n_{..}$ = total number of progeny;

$n_{ij.}$ = number of offspring of the $_j$th dam within the $_i$th sire; d.f = degree of freedom

3.5.3.2 Repeatability estimates

The breeding value of individuals upon which selection can be based, particularly for traits which can be measured more than once in life-time, depends on repeatability estimates of the traits. The repeatability (R) therefore, which indicates the extent to which selection will influence future performance of the rabbits was calculated using the following formula:

$$R = \frac{\sigma^2_D}{\sigma^2_D + \sigma^2_E} = \frac{V_G + V_{EP}}{V_G + V_{EP} + V_{ET}}$$

Where; V_G = Genetic variance; V_{EP} = Permanent (general) environmental variance; and V_{ET} = Temporary (special) environmental variance.

3.5.3.3 Genetic and Phenotypic Correlations

The genetic and phenotypic correlations amongst the measured traits were obtained by a method similar to that used in estimating heritability. The general formula was obtained using appropriate expressions involving the estimated variance components according to Becker (1992) as shown below and separation of significantly different means was carried out using Duncan's Multiple Range Test (Duncan 1955).

$$r_g = \frac{Cov_{S(xy)} + Cov_{D(xy)}}{\sqrt{(\sigma^2_{S(x)} + \sigma^2_{D(x)})(\sigma^2_{S(y)} + \sigma^2_{D(y)})}}$$

$$r_p = \frac{Cov_W + Cov_S + Cov_D}{\sqrt{(\sigma^2_{W(x)} + \sigma^2_{S(x)} + \sigma^2_{D(x)})}\sqrt{(\sigma^2_{W(y)} + \sigma^2_{S(y)} + \sigma^2_{D(y)})}}$$

Table 3.3: Composition of concentrate diet

Ingredients used	Quantity
Maize (%)	43.00
Maize offal (%)	14.00

Rice offal (%)	10.00
Soya bean meal (%)	28.00
Bone Meal (%)	3.00
Methionine (%)	1.00
Lysine (%)	0.15
Limestone (%)	0.25
Salt (%)	0.30
Vitamin/mineral *Premix (%)	0.30
Total	100.00
Calculated Analysis:	
Energy (Kcal ME/Kg)	2650.00
Crude Protein (%)	18.47
Crude Fibre (%)	6.62
Ash (%)	5.62

*Premix used in this experiment supplied the following per kg of diet: Vitamin A (stabilized) 1251 iu; Vitamin D_3 (stabilized) 2,750 iu; Vitamin E (stabilized) 151 iu; Vitamin K (stabilized) 2.01 mg; Vitamin B_2 4.50mg; Vitamin B_6 3.0mg; Nicotinic acid 22.005mg; Calcium D-Pantothenate 6.0mg; Vitamin B_{12} 0.012mg; Choline chloride 200.10mg; D.O.T (3, 5-dinitro-orthotoluamide) 100.05mg; Manganese 80.01mg; Iron 50.01mg; Zinc 40.005mg; Copper 2.4mg; Iodine 1.401mg; Cobalt 0.201mg; Selenium 0.051mg

CHAPTER FOUR

4.0 RESULTS

4.1 Least square means (±SE) for litter traits according to general combining ability (GCA) and specific combining ability (SCA)

Tables 4.1a and 4.1b show the least square means (±SE) for litter traits from birth to 35 days of age according to general (GCA) and specific (SCA) combining abilities. In the purecross, the highest litter size (LS) at birth of 7.33±0.19 was obtained for California White (CAW) with a corresponding litter weight (LW) at birth of 155.94±4.34g. This was followed by New Zealand White (NZW), which gave an average LS at birth of 6.89±0.25 weighing 149.25±3.92g. The Chinchilla (CHC) breed gave the least LS at birth of 6.05±0.29 but had the heaviest LW of 163.68±5.76g. The individual kit weight (IKW) obtained for the three breeds indicated that the CHC breed had the heaviest mean value (27.05±2.14g) and CAW breed the lowest (21.27±1.39g). Generally, the results obtained herein indicated that the effect of breed on litter traits at birth (LS, LW and IKW) was significant ($P<0.05$) although the values for LW and IKW obtained between NZW and CAW were not significantly ($P>0.05$) different.

At 21 and 35 days of age (Table 4.1b) the CAW breed maintained its superiority for LS and LW where it produced 5.94±0.22 kittens that weighed 1067.29±36.78g and 5.86±0.22 kittens that weighed 1838.40±66.22g, respectively. The CHC was the least performing breed in terms of LS and LW at both 21 and 35 days of age, where it gave 4.61±0.29 kittens weighing 952.13±38.11g and 4.58±0.29 kittens weighing 1596.93±66.31g. Nevertheless, CHC was the best breed in terms of IKW, with the mean values of 206.53±2.31g and 348.67±2.77g at 21 and 35 days of age, respectively. It was observed that the NZW was the second best breed for LS (5.5±0.21), LW (1041.02±37.34g) and IKW (189.27±2.77g), at 21 days of age, and LS (5.39±0.23), LW (1764.05±64.36g) and IKW (327.28±2.14g) at 35 days of age, respectively. Breed significantly ($P<0.05$) affected all traits studied at 21 and 35 days

of age, except for IKW at 21 days of age, where the mean values obtained for NZW and CAW did not show any significant (P>0.05) difference.

In the maincross (Table 4.1a), the NZW x CAW combination produced at birth the highest LS (8.50±0.28) with the lowest LW (169.17±8.06g). It was followed by CAW x CHC cross, which gave LS of 7.25±0.52 with the heaviest LW (184.96±7.69g). CHC x NZW cross on the other hand, produced the smallest number of litters at birth (6.41±0.43), which collectively weighed 170.08±11.36g). Based on individual kit weight (IKW) at birth, the CHC x CAW yielded the heaviest kittens (26.53±2.22g) followed by kittens from CAW x CHC (25.51±2.77g) and NZW x CAW (19.9±1.31g). The LS, LW and IKW obtained from NZW x CAW cross were 7.17±0.23, 1248.9±62.16g and 174.18±2.24g at 21 days of age and 7.08±0.31, 2089.5±141.56g and 295.12±2.46g at 35 days of age. The CAW x CHC cross gave the heaviest kittens (IKW) with each weighing 324.24±2.39g at 35 days of age. A non-significant (P>0.05) neonatal mortality of 3.7% was recorded for NZW, 6.1% for CAW and 3.7% for CHC breed. In the main cross however, the highest mortality rate (6.8%) was in the NZW x CAW cross and the lowest (3.6%) in CHC x NZW cross. In the reciprocal cross, a loss of 6.25% pups was recorded for CHC x CAW followed by 5.2% and 5% for NZW x CHC and CAW x NZW reciprocal crosses, respectively.

In the reciprocal cross, CAW x NZW produced the largest (8.25±0.21) and heaviest (170.12±4.66g) litters at birth though with the least IKW (20.62±2.17g). The CHC x CAW reciprocal cross gave the least (6.66±0.28) litters resulting in the highest IKW where each kit weighed 22.52±2.19g. At 21 days of age (Tables 4.1a and 4.1b), 6.08±0.35 kittens per litter individually weighing 173.15±1.88g were obtained from the CAW x NZW reciprocal cross

Table 4.1a: Least Square Means (±SE) for litter traits at birth, 7 and 14 days of age according to General (GCA) and Specific (SCA) Combining Abilities

Age (days)	Traits	GENERAL COMBINING ABILITY			SPECIFIC COMBINING ABILITY					
		PURE CROSS			MAINCROSS			RECIPROCAL CROSS		
		CHC x CHC	NZW x NZW	CAW x CAW	CHC x NZW	NZW x CAW	CAW x CHC	NZW x CHC	CAW x NZW	CHC x CAW
Birth	N	54	66	82	83	102	87	77	99	80
	LS*	6.05±0.29^{c}	6.89±0.25^{b}	7.33±0.19^{a}	6.41±0.43^{c}	8.50±0.28^{a}	7.25±0.52^{b}	6.91±0.28^{b}	8.25±0.21^{a}	6.66±0.28^{c}
	LW* (g)	163.68±5.76^{a}	149.25±3.92^{b}	155.94±4.34^{b}	170.08±11.36^{b}	169.17±8.06^{b}	184.96±7.69^{a}	149.17±4.29^{b}	170.12±4.66^{a}	149.98±9.05^{b}
	IKW* (g)	27.05±2.14^{a}	21.66±1.61^{b}	21.27±1.39^{b}	26.53±2.22^{a}	19.9±1.31^{c}	25.51±2.77^{b}	21.58±2.38^{b}	20.62±2.17^{c}	22.52±2.19^{a}
	NM (%)	3.7^{c}	7.5^{a}	6.1^{b}	3.6^{c}	6.8^{a}	4.6^{b}	5.2^{b}	5.0^{b}	6.25^{a}
7	LS*	5.25±0.28^{c}	5.97±0.49^{b}	6.78±0.27^{a}	6.0±0.53^{b}	8.08±0.22^{a}	5.91±0.49^{b}	6.25±0.39^{a}	6.25±0.35^{a}	6.0±0.30^{b}
	LW* (g)	344.49±14.63^{b}	324.29±13.68^{b}	512.77±128.77^{a}	394.91±26.18^{b}	796.7±382.89^{a}	361.37±20.11^{c}	352.18±22.85^{b}	305.57±24.31^{c}	382.44±22.09^{a}
	IKW* (g)	65.62±2.25^{b}	54.32±2.44^{c}	75.63±2.21^{a}	65.82±2.74^{b}	98.6±2.04^{a}	61.14±2.36^{c}	56.35±2.17^{b}	48.89±2.29^{c}	63.74±2.22^{a}
14	LS*	4.91±0.28^{c}	5.63±0.48^{b}	6.13±0.28^{a}	5.67±0.47^{b}	7.33±0.25^{a}	5.67±0.54^{b}	5.91±0.33^{b}	6.17±0.35^{a}	5.16±0.17^{c}
	LW* (g)	678.02±30.29^{b}	673.96±26.63^{b}	742.69±22.47^{a}	756.65±64.31^{b}	833.11±34.57^{a}	717.31±31.07^{c}	720.77±39.62^{a}	643.6±49.98^{c}	701.25±38.13^{b}
	IKW* (g)	138.09±2.7^{a}	119.71±1.86^{b}	121.15±1.41^{b}	133.45±3.42^{a}	113.66±3.76^{c}	126.51±3.13^{b}	121.96±3.33^{b}	104.31±3.71^{c}	135.9±3.3^{a}

^{abc} =Means within the same row for a particular cross having the same letter are not significantly (P>0.05) different; N=Sample size; LS=litter size; LW=litter weight; IKW=Individual Kit weight; NM=Neonatal mortality; CHC=Chinchilla; NZW=New Zealand White; CAW=California White.

Table 4.1b: Least Square Means (±SE) for litter traits at 21, 28 and 35 days of age according to General (GCA) and Specific (SCA) Combining Abilities

Age (days)	Traits	GENERAL COMBINING ABILITY			SPECIFIC COMBINING ABILITY					
		PURE CROSS			MAINCROSS			RECIPROCAL CROSS		
		CHC x CHC	NZW x NZW	CAW x CAW	CHC x NZW	NZW x CAW	CAW x CHC	NZW x CHC	CAW x NZW	CHC x CAW
21	LS*	4.61±0.29^{c}	5.5±0.21^{b}	5.94±0.22^{a}	5.16±0.47^{c}	7.17±0.23^{a}	5.41±0.54^{b}	5.67±0.21^{b}	6.08±0.35^{a}	4.75±0.17^{c}
	LW* (g)	952.13±38.11^{c}	1041.02±37.34^{b}	1067.29±36.78^{a}	1031.4±67.80^{b}	1248.90±62.16^{a}	1022.59±60.42^{c}	1098.55±58.59^{a}	1052.77±62.57^{b}	957.35±48.12^{c}
	IKW* (g)	206.53±2.31^{a}	189.27±2.77^{b}	179.68±2.02^{c}	199.88±2.91^{a}	174.18±2.24^{c}	189.02±1.96^{b}	193.75±2.53^{b}	173.15±1.88^{c}	201.55±2.43^{a}
28	LS*	4.58±0.29^{c}	5.39±0.23^{b}	5.91±0.22^{a}	5.16±0.47^{c}	7.17±0.29^{a}	5.41±0.54^{b}	5.58±0.31^{b}	6.08±0.35^{a}	4.75±0.17^{c}
	LW* (g)	1264.15±51.85^{c}	1391.5±50.56^{b}	1469.35±54.11^{a}	1374.37±82.04^{c}	1696.5±110.73^{a}	1380.99±86.26^{b}	1472.58±55.37^{a}	1457.08±85.98^{b}	1314.18±59.82^{c}
	IKW* (g)	276.67±2.16^{a}	239.65±2.32^{d}	263.9±2.99^{b}	255.26±2.93^{b}	236.61±2.74^{c}	266.35±2.26^{a}	248.62±2.27^{c}	258.16±2.46^{b}	276.01±2.59^{a}
35	N	38	54	70	67	85	65	62	73	56
	LS*	4.58±0.29^{c}	5.39±0.23^{b}	5.86±0.22^{a}	5.16±0.47^{c}	7.08±0.31^{a}	5.41±0.54^{b}	5.58±0.31^{b}	6.08±0.35^{a}	4.67±0.18^{c}
	LW* (g)	1596.93±66.31^{C}	1764.05±64.36^{b}	1838.40±66.22^{a}	1748.48±96.71^{c}	2089.5±141.56^{a}	1754.15±114.66^{b}	1870.3±65.49^{b}	1890.6±115.04^{a}	1622.0±71.46^{c}
	IKW* (g)	348.67±2.77^{a}	327.28±2.14^{b}	313.72±2.55^{c}	338.85±2.13^{a}	295.12±2.46^{c}	324.24±2.39^{b}	335.18±2.14^{b}	310.95±2.36^{c}	347.32±2.59^{a}
	PWM (%)	14.6^{c}	29.6^{a}	18.2^{b}	19.3^{b}	25.3^{a}	16.6^{c}	19.5^{c}	30^{a}	21^{b}

^{abc} =Means within the same row for a particular cross having the same letter are not significantly (P>0.05) different; N=Sample size; LS=litter size; LW=litter weight; IKW=Individual Kit weight; PWM=Pre-Weaning Mortality; CHC=Chinchilla; NZW=New Zealand White; CAW=California White.

while 4.75±0.17 kittens, each weighing 201.55±2.43g, were produced by the CHC x CAW reciprocal cross. On individual kit weight basis at weaning, the CHC x CAW reciprocal cross had the heaviest rabbits (347.32±2.59g), while the CAW x NZW reciprocal cross gave the lightest (310.95±2.36g).

The overall mean litter loss from birth to 35 days of age (weaning) in the purecross was 14.6% for CHC, 18.2% for CAW and 29.6% for NZW breed, respectively. Highest mortality in the maincross was recorded for the NZW x CAW cross (25.3%) while the lowest was for the CAW x CHC cross (16.6%). In the reciprocal cross however, 30% mortality was recorded for CAW x NZW reciprocal cross and 19.5% for NZW x CHC reciprocal cross.

4.2 Effects of breed of sire, breed of dam, parity and sex on growth traits of rabbits

Tables 4.2, 4.3 and 4.4 show the effects of breed of sire, breed of dam, parity and sex on body weights and body linear measurements of rabbits at various ages. Breed of sire significantly ($P<0.05$) affected body weight (BW) at 6, 8 and 10 weeks of age, with the Chinchilla (CHC) breed weighing heavier than New Zealand White (NZW) and California White (CAW) breeds. For body linear measurements, ear length (EL), body length (BL) and heart girth (HG) at 6; EL, BL and tail length (TL) at 8, and EL and BL at 10 weeks of age were significantly affected by breed of sire.

Similarly, breed of dam significantly ($P<0.05$) influenced BW across all ages. The CHC breed had the highest BW (502.79g, 826.62g and 1103.64g) at 6, 8 and 10 weeks of age, respectively while the NZW breed had the lowest BW (736.56g and 986.10g) at 8 and 10 weeks of age, respectively. Significant differences were observed due to dam effect on EL, BL, TL and HG at 6 and 8 weeks of age. All other linear measurements were also affected at 10 weeks of age except TL and shoulder to tail-drop (STT).

Table 4.2: Effects of breed of sire, breed of dam, parity and sex on body weight (g) and body linear measurements (cm) of rabbits at 6 weeks of age

		Parameters								
	No.	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
Breed of sire										
CHC	157	512.51±7.43^{a}	4.28±0.03^{b}	12.77±0.12^{b}	4.15±0.29^{a}	13.53±0.10^{a}	8.66±0.04^{a}	17.85±0.07^{b}	7.96±0.03^{a}	11.99±0.03^{a}
NZW	183	455.6±6.36^{b}	4.37±0.03^{a}	12.89±0.11^{a}	4.18±0.29^{a}	13.59±0.09^{a}	8.63±0.03^{a}	17.83±0.08^{b}	7.92±0.03^{a}	11.98±0.02^{a}
CAW	188	454.99±7.32^{b}	4.27±0.02^{b}	12.70±0.11^{c}	4.16±0.34^{a}	13.53±0.09^{a}	8.67±0.03^{a}	18.03±0.08^{a}	7.95±0.039^{a}	11.99±0.02^{a}
Breed of dam										
CHC	163	502.79±9.06^{a}	4.41±0.44^{a}	12.79±0.12^{b}	4.16±0.35^{b}	13.48±0.09^{b}	8.69±0.04^{a}	17.93±0.08^{a}	7.95±0.03^{a}	12.0±0.32^{a}
NZW	183	461.28±5.92^{b}	4.24±0.32^{b}	12.70±0.11^{c}	4.14±0.31^{b}	13.51±0.09^{b}	8.65±0.03^{a}	17.93±0.08^{a}	7.95±0.03^{a}	11.99±0.33^{a}
CAW	182	456.09±6.50^{c}	4.28±0.28^{b}	12.88±0.10^{a}	4.20±0.26^{a}	13.65±0.09^{a}	8.63±0.03^{a}	17.84±0.08^{b}	7.92±0.03^{a}	11.97±0.31^{a}
Parity										
1	199	375.57±3.10^{c}	4.04±0.02^{c}	10.92±0.02^{c}	3.85±0.02^{b}	12.03±0.30^{b}	8.61±0.03^{b}	17.79±0.07^{b}	7.86±0.03^{b}	11.93±0.02^{b}
2	174	522.03±5.63^{b}	4.42±0.02^{b}	13.82±0.03^{b}	4.34±0.01^{a}	14.46±0.21^{a}	8.61±0.03^{b}	17.77±0.08^{b}	7.90±0.03^{b}	11.96±0.02^{b}
3	155	540.68±4.99^{a}	4.51±0.03^{a}	14.02±0.03^{a}	4.37±0.01^{a}	14.48±0.18^{a}	8.77±0.04^{a}	18.17±0.09^{a}	8.09±0.03^{a}	12.09±0.03^{a}
Sex										
Male	249	472.45±6.32^{a}	4.29±0.02^{a}	12.79±0.09^{a}	4.16±0.02^{a}	13.55±0.08^{a}	8.66±0.03^{a}	17.89±0.07^{a}	7.96±0.02^{a}	12.04±0.31^{a}
Female	279	472.18±5.65^{a}	4.32±0.02^{a}	12.79±0.09^{a}	4.17±0.02^{a}	13.55±0.07^{a}	8.65±0.03^{a}	17.89±0.06^{a}	7.93±0.02^{a}	11.97±0.32^{a}
Overall	528	472.30±4.21	4.31±0.02	12.79±0.07	4.16±0.31	13.55±0.05	8.66±0.02	17.89±0.05	7.94±0.02	11.99±0.01

BW=Body weight, EL=Ear length, BL=Body length, TL=Tail length, HG=heart girth, NTS=Nose to shoulder, STT=Shoulder to tail-drop, LFL=Length of front leg, LBL=Length of back leg.
CHC=Chinchilla, NZW=New Zealand White, CAW=California White.
^{abc} =Means within the same column having the same letter are not significantly (P>0.05) different.

Table 4.3: Effects of breed of sire, breed of dam, parity and sex on body weight (g) and body linear measurements (cm) of rabbits at 8 weeks of age.

		Parameters								
	No.	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
Breed of sire										
CHC	157	812.96±14.28^{a}	5.47±0.03^{b}	15.34±0.18^{b}	5.17±0.02^{a}	15.26±0.12^{a}	10.53±0.06^{b}	19.44±0.11^{b}	9.75±0.05^{b}	13.40±0.03^{a}
NZW	175	770.61±14.84^{b}	5.61±0.04^{a}	15.48±0.18^{a}	5.10±0.03^{a}	15.26±0.12^{a}	10.52±0.05^{b}	19.48±0.09^{b}	9.75±0.04^{b}	13.40±0.02^{a}
CAW	171	735.42±14.42^{c}	5.41±0.03^{b}	15.29±0.16^{c}	5.08±0.03^{a}	15.23±0.11^{a}	10.63±0.05^{a}	19.68±0.09^{a}	9.85±0.04^{a}	13.39±0.02^{a}
Breed of dam										
CHC	155	826.62±18.78^{a}	5.64±0.05^{a}	15.32±0.19^{b}	5.08±0.03^{b}	15.14±0.12^{c}	10.62±0.06^{a}	19.61±0.09^{a}	9.83±0.04^{a}	13.47±0.03^{a}
NZW	170	736.56±11.50^{c}	5.40±0.03^{b}	15.26±0.17^{c}	5.12±0.02^{a}	15.22±0.11^{b}	10.58±0.06^{a}	19.59±0.10^{a}	9.82±0.04^{a}	13.39±0.02^{b}
CAW	178	755.79±12.91^{b}	5.46±0.03^{b}	15.52±0.16^{a}	5.15±0.02^{a}	15.37±0.11^{a}	10.49±0.06^{b}	19.42±0.09^{b}	9.71±0.05^{b}	13.35±0.02^{b}
Parity										
1	182	549.79±4.29^{b}	5.14±0.02^{c}	12.46±0.01^{c}	4.99±0.04^{b}	13.30±0.03^{b}	10.50±0.05^{b}	19.43±0.09^{b}	9.70±0.04^{b}	13.38±0.02^{b}
2	167	899.32±9.56^{a}	5.68±0.03^{b}	16.92±0.03^{b}	5.19±0.01^{a}	16.36±0.01^{a}	10.47±0.05^{b}	19.34±0.09^{c}	9.71±0.04^{b}	13.39±0.02^{b}
3	154	893.95±6.88^{a}	5.72±0.03^{a}	17.14±0.04^{a}	5.19±0.01^{a}	16.34±0.01^{a}	10.72±0.06^{a}	19.88±0.11^{a}	9.98±0.05^{a}	13.43±0.03^{a}
Sex										
Male	238	770.66±12.52^{a}	5.47±0.03^{a}	15.34±0.15^{a}	5.10±0.02^{a}	15.25±0.09^{a}	10.57±0.05^{a}	19.56±0.08^{a}	9.81±0.04^{a}	13.41±0.02^{a}
Female	265	771.69±11.59^{a}	5.51±0.03^{a}	15.37±0.14^{a}	5.13±0.02^{a}	15.25±0.09^{a}	10.55±0.04^{a}	19.52±0.08^{a}	9.77±0.03^{a}	13.39±0.02^{a}
Overall	503	771.21±8.50	5.49±0.02	15.37±0.09	5.12±0.01	15.25±0.07	10.56±0.03	19.54±0.06	9.79±0.03	13.40±0.01

BW=Body weight, EL=Ear length, BL=Body length, TL=Tail length, HG=heart girth, NTS=Nose to shoulder, STT=Shoulder to tail-drop, LFL=Length of front leg, LBL=Length of back leg.
CHC=Chinchilla, NZW=New Zealand White, CAW=California White.
^{abc} =Means within the same column having the same letter are not significantly (P>0.05) different.

Table 4.4: Effects of breed of sire, breed of dam, parity and sex on body weight (g) and body linear measurements (cm) of rabbits at 10 weeks of age.

		Parameters								
	No.	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
Breed of sire										
CHC	154	1075.23±18.35[a]	6.83±0.04[b]	19.83±0.37[b]	5.96±0.03[a]	16.55±0.10[a]	12.25±0.07[a]	21.00±0.13[a]	11.53±0.04[a]	14.69±0.03[a]
NZW	169	1045.74±21.48[b]	6.94±0.05[a]	20.15±0.35[a]	5.91±0.04[a]	16.59±0.09[a]	12.21±0.07[a]	20.97±0.12[a]	11.49±0.04[a]	14.71±0.02[a]
CAW	177	948.15±20.34[c]	6.83±0.04[b]	19.79±0.33[b]	5.91±0.04[a]	16.55±0.09[a]	12.25±0.06[a]	21.11±0.13[a]	11.51±0.03[a]	14.70±0.01[a]
Breed of dam										
CHC	155	1103.64±26.39[a]	6.98±0.05[a]	19.78±0.38[b]	5.92±0.04[a]	16.47±0.01[c]	12.33±0.07[a]	21.09±0.13[a]	11.61±0.04[a]	14..790.03[a]
NZW	170	989.10±16.04[c]	6.77±0.04[c]	19.71±0.34[b]	5.93±0.03[a]	16.53±0.09[b]	12.26±0.07[b]	21.13±0.13[a]	11.50±0.03[b]	14.68±0.02[b]
CAW	175	1013.17±17.59[b]	6.87±0.04[b]	20.28±0.32[a]	5.93±0.04[a]	16.68±0.09 [a]	12.13±0.06[c]	20.88±0.13[b]	11.43±0.04[c]	14.62±0.02[b]
Parity										
1	179	716.28±5.35[c]	6.33±0.03[b]	15.94±0.03[c]	5.24±0.00[b]	14.88±0.02[b]	12.14±0.06[b]	20.85±0.12[b]	11.44±0.04[b]	14.71±0.02[a]
2	167	1220.26±11.76[a]	7.18±0.03[a]	23.08±0.05[b]	5.74±0.05[a]	17.50±0.01[a]	12.18±0.06[b]	20.84±0.12[b]	11.49±0.03[b]	14.71±0.03[a]
3	154	1198.12±8.97[b]	7.16±0.03[a]	23.48±0.07[a]	5.77±0.01[a]	17.50±0.01[a]	12.41±0.07[a]	21.44±0.15[a]	11.62±0.04[a]	14.67±0.02[a]
Sex										
Male	237	1030.61±17.28[a]	6.84±0.04[a]	19.92±0.29[a]	5.90±0.03[a]	16.55±0.08[a]	12.26±0.06[a]	21.06±0.11[a]	11.51±0.03[a]	14.69±0.02[a]
Female	263	1035.19±16.13[a]	6.89±0.03[a]	19.93±0.28[a]	5.95±0.03[a]	16.57±0.08[a]	12.22±0.05[a]	21.01±0.10[a]	11.51±0.02[a]	14.70±0.02[a]
Overall	500	1033.02±11.78	6.87±0.02	19.93±0.20	5.93±0.02	16.56±0.06	12.24±0.04	21.03±0.08	11.51±0.02	14.70±0.01

BW=Body weight, EL=Ear length, BL=Body length, TL=Tail length, HG=heart girth, NTS=Nose to shoulder, STT=Shoulder to tail-drop, LFL=Length of front leg, LBL=Length of back leg.
CHC=Chinchilla, NZW=New Zealand White, CAW=California White.
[abc] =Means within the same column having the same letter are not significantly (P>0.05) different.

Sex had no significant (P>0.05) effect on all growth parameters measured at the various ages. Parity on the other hand, significantly (P<0.05) influenced the BW of all rabbits at 6, 8 and 10 weeks of age. While rabbits that belong to parity 3 had the highest BW at 6 and 8 weeks of age, those in the first parity had the lowest BW at 6, 8 and 10 weeks of age, respectively. Significant (P<0.05) parity effect for all body measurements was observed except for length of back leg (LBL) at 8 and 10 weeks of age.

4.3 General Combining Ability (GCA) for growth traits

Estimates of general combining ability (GCA) for body weight and linear body measurements are presented in Table 4.5. On the basis of the nine traits studied, general combining ability (GCA) was significant (P<0.05) for five traits and insignificant (P>0.05) for the remaining four. Significant (P<0.05) estimates of GCA were obtained for body weight (BW), ear length (EL), body length (BL), heart girth (HG) and shoulder to tail (STT), while tail length (TL), nose to shoulder (NTS), length of front leg (LFL) and length of back leg (LBL) were observed to be insignificant (P>0.05). On the basis of breed, the Chinchilla (CHC) rabbit gave the highest estimate for eight traits namely; BW (16.741), EL (0.374), BL (0.778), TL (0.226) NTS (0.317) STT (0.486), LFL (0.179) and LBL (0.331); although, the values for TL, NTS, LFL and LBL were not significant (P>0.05). The New Zealand White (NZW) rabbit had the highest and significant (P<0.05) estimate for HG (0.596), while the California White (CAW) rabbit showed the least estimate of GCA for six traits. Negative but insignificant (P>0.05) estimates were observed for TL (-0.24), NTS (-0.075) and STT (-0.383) in the NZW.

4.4 Specific Combining Ability (SCA) for growth traits

Table 4.5 shows the effects of Specific Combining Ability (SCA) on body weight and linear body measurements. SCA was significant (P<0.05) for three traits (BW, TL and NTS) and not significant (P>0.05) for the six others (EL, BL, HG, STT, LFL and LBL).

Table 4.5: Estimates of General Combining Ability (GCA) and Specific Combining Ability (SCA) for body weight and body linear measurements

Combining Ability	Traits								
	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
GCA									
CHC	16.741*	0.374*	0.778*	0.226	0.592*	0.317	0.486*	0.179	0.331
NZW	12.330*	0.266*	0.422*	-0.240	0.596*	-0.075	-0.383	0.024	0.113
CAW	9.962*	0.295*	0.161*	0.117	0.377*	0.144	0.423*	-0.155	0.117
SCA									
CHC x NZW	13.271*	0.242	4.331	-0.101	0.782	0.172*	0.360	-0.066	-0.062
NZW x CAW	10.111*	-0.236	1.200	0.216*	0.415	0.088	0.210	-0.100	-0.236
CAW x CHC	6.777*	0.174	0.184	0.314*	0.479	0.104*	0.226	-0.032	0.172

BW=Body weight; EL=Ear length; BL=Body length; TL=Tail length; HG=Heart girth; NTS=Nose to shoulder; STT=Shoulder to tail-drop; LFL=Length of front leg; LBL=Length of back leg.
CHC=Chinchilla; NZW=New Zealand White; CAW=California White.
* $P<0.05$

Table 4.6: Estimates of Percent Heterosis (%H') and Percent Reciprocal (%R') effects for birth traits

Mating group	Traits					
	GL	LSB	LWB	GG	KL	PWM
CHC x NZW (%H')	3.41	41.85	38.74	45.12	-18.11	-21.17
NZW x CAW (%H')	6.67	63.24	52.18	56.44	-24.42	-26.03
CAW x CHC (%H')	-4.33	36.19	46.25	48.36	-13.99	-28.75
Overall (%H')	8.74±5.11	54.28±15.72	49.22±8.41	53.76±8.44	-27.48±16.33	-33.26±17.74
NZW x CHC (%R')	20.79*	16.27*	31.39*	33.57*	5.07 NS	0.62 NS
CAW x NZW (%R')	1.35NS	07.36 NS	24.07 NS	17.66 NS	19.14 NS	3.52 NS
CHC x CAW (%R')	11.16*	25.13*	39.30 NS	24.0 NS	12.53 NS	12.07 NS
Overall (%R')	13.44±1.54	19.17±10.14	30.99±9.24	26.13±21.81	18.46±11.06	10.18±44.13

CHC=Chinchilla; NZW=New Zealand white; CAW=California white
GL=Gestation length; LSB=Litter size at birth; LWB=Litter weight at birth; GG=Gestation gain;
KL=Kindling loss; PWM=Pre-Weaning Mortality;
* ($P<0.05$); NS = Not significant.

Table 4.7: Estimate of Percent Heterosis (%H') and Percent Reciprocal (%R') effects for weaning traits

Mating group	Traits					
	LSW	LWW	LWG	WSR	SRW	WM
CHC x NZW (%H')	37.11	29.27	67.40	43.11	35.38	2.43
NZW x CAW (%H')	38.48	29.49	53.21	46.74	27.31	4.51
CAW x CHC (%H')	33.23	25.66	60.88	48.36	29.74	4.32
Overall (%H')	31.27±9.44	20.18±6.66	63.32±17.0	45.82±10.3	32.11±11.1	6.55±1.08
NZW x CHC (%R')	10.6	12.12	20.89	0.35	9.9	3.1
CAW x NZW (%R')	5.55	13.73	16.22	0.48	18.74	1.87
CHC x CAW (%R')	16.37*	19.19	27.06	16.68	6.44	2.29
Overall (%R')	10.10±4.4	17.91±11.4	25.50±11.1	16.37±9.66	14.29±4.23	4.07±1.36

CHC=Chinchilla; NZW=New Zealand White; CAW=California White
LSW=Litter size at weaning; LWW=Litter weight at weaning; LWG=Litter weight gain; WSR=Weaning sex ratio; SRW=Survival rate to weaning; WM=Weaning Mortality
* ($P<0.05$)

The CHC x NZW cross showed superiority over NZW x CAW and CAW x CHC crosses for BW (13.271), EL (0.242) BL (4.331), HG (0.782), NTS (0.172) and STT (0.360). However, the superiority was only significant ($P<0.05$) for BW and NTS. The CAW x CHC cross on the other hand was superior to NZW x CAW for EL (0.174), TL (0.314), HG (479), NTS (0.104) and STT (0.226) respectively. Negatively insignificant ($P>0.05$) estimates of SCA were obtained in almost all the crosses for LFL and LBL.

4.5 Percent Heterotic (%H') and Reciprocal (%R') effects for litter traits

4.5.1 Litter birth traits

Table 4.6 shows the estimates of heterotic and reciprocal effects for birth traits. The NZW x CAW cross produced the highest (63.24) percent heterosis (%H') for litter size at birth (LSB) followed by CHC x NZW cross (41.85) and CAW x CHC cross (36.19). The %H' obtained for kindling loss (KL) and neonatal mortality (NM) was negative in all the three crosses. This means that crossing had improved these breeds and made the young more vigorous resulting to less mortality. Based on overall performance, the highest %H' obtained was for LSB (45.28%) followed by GG (53.76%) and LWB (49.22%), GL recorded low %H' (8.74%) while desirably negative values were recorded for KL (-27.48%) and NM (-33.26%).

Estimates of percent reciprocal effect (%R') for birth traits are presented in Table 4.6. The results showed a highly significant effect ($P<0.01$) in LWB attributed to reciprocal effects (31.39) for NZW x CHC cross. Significant effect ($P<0.05$) due to reciprocal cross was observed for GL and LSB in NZW x CHC and CHC x CAW. Kindling loss and neonatal mortality showed no significant ($P>0.05$) reciprocal effect in NZW x CHC and CHC x CAW crosses. Similarly, reciprocal effect was not important in CAW x NZW cross for all birth traits studied.

4.5.2 Weaning traits

Crossbreeding has improved positively the litter size (LSW) and weight at weaning (LWW) in all the three crosses (Table 4.7). The estimates of %H' obtained for LSW and LWW in CHC x NZW, NZW x CAW and CAW x CHC were 37.11% and 29.7%, 38.48% and 29.49% and 33.23% and 25.66%, respectively. Litter weight gain (LWG), weaning sex ratio (WSR) and survival rate to weaning (SRW) were all favoured by crossbreeding.

Estimates of percent reciprocal effect (%R') for weaning traits are given in Table 4.7. The %R' obtained in CHC x CAW cross for LSW, LWW and LWG were 16.37%, 19.19% and 27.06%, respectively, and the effect was significant ($P<0.05$). However, weaning sex ratio, survival rate to weaning and weaning mortality were not affected by CHC x CAW cross. The matings NZW x CHC and CAW x NZW showed no significant ($P>0.05$) effect for all weaning traits examined.

4.6 Genetic parameter estimates

4.6.1 Heritability estimates for litter and growth traits

The estimates of heritability from sire ($h^2_S \pm SE$) and dam ($h^2_D \pm SE$) component of variance for reproductive and litter traits from birth to weaning in the three breeds of rabbits are given in Tables 4.8a and 4.8b. The sire component ($h^2_S \pm SE$) in the CHC breed from birth to weaning for gestation length (GL) ranged from 0.18±0.27 to 0.26±0.27, while the dam component ($h^2_D \pm SE$) ranged from 0.24±0.21 to 0.33±0.30, respectively. The corresponding values of ($h^2_S \pm SE$) in the NZW breed from birth to weaning ranged from 0.11±0.24 to 0.15±0.27 and the ($h^2_D \pm SE$) values ranged from 0.17±0.14 to 0.34±0.30. In the CAW, the values of ($h^2_S \pm SE$) ranged from 0.11±0.24 to 0.17±0.24, while the dam component ($h^2_S \pm SE$) ranged from 0.18±0.22 to 0.33±0.30. Moderate to high estimate of heritability for litter size and weight at birth (LSB, LWB) and at weaning (LSW, LWW) were observed in the CHC,

NZW and CAW breeds. The highest h^2_S in the CHC breed for Litter size (LS) was 0.64 at 7 days of age and the lowest estimate was 0.49 at 21 days of age. For litter weight (LW) in the same breed, the highest h^2_S was 0.52 at weaning and the lowest h^2 was 0.34 at 7 days of age. The highest value of h^2_D for LS was 0.68 at 7 days of age and the lowest was 0.53 at 14 days of age. In the New Zealand White breed, 0.46 was obtained as the highest h^2_S estimate for LS at 21 days of age, while the lowest was 0.30 at 28 days of age. For litter weight in the same breed, the highest value (0.41) was at 21 days of age and the lowest value (0.28) was at 14 days of age. In the CAW breed, the highest and lowest estimates of h^2_S for litter size were 0.42 and 0.31 at 42 and 21 days of age, respectively. The highest and lowest estimates of h^2_S for litter weight in this breed were 0.41 and 0.32 obtained at birth and weaning, respectively. The highest and lowest values of h^2_D in the CAW breed were 0.44 at 28 days and 0.37 at 7 days of age for LS and LW, respectively.

Tables 4.9a, 4.9b, 4.10a, 4.10b and 4.11a and 4.11b show the estimates of heritability from sire (h^2_S) and dam (h^2_D) component of variance for growth traits in the Chinchilla (CHC), New Zealand White (NZW) and California White (CAW) breeds at various ages. Moderate to high estimates of h^2_S were obtained in the CHC breed (Table 4.9a) for STT (0.45), NTS (0.35), HG (0.47), BL (0.66) and BW (0.38) at 6 weeks of age, for STT (0.37), NTS (0.31), BW (0.38), HG (0.51) and BL (0.58) at 8 weeks of age and for STT (0.37), NTS (0.30), HG (043), BW (0.39) and BL (0.55) at 10 weeks of age. Low estimates of h^2_S were recorded for EL at 6 and 8 weeks of age, TL at 8 and 10 weeks of age, LFL at 8 weeks of age, and LBL at 10 weeks of age.

In the NZW breed (Table 4.10a) the estimates of h^2_S were moderate to high for BW, BL, HG, NTS and STT at 6 weeks of age, for BW, BL, TL, NTS, STT and HG at 8 weeks of age and for BL, HG and STT at 10 weeks of age. Ear length at 6 weeks of age and length of

back leg at 10 weeks of age were lowly heritable in the NZW breed of rabbit. The dam component of heritability (h^2_D) obtained in the NZW breed (Table 4.10b) were low for EL, LFL and LBL across all ages, and TL at 7, 8, 9 and 10 weeks of age, respectively. They were moderate to high for BW, BL, HG, NTS and STT, respectively.

In the CAW breed (Tables 4.11a and 4.11b) on the other hand, all the growth traits studied at 6, 8 and 10 weeks of age were moderate to high except the h^2_S for EL and LBL at 6 weeks of age as well as TL and LBL at 10 weeks of age and the h^2_D for EL and LBL, respectively. Heritability values for certain traits were "Not Available" (ie unestimable) and they include LFL and LBL at week 6 and EL at week 10 in the CHC breed, TL and LBL at week 6, LFL and LBL at week 8 and EL and LFL at week 10 in the NZW breed. TL and LFL at week 6, EL, TL and LFL at week 8 and EL and STT at week 10 in the CAW breed.

Table 4.8a: Estimates of heritability (h^2_S±SE) from sire variance component for gestation length and litter traits from birth to 35 days of age

		Age (days)					
Breed	Trait	Birth	7	14	21	28	35
CHC	Gestation length	0.23±0.21	NA	0.26±0.27	NA	NA	0.18±0.27
	Litter size	0.53±0.35	0.64±0.31	0.53±0.27	0.49±0.31	0.60±0.23	0.58±0.34
	Litter weight	0.41±0.27	0.34±0.32	0.49±0.31	0.47±0.34	0.43±0.31	0.52±0.28
NZW	Gestation length	0.11±0.24	0.15±0.27	NA	NA	NA	NA
	Litter size	0.44±0.37	0.37±0.41	0.33±0.41	0.46±0.37	0.30±0.41	0.43±0.41
	Litter weight	0.37±0.33	0.29±0.21	0.28±0.28	0.41±0.24	0.34±0.21	0.39±0.33
CAW	Gestation length	0.17±0.24	NA	NA	NA	0.11±0.27	NA
	Litter size	0.32±0.40	0.42±0.36	0.38±0.44	0.31±0.40	0.36±0.36	0.40±0.44
	Litter weight	0.41±0.37	0.34±0.31	NA	0.36±0.31	0.40±0.33	0.32±0.31

CHC=Chinchilla; NZW=New Zealand White; CAW=California White; SE = Standard error; NA = Not available.

Table 4.8b: Estimates of heritability (h^2_D±SE) from dam variance component for gestation length and litter traits from birth to 35 days of age

		Age (days)					
Breed	Trait	Birth	7	14	21	28	35
CHC	Gestation length	0.27±0.25	0.33±0.30	NA	NA	0.32±0.29	0.24±0.21
	Litter size	0.59±0.44	0.68±0.42	0.53±0.27	0.54±0.43	0.66±0.37	0.62±0.42
	Litter weight	0.52±0.42	0.41±0.38	0.55±0.47	0.49±0.41	0.50±0.44	0.58±0.37
NZW	Gestation length	0.17±0.14	0.22±0.22	NA	0.34±0.30	NA	NA
	Litter size	0.48±0.41	0.43±0.38	0.38±0.35	0.49±0.40	0.36±0.33	0.41±0.38
	Litter weight	0.43±0.37	0.36±0.30	0.33±0.32	0.45±0.36	0.38±0.31	0.44±0.36
CAW	Gestation length	0.19±0.19	NA	0.32±0.30	NA	0.18±0.22	0.33±0.30
	Litter size	0.37±0.33	0.46±0.40	0.40±0.41	0.38±0.38	0.41±0.39	0.42±0.40
	Litter weight	0.40±0.38	0.37±0.38	0.38±0.32	0.39±0.33	0.44±0.39	0.40±0.35

CHC=Chinchilla; NZW=New Zealand White; CAW=California White; SE = Standard error;
NA = Not available.

Table 4.9a: Estimates of heritability (h^2±SE) from sire variance component for growth traits at various ages in the **Chinchilla** breed

	Age (weeks)					
Trait	5	6	7	8	9	10
Body weight (BW)	0.61±0.37	0.55±0.26	0.53±0.33	0.33±0.35	0.41±0.31	0.39±0.28
Ear length (EL)	0.19±0.21	0.14±0.20	0.15±0.21	0.11±0.26	NA	NA
Body length (BL)	0.44±0.32	0.66±0.27	0.36±0.27	0.58±0.32	0.39±0.31	0.55±0.43
Tail length (TL)	NA	0.24±0.23	0.18±0.21	0.18±0.21	0.24±0.23	0.18±0.21
Heart girth (HG)	0.51±0.41	0.47±0.32	0.66±0.39	0.51±0.41	0.43±0.36	0.43±0.36
Nose to shoulder (NTS)	0.35±0.32	0.35±0.33	0.27±0.34	0.31±0.31	0.40±0.38	0.30±0.31
Shoulder to tail-drop (STT)	0.55±0.36	0.45±0.52	0.45±0.52	0.37±0.19	NA	0.37±0.41
Length of front leg (LFL)	0.16±0.23	NA	NA	0.11±0.23	0.45±0.37	0.26±0.37
Length of back leg (LBL)	NA	NA	0.11±0.23	0.26±0.20	0.26±0.20	0.18±0.21

SE=Standard error; NA=Not available.

Table 4.9b: Estimates of heritability (h^2_D±SE) from dam variance component for growth traits at various ages in the **Chinchilla** breed

	Age (weeks)					
Trait	5	6	7	8	9	10
Body weight (BW)	0.66±0.48	NA	0.57±0.45	0.38±0.36	0.45±0.35	0.46±0.36
Ear length (EL)	0.26±0.28	0.29±0.25	0.21±0.20	NA	0.23±0.22	NA
Body length (BL)	0.47±0.39	0.68±0.36	0.39±0.33	0.63±0.45	NA	NA
Tail length (TL)	0.36±0.31	0.32±0.30	0.22±0.22	0.25±0.23	0.30±0.28	0.24±0.22
Heart girth (HG)	0.58±0.46	0.50±0.41	0.68±0.42	0.57±0.46	NA	0.47±0.33
Nose to shoulder (NTS)	0.44±0.37	0.44±0.37	0.35±0.33	0.44±0.38	0.46±0.40	0.39±0.33
Shoulder to tail-drop (STT)	0.59±0.42	0.48±0.42	NA	0.39±0.27	NA	0.39±0.35
Length of front leg (LFL)	NA	0.25±0.25	0.29±0.27	0.17±0.20	NA	0.30±0.30
Length of back leg (LBL)	NA	NA	NA	NA	NA	0.23±0.21

SE=Standard error; NA=Not available.

Table 4.10a: Estimates of heritability (h^2±SE) from sire component of variance for growth traits at various ages in the **New Zealand white** breed

	Age (weeks)					
Trait	5	6	7	8	9	10
Body weight (BW)	0.47±0.35	0.43±0.22	0.50±0.31	0.29±0.18	0.53±0.33	0.26±0.25
Ear length (EL)	NA	0.11±0.20	0.24±0.22	0.24±0.22	0.28±0.21	NA
Body length (BL)	0.42±0.30	0.68±0.47	0.28±0.24	0.52±0.24	0.37±0.30	0.30±0.26
Tail length (TL)	0.29±0.22	NA	0.12±0.14	0.27±0.30	0.28±0.21	0.24±0.23
Heart girth (HG)	0.48±0.44	0.38±0.33	0.39±0.39	0.40±0.27	0.33±0.27	0.62±0.42
Nose to shoulder (NTS)	0.40±0.31	0.33±0.30	0.33±0.30	0.27±0.27	0.39±0.31	0.27±0.23
Shoulder to tail-drop (STT)	0.46±0.31	0.38±0.44	NA	0.35±0.30	NA	0.65±0.48
Length of front leg (LFL)	0.11±0.10	0.26±0.26	NA	NA	NA	NA
Length of back leg (LBL)	NA	NA	0.12±0.13	0.11±0.24	NA	0.11±0.24

SE=Standard error; NA=Not available.

Table 4.10b: Estimates of heritability (h^2_D±SE) from dam component of variance for growth traits at various ages in the **New Zealand White** breed

	Age (weeks)					
Trait	5	6	7	8	9	10
Body weight (BW)	0.52±0.41	0.45±0.31	NA	0.34±0.28	0.56±0.40	NA
Ear length (EL)	0.46±0.42	0.16±0.15	0.26±0.23	0.31±0.26	0.34±0.26	0.30±0.30
Body length (BL)	NA	0.68±0.52	0.29±0.26	0.55±0.42	0.40±0.34	0.35±0.30
Tail length (TL)	NA	0.32±0.30	NA	0.33±0.31	0.32±0.30	NA
Heart girth (HG)	0.53±0.45	0.41±0.39	0.42±0.40	0.42±0.28	0.37±0.30	0.58±0.40
Nose to shoulder (NTS)	0.45±0.37	0.37±0.31	0.38±0.33	0.29±0.29	NA	0.27±0.26
Shoulder to tail-drop (STT)	0.49±0.36	0.42±0.38	NA	NA	0.53±0.35	0.66±0.50
Length of front leg (LFL)	NA	NA	NA	0.42±0.30	NA	0.37±0.31
Length of back leg (LBL)	NA	0.22±0.20	NA	NA	0.20±0.18	NA

SE=Standard error; NA=Not available.

Table 4.11a: Estimates of heritability (h^2±SE) from sire component of variance for growth traits at various ages in the **Californian white** breed

	Age (weeks)					
Trait	5	6	7	8	9	10
Body weight (BW)	0.38±0.27	0.45±0.32	NA	0.40±0.36	0.28±0.32	0.37±0.37
Ear length (EL)	0.14±0.06	0.22±0.20	0.31±0.28	NA	NA	NA
Body length (BL)	0.34±0.30	0.40±0.37	0.31±0.25	0.37±0.41	0.35±0.24	0.30±0.36
Tail length (TL)	0.38±0.25	NA	0.22±0.18	NA	0.24±0.22	0.24±0.36
Heart girth (HG)	0.49±0.42	0.42±0.35	0.34±0.30	0.40±0.37	0.31±0.22	0.40±0.37
Nose to shoulder (NTS)	0.42±0.33	0.35±0.31	0.34±0.23	NA	0.37±0.26	0.30±0.30
Shoulder to tail-drop (STT)	NA	0.33±0.30	NA	0.33±0.33	NA	NA
Length of front leg (LFL)	NA	NA	0.29±0.22	0.28±0.23	NA	0.28±0.26
Length of back leg (LBL)	0.16±0.11	0.25±0.25	NA	NA	NA	0.26±0.26

SE=Standard error; NA=Not available.

Table 4.11b: Estimates of heritability (h^2_D±SE) from dam component of variance for growth traits at various ages in the **Californian White** breed

	Age (weeks)					
Trait	5	6	7	8	9	10
Body weight (BW)	0.43±0.38	0.50±0.41	NA	0.46±0.39	0.35±0.33	NA
Ear length (EL)	NA	0.24±0.20	0.37±0.30	NA	0.30±0.30	0.42±0.30
Body length (BL)	NA	0.46±0.38	0.37±0.28	0.39±0.32	0.38±0.30	NA
Tail length (TL)	0.40±0.32	0.36±0.30	0.32±0.27	NA	0.30±0.28	0.34±0.31
Heart girth (HG)	0.53±0.38	0.46±0.37	0.35±0.31	NA	0.36±0.30	0.44±0.39
Nose to shoulder (NTS)	NA	0.39±0.32	0.36±0.31	0.45±0.36	NA	0.33±0.31
Shoulder to tail-drop (STT)	0.47±0.38	0.35±0.31	NA	0.39±0.35	0.35±0.31	NA
Length of front leg (LFL)	0.45±0.35	NA	0.34±0.23	0.30±0.27	NA	NA
Length of back leg (LBL)	NA	NA	0.22±0.20	NA	0.27±0.25	0.28±0.27

SE=Standard error; NA=Not available.

Table 4.12: Estimates of repeatability (R±SE) for gestation length and litter traits from birth to 35 days of age for different breeds of rabbits

		Age (days)					
Breed	Trait	Birth	7	14	21	28	35
CHC	Gestation length	0.67±0.30	NA	0.59±0.32	NA	NA	0.63±0.30
	Litter size	0.72±0.32	0.64±0.31	0.75±0.33	0.69±0.31	0.54±0.30	0.68±0.34
	Litter weight	0.86±0.37	0.54±0.32	0.80±0.34	0.67±0.30	0.56±0.30	0.52±0.28
NZW	Gestation length	0.51±0.29	NA	0.47±0.28	NA	NA	NA
	Litter size	0.50±0.28	0.58±0.31	0.66±0.30	0.48±0.30	0.46±0.30	0.58±0.30
	Litter weight	0.74±0.32	0.41±0.27	0.54±0.29	0.59±0.32	0.56±0.30	NA
CAW	Gestation length	0.59±0.32	NA	NA	0.43±0.27	NA	NA
	Litter size	0.70±0.33	0.52±0.31	0.47±0.30	0.37±0.40	NA	0.54±0.30
	Litter weight	0.69±0.30	0.50±0.31	0.38±0.20	NA	0.54±0.30	0.47±0.31

CHC=Chinchilla; NZW=New Zealand White; CAW=California White; SE=Standard error; NA=Not available.

Table 4.13: Estimates of repeatability (R±SE) for growth traits at various ages in the **Chinchilla** breed

	Age (weeks)					
Trait	5	6	7	8	9	10
Body weight (BW)	0.86±0.19	0.73±0.14	0.70±0.26	NA	0.66±0.24	0.74±0.13
Ear length (EL)	0.49±0.24	0.54±0.22	0.63±0.17	0.84±0.14	NA	0.86±0.27
Body length (BL)	0.55±0.31	0.80±0.43	0.73±0.36	0.65±0.21	0.68±0.30	0.72±0.18
Tail length (TL)	0.76±0.33	NA	NA	0.37±0.08	NA	0.38±0.24
Heart girth (HG)	0.25±0.11	0.56±0.31	0.56±0.20	0.70±0.04	NA	0.49±0.21
Nose to shoulder (NTS)	0.74±0.23	0.55±0.27	0.51±0.38	0.58±0.24	0.36±0.21	0.52±0.17
Shoulder to tail-drop (STT)	0.72±0.19	0.69±0.24	0.60±0.21	0.68±0.33	0.62±0.24	0.63±0.32
Length of front leg (LFL)	0.36±0.21	NA	NA	0.61±0.34	NA	0.49±0.20
Length of back leg (LBL)	0.28±0.17	0.42±0.19	NA	0.34±0.22	0.47±0.23	0.39±0.14

SE=Standard error; NA=Not available.

Table 4.14: Estimates of repeatability (R±SE) for growth traits at various ages in the **New Zealand White** breed

	Age (weeks)					
Trait	5	6	7	8	9	10
Body weight (BW)	0.77±0.08	NA	0.72±0.28	0.63±0.11	0.63±0.13	0.76±0.21
Ear length (EL)	0.52±0.11	0.49±0.18	0.54±0.20	0.80±0.14	0.62±0.17	0.55±0.11
Body length (BL)	NA	0.65±0.21	0.69±0.21	NA	NA	0.47±0.06
Tail length (TL)	0.63±0.07	0.36±0.22	0.38±0.16	NA	0.51±0.17	NA
Heart girth (HG)	0.18±0.12	0.59±0.21	0.49±0.18	0.47±0.23	0.58±0.13	0.53±0.18
Nose to shoulder (NTS)	0.57±0.21	NA	0.36±0.20	0.41±0.17	0.40±0.21	NA
Shoulder to tail-drop (STT)	0.66±0.14	0.51±0.21	NA	0.63±0.27	NA	NA
Length of front leg (LFL)	NA	0.39±0.14	NA	0.73±0.23	NA	NA
Length of back leg (LBL)	NA	0.40±0.10	0.25±0.12	NA	NA	0.36±0.30

SE=Standard error; NA=Not available.

Table 4.15: Estimates of repeatability (R±SE) for growth traits at various ages in the **California White** breed

	Age (weeks)					
Trait	5	6	7	8	9	10
Body weight (BW)	0.80±0.14	NA	0.67±0.16	0.69±0.17	0.69±0.11	NA
Ear length (EL)	0.50±0.17	0.44±0.10	NA	0.73±0.12	0.53±0.07	0.60±0.15
Body length (BL)	0.41±0.03	NA	NA	0.52±0.15	0.38±0.12	0.56±0.14
Tail length (TL)	NA	NA	0.47±0.08	0.28±0.06	0.48±0.26	0.49±0.11
Heart girth (HG)	0.35±0.18	0.33±0.18	NA	NA	0.38±0.21	NA
Nose to shoulder (NTS)	NA	0.49±0.17	0.44±0.27	NA	NA	0.49±0.20
Shoulder to tail-drop (STT)	0.59±0.11	NA	0.53±0.15	NA	0.56±0.19	0.50±0.20
Length of front leg (LFL)	0.42±0.23	0.47±0.19	0.39±0.13	0.58±0.21	0.45±0.16	0.54±0.19
Length of back leg (LBL)	0.40±0.12	0.35±0.17	0.30±0.15	0.43±0.13	0.42±0.21	0.28±0.21

SE=Standard error; NA=Not available.

4.6.2 Repeatability estimates for litter and growth traits:

The repeatability estimates for litter traits from birth to weaning obtained in this study are presented in Table 4.12. The values obtained for the CHC breed for gestation length, litter size and litter weight from birth to weaning ranged from 0.59±0.32 to 0.67±0.30, 0.54±0.30 to 0.75±0.33 and 0.52±0.28 to 0.86±0.37 respectively. The corresponding values obtained from the NZW breed ranged from 0.47±0.28 to 0.51±0.29, 0.46±0.30 to 0.66±0.30 and 0.41±0.27 to 0.74±0.32, for GL, LS and LW, respectively. The estimates of repeatability for the CAW breed ranged from 0.43±0.27 to 0.59±0.32, 0.37±0.40 to 0.70±0.33 and 0.38±0.20 to 0.69±0.30 for GL, LS and LW, respectively. Generally, the estimates of repeatability obtained for the CHC breed were high in all the traits studied while the values for the NZW and CAW were moderate to high.

Table 4.13 shows the estimates of repeatability for body weight and body linear measurements at various ages in the CHC breed. High estimates of repeatability for all traits were obtained in the CHC breed except for HG, LFL and LBL at week 5, TL, and LBL at week 8, NTS at week 9, and TL and LBL at week 10 which were moderate. High estimates were also obtained in the NZW breed (Table 4.14) except for TL and LFL at 6 weeks of age, TL and NTS at 7 weeks of age, and LBL at 10 weeks of age, which were moderate. The repeatability estimate obtained in this breed for HG at 5 weeks of age and LBL at 7 weeks of age were low. In the CAW breed of rabbit (Table 4.15) all the estimates obtained for the growth traits at all ages were moderate to highly repeatable, except LBL at 10 weeks of age.

4.7 Estimates of genetic correlation

Tables 4.16, 4.17 and 4.18 show the genetic correlations between growth traits in the Chinchilla (CHC) breed at 5 and 6, 7 and 8 and 9 and 10 weeks of ages, respectively. The genetic correlations were positive and moderate to high, ranging between 0.38±0.15 and

0.92±0.22 for all traits at 5 weeks of age. Similarly, positively high genetic correlation coefficients were obtained at 6 weeks of age between the various growth traits except for TL and BW (0.43±0.03), HG and TL (0.48±0.07), LFL and TL (0.43±0.03) and LBL and TL (0.44±0.03), which were moderate. The results of the genetic correlation analyses for week 7 indicated low coefficients between EL and LFL (0.19±0.02), EL and LBL (0.14±0.02), TL and LFL (0.22±0.03) and STT and LBL (0.22±0.04). Also, low values were obtained at week 8 between TL and EL (0.21±0.05), HG and TL (0.29±0.04), NTS and EL (0.27±0.04) and LFL and TL (0.26±0.05). The highest coefficient of genetic correlation obtained in the CHC breed at week 9 was 0.89±0.13 between BL and HG and the lowest coefficient was 0.25±0.02 between EL and LFL. At week 10, the highest coefficient was between STT and NTS (0.83±0.14) while the lowest coefficient was between LFL and EL (0.20±0.03).

In the New Zealand White (NZW) breed of rabbits, the results of genetic correlation analysis are shown in Tables 4.19, 4.20 and 4.21 for weeks 5 and 6, 7 and 8 and 9 and 10, respectively. Positively moderate to high coefficients of genetic correlation among all the growth traits were obtained at 5 and 6 weeks of age. Similar positive and moderate to high coefficients were observed at weeks 7 and 8 for all traits studied except between LFL and EL (0.25±0.06) which was low. At 9 weeks of age, the highest coefficient of genetic correlation was between BW and HG (0.84±0.22) and the lowest between EL and TL (0.39±0.11). The highest coefficient of genetic correlation obtained at 10 weeks of age in the NZW breed was between HG and BW (0.90±0.24) and the lowest between TL and EL (0.36±0.12).

The coefficient of genetic correlations at 5 and 6, 7 and 8 and 9 and 10 weeks of age in the California White (CAW) breed are shown in Tables 4.22, 4.23 and 4.24, respectively. At week 5, the highest genetic correlation coefficient of 0.86±0.24 was between BL and STT and the lowest of 0.30±0.05 between BW and LBL. The highest coefficient obtained at week

6 was between HG and BL (0.82±0.24) and the lowest coefficient (0.36±0.06) was between LBL and EL. The coefficients of genetic correlation obtained for all traits were positive, moderate to high ranging from 0.35±0.08 to 0.80±0.20 at 7 weeks of age and from 0.30±0.08 to 0.80±0.20 at 8 weeks of age. The coefficients observed in this breed for all growth traits at 9 weeks of age were also positive, moderate to high except between BW and TL (0.25±0.06), EL and LFL (0.22±0.05), TL and STT (0.26±0.06), TL and LFL (0.28±0.06) and STT and LBL (0.28±0.09). Similarly at 10 weeks of age, low but positive coefficients were obtained between TL and EL (0.22±0.05), LFL and EL (0.22±0.05) and LBL and EL (0.24±0.06).

4.8 Estimates of phenotypic correlation

Tables 4.25, 4.26 and 4.27 show the phenotypic correlations for growth traits in the Chinchilla (CHC) breed of rabbits at 5 and 6, 7 and 8 and 9 and 10 weeks of ages, respectively. The results indicated positive, moderate to high and highly significant ($P<0.01$) coefficients at all ages. The highest coefficient of phenotypic correlation obtained in this breed was 0.88 for HG and BL at 6 weeks of age while the lowest value was 0.42 for TL and NTS at 9 weeks of age.

In the New Zealand White (NZW) breed of rabbits, results of the coefficients of phenotypic correlations are presented in Tables 4.28, 4.29 and 4.30 for the growth traits studied at 5 and 6, 7 and 8 and 9 and 10 weeks of age, respectively.

Table 4.16: Genetic correlation (r_g±SE) for various traits in the **Chinchilla** breed at 5 (below diagonal) and 6 weeks (above diagonal) of age

Trait	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
BW		0.72±0.15	0.70±0.15	0.43±0.03	0.79±0.12	0.82±0.13	0.68±0.17	0.61±0.12	0.65±0.13
EL	0.69±0.14		0.65±0.08	0.67±0.15	0.55±0.13	0.52±0.07	0.74±0.19	0.53±0.06	0.50±0.06
BL	0.73±0.11	0.76±0.13		0.71±0.18	0.84±0.23	0.81±0.23	0.88±0.24	0.67±0.14	0.63±0.14
TL	0.58±0.06	0.53±0.01	0.63±0.08		0.48±0.07	0.60±0.10	0.50±0.04	0.43±0.03	0.44±0.03
HG	0.89±0.13	0.79±0.13	0.71±0.15	0.65±0.23		0.79±0.22	0.71±0.17	0.52±0.13	0.61±0.18
NTS	0.81±0.16	0.65±0.10	0.77±0.13	0.76±0.23	0.65±0.20		0.75±0.15	0.50±0.05	0.53±0.05
STT	0.77±0.21	0.71±0.03	0.92±0.22	0.53±0.13	0.52±0.07	0.51±0.03		0.66±0.17	0.58±0.14
LFL	0.55±0.10	0.67±0.13	0.74±0.03	0.59±0.13	0.49±0.07	0.50±0.03	0.38±0.15		0.56±0.14
LBL	0.46±0.12	0.53±0.11	0.64±0.13	0.40±0.06	0.54±0.05	0.47±0.02	0.52±0.16	0.44±0.08	

BW=Body weight; EL=Ear length; BL=Body length; TL=Tail length; HG=Heart girth; NTS=Nose to shoulder; STT=Shoulder to tail-drop; LFL=Length of front leg; LBL=Length of back leg. SE=Standard error.

Table 4.17: Genetic correlation (r_g±SE) for various traits in the **Chinchilla** breed at 7 (below diagonal) and 8 weeks (above diagonal) of age

Trait	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
BW		0.63±0.06	0.81±0.12	0.37±0.11	0.85±0.15	0.68±0.05	0.66±0.12	0.32±0.05	0.40±0.11
EL	0.55±0.07		0.48±0.04	0.21±0.03	0.43±0.11	0.27±0.04	0.57±0.11	0.18±0.02	0.27±0.05
BL	0.87±0.12	0.64±0.06		0.56±0.06	0.72±0.12	0.66±0.16	0.81±0.14	0.69±0.10	0.69±0.12
TL	0.41±0.03	0.31±0.01	0.59±0.04		0.29±0.04	0.53±0.08	0.63±0.12	0.55±0.09	0.26±0.05
HG	0.84±0.07	0.62±0.03	0.83±0.12	0.40±0.01		0.77±0.16	0.74±0.13	0.38±0.06	0.41±0.06
NTS	0.86±0.11	0.33±0.01	0.62±0.11	0.51±0.02	0.73±0.13		0.79±0.14	0.46±0.09	0.48±0.09
STT	0.82±0.11	0.50±0.03	0.77±0.12	0.39±0.01	0.69±0.12	0.74±0.13		0.54±0.05	0.51±0.11
LFL	0.45±0.01	0.19±0.02	0.46±0.02	0.22±0.02	0.56±0.13	0.40±0.06	0.49±0.12		0.47±0.10
LBL	0.41±0.01	0.14±0.02	0.53±0.02	0.34±0.03	0.38±0.07	0.54±0.04	0.22±0.03	0.52±0.10	

BW=Body weight; EL=Ear length; BL=Body length; TL=Tail length; HG=Heart girth; NTS=Nose to shoulder; STT=Shoulder to tail-drop; LFL=Length of front leg; LBL=Length of back leg. SE=Standard error.

Table 4.18: Genetic correlation (r_g±SE) for various traits in the **Chinchilla** breed at 9 (below diagonal) and 10 weeks (above diagonal) of age

Trait	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
BW		0.50±0.04	0.77±0.06	0.40±0.05	0.82±0.12	0.73±0.12	0.81±0.13	0.60±0.11	0.53±0.12
EL	0.26±0.04		0.62±0.05	0.25±0.02	0.51±0.10	0.40±0.05	0.54±0.10	0.20±0.02	0.30±0.05
BL	0.64±0.03	0.64±0.04		0.60±0.06	0.80±0.14	0.76±0.13	0.79±0.11	0.56±0.05	0.63±0.06
TL	0.30±0.02	0.42±0.02	0.38±0.04		0.47±0.06	0.48±0.06	0.50±0.10	0.55±0.05	0.34±0.04
HG	0.68±0.11	0.56±0.04	0.89±0.13	0.43±0.02		0.73±0.11	0.76±0.13	0.56±0.05	0.39±0.06
NTS	0.61±0.09	0.36±0.02	0.73±0.12	0.56±0.05	0.64±0.07		0.83±0.14	0.60±0.10	0.45±0.06
STT	0.70±0.12	0.45±0.03	0.74±0.12	0.30±0.02	0.73±0.10	0.64±0.06		0.63±0.11	0.48±0.06
LFL	0.33±0.03	0.25±0.02	0.55±0.05	0.42±0.04	0.40±0.03	0.32±0.04	0.36±0.02		0.40±0.05
LBL	0.47±0.03	0.30±0.02	0.47±0.03	0.37±0.03	0.40±0.03	0.41±0.04	0.33±0.02	0.42±0.04	

BW=Body weight; EL=Ear length; BL=Body length; TL=Tail length; HG=Heart girth; NTS=Nose to shoulder; STT=Shoulder to tail-drop; LFL=Length of front leg; LBL=Length of back leg. SE=Standard error.

Table 4.19: Genetic correlation (r_g±SE) for various traits in the **New Zealand White** breed at 5 (below diagonal) and 6 weeks (above diagonal) of age

Trait	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
BW		0.54±0.11	0.85±0.21	0.47±0.06	0.83±0.23	0.68±0.08	0.71±0.15	0.46±0.06	0.38±0.06
EL	NA		0.32±0.04	0.52±0.06	0.62±0.10	0.44±0.04	0.56±0.07	0.57±0.06	0.43±0.06
BL	0.62±0.18	0.58±0.11		0.66±0.07	0.88±0.23	0.73±0.16	0.69±0.12	0.67±0.13	0.65±0.09
TL	0.52±0.16	0.37±0.08	0.45±0.10		0.54±0.06	0.52±0.07	0.45±0.06	0.44±0.05	NA
HG	0.73±0.13	0.66±0.07	0.66±0.12	0.48±0.04		0.64±0.12	0.67±0.11	0.55±0.08	0.38±0.03
NTS	0.69±0.16	0.41±0.05	0.63±0.11	0.39±0.03	0.62±0.05		0.72±0.11	0.55±0.08	0.47±0.05
STT	0.72±0.12	0.34±0.04	0.75±0.14	0.40±0.03	0.55±0.05	0.67±0.11		0.51±0.07	0.44±0.05
LFL	0.42±0.11	0.40±0.04	0.42±0.06	NA	0.43±0.04	0.62±0.11	0.42±0.10		0.60±0.08
LBL	0.42±0.11	0.38±0.05	0.50±0.06	0.32±0.02	0.43±0.04	0.51±0.10	0.40±0.07	0.36±0.06	

BW=Body weight; EL=Ear length; BL=Body length; TL=Tail length; HG=Heart girth; NTS=Nose to shoulder; STT=Shoulder to tail-drop; LFL=Length of front leg; LBL=Length of back leg. SE=Standard error.
NA=Not available.

Table 4.20: Genetic correlation (r_g±SE) for various traits in the **New Zealand White** breed at 7 (below diagonal) and 8 weeks (above diagonal) of age

Trait	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
BW		0.50±0.10	0.88±0.21	0.48±0.14	0.92±0.24	0.82±0.21	0.84±0.23	0.68±0.12	0.52±0.12
EL	0.38±0.11		0.63±0.13	0.35±0.10	0.63±0.18	0.48±0.10	0.49±0.10	0.25±0.06	0.47±0.10
BL	0.92±0.26	0.47±0.10		0.74±0.14	0.86±0.21	0.70±0.14	0.73±0.14	0.64±0.11	0.63±0.12
TL	0.57±0.07	0.40±0.07	0.67±0.12		0.64±0.18	0.66±0.12	0.56±0.11	0.61±0.11	0.40±0.10
HG	0.91±0.26	0.59±0.12	0.90±0.25	0.66±0.11		0.77±0.15	0.80±0.21	0.45±0.10	0.57±0.11
NTS	0.75±0.20	0.46±0.08	0.76±0.22	0.60±0.11	0.77±0.21		0.80±0.21	0.52±0.10	0.57±0.11
STT	0.77±0.26	0.57±0.11	0.79±0.22	0.45±0.09	0.77±0.21	0.86±0.24		0.52±0.10	0.63±0.12
LFL	0.61±0.20	0.40±0.11	0.46±0.06	0.33±0.07	0.66±0.12	0.52±0.11	0.58±0.14		0.60±0.11
LBL	0.58±0.20	0.33±0.10	0.48±0.06	0.38±0.07	0.54±0.10	0.53±0.11	0.44±0.10	0.66±0.14	

BW=Body weight; EL=Ear length; BL=Body length; TL=Tail length; HG=Heart girth; NTS=Nose to shoulder; STT=Shoulder to tail-drop; LFL=Length of front leg; LBL=Length of back leg. SE=Standard error.

Table 4.21: Genetic correlation (r_g±SE) for various traits in the **New Zealand White** breed at 9 (below diagonal) and 10 weeks (above diagonal) of age

Trait	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
BW		0.66±0.16	0.86±0.21	NA	0.90±0.24	0.77±0.21	0.72±0.20	0.55±0.15	0.69±0.17
EL	0.62±0.17		0.57±0.15	0.36±0.12	0.63±0.15	0.51±0.15	0.49±0.15	NA	NA
BL	0.79±0.20	0.58±0.15		0.55±0.15	0.76±0.20	0.84±0.21	0.83±0.21	0.62±0.15	0.68±0.17
TL	0.54±0.15	0.39±0.11	0.66±0.15		0.52±0.15	0.53±0.15	0.62±0.15	NA	0.48±0.15
HG	0.84±0.22	0.60±0.15	0.82±0.22	0.57±0.15		0.75±0.21	0.80±0.20	0.48±0.15	0.60±0.15
NTS	0.76±0.20	0.55±0.15	0.80±0.22	0.61±0.15	0.74±0.20		0.80±0.20	0.54±0.15	0.40±0.12
STT	0.79±0.20	0.55±0.15	0.80±0.22	0.43±0.13	0.75±0.20	0.76±0.20		0.55±0.15	0.65±0.15
LFL	0.52±0.15	NA	0.48±0.15	0.40±0.12	0.57±0.15	0.45±0.14	0.53±0.13		0.67±0.15
LBL	0.55±0.15	NA	0.52±0.15	NA	0.52±0.15	0.46±0.14	0.47±0.14	0.54±0.13	

BW=Body weight; EL=Ear length; BL=Body length; TL=Tail length; HG=Heart girth; NTS=Nose to shoulder; STT=Shoulder to tail-drop; LFL=Length of front leg; LBL=Length of back leg. SE=Standard error.
NA=Not available

Table 4.22: Genetic correlation (r_g±SE) for various traits in the **California White** breed at 5 (below diagonal) and 6 weeks (above diagonal) of age

Trait	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
BW		0.66±0.13	0.73±0.18	0.64±0.12	0.70±0.15	0.75±0.15	0.64±0.12	0.38±0.06	0.50±0.08
EL	0.43±0.07		0.59±0.08	0.67±0.13	0.47±0.08	0.50±0.08	0.45±0.08	0.40±0.06	0.36±0.06
BL	0.81±0.24	0.63±0.13		0.68±0.13	0.80±0.24	0.77±0.15	0.75±0.15	0.60±0.08	0.70±0.15
TL	0.40±0.07	0.33±0.05	0.51±0.08		0.40±0.06	NA	0.68±0.13	NA	NA
HG	0.76±0.17	0.52±0.08	0.83±0.24	0.54±0.08		0.80±0.24	0.79±0.15	0.62±0.08	0.44±0.06
NTS	0.72±0.17	0.50±0.08	0.80±0.24	0.47±0.08	0.78±0.16		0.75±0.15	0.69±0.10	0.60±0.08
STT	0.69±0.15	0.53±0.08	0.86±0.24	0.66±0.15	0.81±0.24	0.73±0.15		0.63±0.08	0.62±0.08
LFL	0.51±0.08	0.50±0.08	0.67±0.15	NA	0.62±0.14	0.70±0.15	0.69±0.15		0.42±0.06
LBL	0.30±0.05	0.53±0.08	0.60±0.12	NA	0.63±0.14	0.64±0.14	0.71±0.15	0.59±0.14	

BW=Body weight; EL=Ear length; BL=Body length; TL=Tail length; HG=Heart girth; NTS=Nose to shoulder; STT=Shoulder to tail-drop; LFL=Length of front leg; LBL=Length of back leg. SE=Standard error.
NA=Not available

Table 4.23: Genetic correlation (r_g±SE) for various traits in the **California White** breed at 7 (below diagonal) and 8 weeks (above diagonal) of age

Trait	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
BW		NA	0.74±0.18	0.43±0.10	0.80±0.20	0.70±0.18	0.64±0.15	0.30±0.08	0.32±0.08
EL	0.44±0.10		0.60±0.15	NA	0.40±0.08	0.33±0.08	0.37±0.07	NA	NA
BL	0.71±0.18	0.53±0.13		0.60±0.15	0.74±0.18	0.54±0.13	0.66±0.15	0.53±0.12	0.57±0.12
TL	0.38±0.08	NA	0.50±0.12		0.33±0.08	0.43±0.08	0.45±0.08	NA	NA
HG	0.80±0.20	0.45±0.10	0.77±0.18	0.50±0.12		0.68±0.16	0.68±0.15	0.30±0.08	0.34±0.08
NTS	0.79±0.20	0.35±0.08	0.70±0.16	0.46±0.10	0.70±0.18		0.70±0.18	0.40±0.10	0.30±0.08
STT	0.73±0.18	0.46±0.10	0.68±0.16	0.60±0.15	0.70±0.18	0.66±0.15		0.45±0.10	0.40±0.10
LFL	0.59±0.15	NA	0.55±0.12	NA	0.60±0.15	0.37±0.08	0.40±0.10		0.40±0.10
LBL	0.50±0.13	NA	0.44±0.10	NA	NA	0.41±0.10	0.35±0.08	0.48±0.10	

BW=Body weight; EL=Ear length; BL=Body length; TL=Tail length; HG=Heart girth; NTS=Nose to shoulder; STT=Shoulder to tail-drop; LFL=Length of front leg; LBL=Length of back leg. SE=Standard error.
NA=Not available

Table 4.24: Genetic correlation (r_g±SE) for various traits in the **California White** breed at 9 (below diagonal) and 10 weeks (above diagonal) of age

Trait	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
BW		0.41±0.13	0.68±0.16	0.37±0.11	0.76±0.17	0.68±0.16	0.68±0.16	0.51±0.14	0.48±0.12
EL	0.30±0.09		0.45±0.12	0.22±0.05	NA	NA	0.41±0.13	0.22±0.05	0.24±0.06
BL	0.57±0.14	0.51±0.14		0.51±0.14	0.72±0.15	0.70±0.16	0.75±0.15	0.55±0.14	0.60±0.15
TL	0.25±0.06	0.33±0.10	NA		0.40±0.11	0.39±0.12	0.44±0.12	NA	0.34±0.10
HG	0.59±0.14	0.54±0.14	0.80±0.19	NA		0.70±0.16	0.68±0.16	0.33±0.10	0.42±0.13
NTS	0.53±0.14	0.33±0.10	0.67±0.16	0.43±0.12	0.60±0.14		0.76±0.15	0.46±0.12	0.42±0.13
STT	0.62±0.15	0.45±0.12	0.70±0.16	0.26±0.06	0.67±0.16	0.57±0.14		0.37±0.11	NA
LFL	0.30±0.09	0.22±0.05	0.42±0.12	0.28±0.06	0.44±0.12	0.36±0.10	0.30±0.09		NA
LBL	0.44±0.12	NA	NA	NA	NA	0.36±0.10	0.28±0.09	0.34±0.10	

BW=Body weight; EL=Ear length; BL=Body length; TL=Tail length; HG=Heart girth; NTS=Nose to shoulder; STT=Shoulder to tail-drop; LFL=Length of front leg; LBL=Length of back leg. SE=Standard error.
NA=Not available

Table 4.25: Phenotypic correlations (r_p) for various traits in the **Chinchilla** breed at 5 (below diagonal) and 6 weeks (above diagonal)

Trait	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
Body weight (BW)		0.62	0.79	0.60	0.85	0.73	0.73	0.56	NA
Ear length (EL)	0.73		0.58	0.58	0.64	0.54	0.51	0.58	0.50
Body length (BL)	0.87	0.49		0.55	0.88	0.69	0.68	0.64	0.55
Tail length (TL)	0.54	0.54	0.57		0.53	0.52	0.71	0.56	0.56
Heart girth HG)	0.76	0.43	0.82	NA		0.77	0.85	0.57	0.79
Nose to shoulder (NTS)	0.66	0.63	0.54	0.68	0.71		0.68	0.63	NA
Shoulder to tail-drop (STT)	0.71	0.51	0.72	0.66	0.80	0.74		NA	0.54
Length of front leg (LFL)	0.52	0.56	NA	0.57	0.54	NA	0.74		0.77
Length of back leg (LBL)	NA	0.50	NA	0.62	0.50	0.58	0.50	0.62	

NA=Not available

Table 4.26: Phenotypic correlations (r_p) for various traits in the **Chinchilla** breed at 7 (below diagonal) and 8 weeks (above diagonal)

Trait	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
Body weight (BW)		0.57	0.84	0.62	0.73	0.71	0.82	0.56	0.52
Ear length (EL)	0.66		0.55	0.57	0.51	0.56	0.51	NA	0.51
Body length (BL)	0.80	NA		0.64	0.80	0.74	0.74	0.54	NA
Tail length (TL)	0.58	0.60	NA		0.57	0.55	0.52	0.52	NA
Heart girth HG)	0.83	0.50	0.75	0.55		0.82	0.73	0.50	0.56
Nose to shoulder (NTS)	0.70	0.66	0.75	0.68	0.77		0.77	0.52	NA
Shoulder to tail-drop (STT)	0.73	NA	0.80	0.50	0.69	0.65		0.60	0.53
Length of front leg (LFL)	0.54	0.60	NA	0.58	0.57	0.50	0.57		0.55
Length of back leg (LBL)	0.59	NA	0.53	0.53	0.58	0.54	0.51	0.60	

NA=Not available

Table 4.27: Phenotypic correlations (r_p) for various traits in the **Chinchilla** breed at 9 (below diagonal) and 10 weeks (above diagonal)

Trait	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
Body weight (BW)		0.55	0.72	0.52	0.80	0.63	0.74	0.77	0.50
Ear length (EL)	0.53		0.64	NA	0.54	0.54	0.57	NA	NA
Body length (BL)	0.71	0.64		0.57	0.86	0.79	0.81	0.53	0.77
Tail length (TL)	NA	0.66	0.52		0.50	0.51	0.53	NA	0.58
Heart girth HG)	0.71	0.58	0.83	0.56		0.66	0.65	NA	0.59
Nose to shoulder (NTS)	0.79	0.64	0.81	0.42	0.80		0.70	0.60	0.56
Shoulder to tail-drop (STT)	0.65	0.60	0.73	0.51	0.69	0.81		NA	NA
Length of front leg (LFL)	NA	0.52	0.76	NA	NA	0.50	0.54		0.59
Length of back leg (LBL)	0.58	0.66	NA	0.69	NA	0.57	NA	NA	

NA=Not available

Table 4.28: Phenotypic correlations (r_p) for various traits in the **New Zealand White** breed at 5 (below diagonal) and 6 weeks (above diagonal)

Trait	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
Body weight (BW)		NA	0.78	0.59	0.90	0.76	0.88	NA	0.64
Ear length (EL)	0.63		0.67	0.54	0.62	0.52	0.63	0.54	NA
Body length (BL)	0.81	0.71		0.67	0.93	0.84	0.91	0.75	0.70
Tail length (TL)	0.66	0.63	0.57		0.52	NA	0.73	0.63	0.69
Heart girth HG)	0.73	0.59	0.82	0.60		0.82	0.86	0.71	0.63
Nose to shoulder (NTS)	0.58	0.67	0.79	0.57	0.73		0.84	0.75	NA
Shoulder to tail-drop (STT)	0.62	0.52	0.77	0.59	0.63	0.77		0.66	NA
Length of front leg (LFL)	0.54	0.56	NA	0.55	0.59	0.60	0.59		NA
Length of back leg (LBL)	0.60	NA	0.63	NA	0.57	0.53	0.61	0.56	

NA=Not available

Table 4.29: Phenotypic correlations (r_p) for various traits in the **New Zealand White** breed at 7 (below diagonal) and 8 weeks (above diagonal)

Trait	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
Body weight (BW)		0.44	0.76	0.40	0.70	0.66	0.76	0.58	0.45
Ear length (EL)	0.57		0.51	0.40	NA	0.50	0.43	0.55	NA
Body length (BL)	0.74	0.68		0.55	0.73	0.76	0.70	0.41	0.51
Tail length (TL)	NA	0.59	0.63		0.44	0.52	0.46	0.47	0.42
Heart girth HG)	0.68	NA	0.85	0.50		0.73	0.73	NA	NA
Nose to shoulder (NTS)	0.74	NA	0.79	0.59	0.82		0.72	0.44	0.50
Shoulder to tail-drop (STT)	0.79	0.60	0.75	0.54	0.74	NA		0.44	NA
Length of front leg (LFL)	NA	0.47	NA	0.60	0.60	NA	0.53		NA
Length of back leg (LBL)	0.46	0.52	NA	NA	0.51	0.42	NA	NA	

NA=Not available

Table 4.30: Phenotypic correlations (r_p) for various traits in the **New Zealand White** breed at 9 (below diagonal) and 10 weeks (above diagonal)

Trait	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
Body weight (BW)		0.43	0.69	0.60	0.84	0.70	0.66	0.53	0.46
Ear length (EL)	NA		0.6	0.42	0.50	0.43	0.40	0.41	0.39
Body length (BL)	0.73	NA		0.56	0.80	0.72	0.74	0.43	0.42
Tail length (TL)	NA	0.40	0.47		0.63	NA	0.43	0.54	NA
Heart girth HG)	0.68	0.43	0.79	0.44		0.70	NA	0.60	NA
Nose to shoulder (NTS)	0.72	0.40	0.69	0.41	0.73		0.75	NA	0.44
Shoulder to tail-drop (STT)	0.56	0.47	0.71	0.46	0.65	NA		0.56	0.45
Length of front leg (LFL)	0.57	NA	NA	NA	0.40	0.45	0.51		0.47
Length of back leg (LBL)	NA	0.40	NA	0.39	NA	NA	0.43	0.55	

NA=Not available

Table 4.31: Phenotypic correlations (r_p) for various traits in the **California White** breed at 5 (below diagonal) and 6 weeks (above diagonal)

Trait	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
Body weight (BW)		0.52	0.67	0.63	0.71	0.71	0.65	0.55	0.52
Ear length (EL)	NA		0.54	NA	NA	0.54	NA	NA	0.43
Body length (BL)	0.63	0.53		NA	0.73	0.58	0.60	0.60	0.41
Tail length (TL)	0.51	NA	0.51		0.60	NA	0.77	NA	0.48
Heart girth HG)	0.70	0.47	0.74	0.54		NA	0.73	0.55	0.47
Nose to shoulder (NTS)	0.60	0.63	0.42	0.43	0.65		0.62	0.55	0.60
Shoulder to tail-drop (STT)	0.68	0.55	0.67	0.58	0.71	0.62		0.38	0.57
Length of front leg (LFL)	NA	0.35	NA	0.37	0.50	0.45	0.40		0.46
Length of back leg (LBL)	NA	0.37	0.41	NA	NA	NA	NA	NA	

NA=Not available

Table 4.32: Phenotypic correlations (r_p) for various traits in the **California White** breed at 7 (below diagonal) and 8 weeks (above diagonal)

Trait	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
Body weight (BW)		0.52	0.77	0.50	0.70	0.68	0.64	0.60	0.44
Ear length (EL)	0.48		0.60	0.42	0.62	0.60	0.53	0.58	0.38
Body length (BL)	0.75	0.54		0.53	0.75	0.65	0.68	0.52	0.43
Tail length (TL)	0.51	0.43	0.61		0.46	0.59	0.62	0.40	0.46
Heart girth HG)	0.75	0.48	0.72	0.60		0.69	0.66	0.43	0.43
Nose to shoulder (NTS)	0.71	0.53	0.70	0.56	0.51		0.64	0.47	0.51
Shoulder to tail-drop (STT)	0.67	0.67	0.69	0.55	0.74	0.60		0.42	0.40
Length of front leg (LFL)	0.58	0.55	0.42	0.40	0.43	0.59	0.54		0.42
Length of back leg (LBL)	0.44	0.53	0.46	0.39	0.50	0.41	0.56	0.47	

Table 4.33: Phenotypic correlations (r_p) for various traits in the **California White** breed at 9 (below diagonal) and 10 weeks (above diagonal)

Trait	BW	EL	BL	TL	HG	NTS	STT	LFL	LBL
Body weight (BW)		0.49	0.66	0.57	0.70	0.68	0.61	0.40	0.55
Ear length (EL)	0.49		0.66	0.42	0.41	0.52	0.40	0.40	0.52
Body length (BL)	0.67	0.49		0.50	0.74	0.72	0.73	0.38	0.45
Tail length (TL)	0.54	0.47	0.43		0.54	0.43	0.44	0.47	0.48
Heart girth HG)	0.68	0.52	0.71	0.50		0.52	0.55	0.50	0.51
Nose to shoulder (NTS)	0.72	0.46	0.76	0.40	0.73		0.65	0.58	0.43
Shoulder to tail-drop (STT)	0.68	0.43	0.68	0.46	0.59	0.75		0.47	0.51
Length of front leg (LFL)	0.64	0.47	0.38	0.39	0.50	0.43	0.42		0.49
Length of back leg (LBL)	0.42	0.40	0.40	0.40	0.46	0.44	0.36	0.37	

Positively moderate to high correlations were observed for all traits, with the highest value of 0.93 between HG and BL at 6 weeks of age and the lowest of 0.39 between LBL and EL at 10 weeks of age. The relationships amongst these traits were found to be significant ($P<0.05$; $P<0.01$) across all ages.

Tables 4.31, 4.32 and 4.33 showed the results of the phenotypic correlations analysis for all growth traits in the California White (CAW) breed at 5 and 6, 7 and 8 and 9 and 10 weeks of age. The correlation obtained between BL and BW at 8 weeks of age was the highest (0.77) while the value observed between EL and LFL at 5 weeks of age was the lowest (0.35). Generally, the correlations observed herein for the CAW breed were moderate to high, positive and significant ($P<0.05$; $P<0.01$).

4.9 Carcass traits analysis

The carcass traits for the pure-, main- and reciprocal-crosses are presented in Table 4.34. For the purecross, breed differences were observed for carcass weight, where the CHC had significantly ($P<0.05$) higher carcass weight (1214g) than the NZW (1195g) and CAW (1174). Initial or pre-slaughter weight, carcass weight and dressing percentage were also affected by breed in the main and reciprocal crosses. The mean values obtained were 1734g, 1062g and 61.24% in the CHC x NZW cross; 1693g, 1139g and 67% in NZW x CAW cross and 1616g, 1056g and 65.34% in the CAW x CHC cross, for pre-slaughter weight, carcass weight and dressing percentage, respectively. The corresponding values obtained in the reciprocal crosses were 1711g, 1188g and 69% in the NZW x CHC cross; 1655g, 1150g and 69% in the CAW x NZW and 1709g, 1263g and 73% in the CHC x CAW cross.

From the maincross (Table 4.34), the CHC x NZW gave significantly ($P<0.05$) higher preslaughter weight (1734g) than NZW x CAW (1693g) and CAW x CHC (1616g), while the NZW x CAW cross had higher carcass weight (1139g) and dressing percentage (67%) than

the CHC x NZW (1062g and 61.24%) and CAW x CHC (1056g and 65.34%). In the reciprocal cross on the other hand, NZW x CHC was highest for preslaughter weight (1711g) while CHC x CAW had the highest carcass weight (1263g) and dressing percentage (73.9%). The heart, liver, kidneys, lungs and other visceral organs showed no significant ($P>0.05$) differences among the breed groups.

4.10 Heterosis and maternal effects for carcass traits

Estimates of heterotic effect (%H') calculated for carcass characteristics are presented in Table 4.35. The estimates of heterosis in unit and percent (%) for preslaughter weight in the CHC x NZW, NZW x CAW and CAW x CHC crosses obtained were 27.4 and 42%, 25.1 and 29% and 23.7 and 36%, respectively. The examined carcass traits showed generally insignificant ($P>0.05$) heterosis.

Maternal effects for various carcass traits (Tables 4.35) showed no differences in all the crosses except on heart, kidneys and lungs ($P<0.05$). However, no particular trend was established for the maternal effect on carcass traits studied.

Table 4.34: Least square means (±SE) for carcass traits

Traits	BREED GROUP [a]								
	PURECROSS			MAINCROSS			RECIPROCAL CROSS		
	CHC x CHC	NZW x NZW	CAW x CAW	CHC x NZW	NZW x CAW	CAW x CHC	NZW x CHC	CAW x NZW	CHC x CAW
Preslaughter/live weight (g)	1696±47[a]	1674±40[a]	1638±41[a]	1734±63[a]	1693±48[b]	1616±52[c]	1711±88[a]	1655±20[b]	1709±53[a]
Carcass weight (g)	1214±42[a]	1195±66[a]	1174±53[b]	1062±34[b]	1139±71[a]	1056±18[b]	1188±50[b]	1150±38[c]	1263±49[a]
Dressing out percentage (%)	71.58[a]	71.38[a]	71.67[a]	61.24[b]	67.28[a]	65.34[a]	69.43[b]	69.48[b]	73.9[a]
Heart (%) (as % of carcass weight)	0.44	0.41	0.46	0.47	0.35	0.51	0.44	0.53	0.49
Liver (%) "	5.10	5.12	5.96	5.93	4.66	5.25	5.70	4.93	5.11
Kidney (%) "	0.94	0.96	0.91	1.03	0.96	0.88	0.92	0.76	0.80
Lungs (%) "	1.25	1.21	1.15	1.22	1.07	1.13	1.26	1.05	1.19
Full gut (%) "	23.08	24.33	22.84	27.4	19.75	15.06	22.47	19.80	24.54
Empty gut (%) "	10.50	10.17	10.44	10.36	9.34	10.87	11.21	9.75	9.62
Head (%) "	13.95	13.88	13.23	13.93	14.61	13.74	14.31	14.85	13.96
Thigh (%) "	28.73	29.02	26.47	27.02	23.71	30.68	29.45	25.55	28.39
Skin (%) "	17.77	17.69	17.46	17.64	15.42	16.92	17.36	17.94	17.25
Length of small intestine (cm)	313[a]	295[a]	305[a]	316[a]	296[a]	278[b]	310[a]	264[b]	304[a]
Length of large intestine (cm)	184[a]	177[b]	181[a]	198[a]	184[b]	179[b]	190[a]	166[c]	170[b]

[a] CHC=chinchilla; NZW=New Zealand white; CAW=California white; N=Sample size
[abc] = Means in the same row (within the same cross) having the same letter are not significantly different

Table 4.35: Heterosis and Maternal effects (±SE) for carcass traits

Traits	Direct heterosis						Maternal effect		
	CHC x NZW		NZW x CAW		CAW x CHC				
	Units	%	Units	%	Units	%	CHC x NZW	NZW x CAW	CAW x CHC
Preslaughter/live weight (g)	27.4±34.7	42.1	25.1±11.4	29.42	23.73±30.0	36	-31.4±61.0	-28.3±45.4	-24.0±22.8
Carcass weight (g)	1.66±0.51	11.5	0.96±0.05	7.77	1.07±0.11	9.24	0.27±0.14	0.24±0.20	0.26±0.31
Dressing out percentage (%)	3.07±0.37	6.23	2.66±0.75	2.06	2.0±0.66	4.90	0.16±0.11	0.10±0.23	0.13±0.08
Heart (%) (as percentage of carcass weight)	0.05±0.04	4.61	0.13±0.06	6.22	0.08±0.08	5.32	0.29±0.17*	0.21±0.21	0.18±0.16
Liver (%) "	0.08±0.02	2.19	0.05±0.02	2.27	0.16±0.32	1.94	-0.21±0.22	-0.18±0.20	-0.13±0.17
Kidney (%) "	0.02±0.03	3.33	0.04±0.01	3.72	0.67±0.25	2.69	0.16±0.13*	0.12±0.23	0.93±0.21
Lungs (%) "	0.05±0.04	3.06	0.05±0.06	4.02	0.08±0.05	3.62	0.32±0.14*	0.27±0.24	0.23±0.23
Full gut (%) "	-0.63±0.56	-6.29	-0.54±0.43	-4.36	0.11±0.26	2.54	-0.18±0.13	-0.15±0.21	0.10±0.17
Empty gut (%) "	-0.49±0.32	-5.45	-0.35±0.28	-2.99	-0.28±0.15	-0.30	-0.08±0.06	-0.11±0.15	0.07±0.09
Head (%) "	0.58±0.24*	18.36	0.39±0.41	16.18	0.41±0.41	0.32	0.25±0.51	0.21±0.30	0.30±0.23
Thigh (%) "	-0.01±0.21	-2.90	-0.03±0.33	-3.14	-0.06±0.21	-3.02	-0.11±0.34	-0.32±0.26	-0.28±0.18
Skin (%) "	-0.44±0.17	-8.98	-0.27±0.17	-6.22	-0.36±0.23	-7.14	-0.07±0.22	-0.13±0.17	-0.09±0.14
Length of small intestine (cm)	6.44±3.02	16.66	3.78±3.11	19.65	3.11±3.26	18.19	11.42±6.02	7.39±4.55	5.29±4.32
Length of large intestine (cm)	3.39±3.18	21.30	4.46±3.24	19.82	3.67±3.18	17.25	8.33±6.17	6.54±4.11	5.63±3.62

CHC=Chinchilla; NZW=New Zealand white; CAW=California white
* = P<0.05

CHAPTER FIVE

5.0 DISCUSSION

5.1 Mean litter performance

5.1.1 Performance of the purebreds

The California White (CAW) does had significantly ($P<0.05$) higher litter size (LS) at birth than the Chinchilla (CHC) and New Zealand White (NZW) does. This result agreed with the reports of Irekhore (2007) who stated that the California breed produced higher litter size at birth than New Zealand White, New Zealand Black and Flemish Giant breeds. Mariana *et al*. (1988) earlier reported that California does normally ovulate two eggs more than New Zealand White does. Although ovulation rate was not monitored in this study, it could be asserted that the CAW does used herein probably ovulated more eggs than NZW and CHC does hence the larger litter size. The result observed in this study was at variance with the results of Yahaya (1993) who reported higher litter size at birth for Chinchilla does than for New Zealand White and California White does. Though the mean LS at birth obtained in this study compares with that reported by Patial *et al*. (1991), it was higher than that (5.6) reported by Odubote and Akinokun (1991). The range of 6.05–7.33 for LS at birth obtained herein was higher than the litter size values of 4.4 (Iyeghe-Erakpotobor *et al*., 1996b), 4.77 (Fayeye and Ayorinde 2003), 5.8–6.61 (Irekhore, 2007), 4.27–5.33 (Zalla *et al*., 2007) and 5.69 (Akpa and Alphonsus 2008). It was also higher than other reported values in literature (Ayorinde, 1997; Oseni *et al*., 1999; Akanno *et al*., 2004).

California White (CAW) does produced heavier litters at birth compared to NZW and CHC does. This could be explained by the findings of Rao *et al*. (1977)

who stated that the total weight of rabbits in a given litter increased with increased litter size. It also corroborated the earlier submissions of Ozimba and Lukefahr (1991). The Chinchilla kits had significantly ($P<0.05$) higher individual kit weight (IKW) than their New Zealand White and California counterparts. Although the CAW had the highest litter weight at birth, this did not confer any significant advantage on the individual birth weight of its kits. The average kit weights obtained in this study were lower than those reported by Oseni *et al*. (1999), Akanno *et al*. (2004) and Zalla *et al*. (2007). Litter birth weight is directly related to weights of individual kits constituting the litter.

The Chinchilla does produced heavier kits at 21 (206.53g) and 35 (348.67g) days of age, than New Zealand White and California does. This result is at variance with the report of Ferraz *et al*. (1992), who observed higher litter weight at weaning for California than NZW does. It also disagreed with that of Lukefahr *et al*. (1983a), who reported better performance by NZW does over CAW does. The result observed herein are also not in conformity with the work of Hamilton *et al*. (1997) who reported that litters raised by California does were lighter at weaning compared with litters reared by NZW and CAW x NZW does. Hamilton *et al*. (1997) suggested that this was due to smaller litters and/or milk production by the California does. The high performance of the CHC breed observed in this study could probably be attributed to better milking ability of the Chinchilla does. Iyeghe-Erakpotobor *et al*. (1996b) reported that Chinchilla does raised heavier kits at weaning than NZW and CAW does, probably an indication that Chinchilla does have better maternal ability and/or milk production than NZW and CAW does. All kits in this study were weaned at 35 days postpartum, which was regarded early as compared to the weaning practices in other conventional and commercial setups. Fortun-Lamothe *et al*. (2001) observed

that early weaning provides higher viability and faster growth in the weaned rabbits. The peak of milk production in the rabbits is considered to be at the 3rd week of lactation following the reports that lactation increases until the end of the 3rd week of lactation (Lebas, 1969; Kustos *et al*., 1996); McNitt and Lukefahr 1996).

The high mortality rate recorded in this study for all crosses (29.6% in the purecross, 25.3% in the main-cross and 30% in the reciprocal cross) can be attributed to the sudden attack on the rabbits by some giant wild cats, which caused substantial loss. In addition to this attack and in line with the report by Fayeye *et al*. (2000), the first few weeks of life witnessed the highest loss rate for the newborn kits. At this time, the kits are fragile, furless, blind and obligatorily-milk dependent. However, the rate recorded in this study was higher than the average (17.6%) of the values reported for preweaning litter losses for Dutch and New Zealand rabbits in the literature (Somade, 1982; Abdulmalik *et al.*, 1992; Ayorinde, 1997; Fayeye and Ayorinde, 2003; Akanno *et al.*, 2004; Onyiro *et al.*, 2004; Zalla *et al*., 2007). However it compares favourably with the report of Aduku and Olukosi (1990) who estimated 25% mortality for every litter. Jokthan *et al.*, (1996) recorded 26.6% and 28.7% for concrete floor and caged rabbits, respectively. Kitten mortality of 26% was reported by Akpa and Jokthan (1996).

Causes of preweaning mortality has been reported by Partridge *et al.* (1981) to be due to chilling and starvation (82%), trauma resulting from physical injury (15%) and disease (3%). It was also reported that the proportion of post-natal deaths due to starvation was as high in small litters as in large litters (Rao *et al*., 1977; Partridge *et al.*, 1981). Other factors are the milk production of the doe and the ability of the kits to successfully find a teat during the once-a-day suckling period (Rajadevan *et al.*, 1986).

5.1.2 Performance of the crossbreds (Maincross and Reciprocal cross)

The performances of the crossbreds (main cross and reciprocal cross) were assessed using the cross breeding effects (CBE) to determine the heterosis and reciprocal effects.

5.2 Effect of breed of sire, breed of dam, parity and sex on growth traits of rabbits

The mean body weight observed in this study for CHC, NZW and CAW breeds at 6 weeks of age were higher than those reported by Obasi and Ibe (2008). The authors reported 384.8g, 335.12g and 335.16g for CHC, NZW and Dutch breeds, though age was not specified in their study. Reporting on the effect of breed of sire on growth performance of crossbred rabbits, Oke *et al*. (2010) found significant breed effect on most of the parameters tested. The authors reported 9.68cm (CHC x NZW) and 10.7cm (NZW x NZW), 7.48cm (CHC x NZW) and 6.03cm (NZW x NZW) for BL and HG at 6 weeks of age, which were lower than values for same traits observed in this study at same age. However the values reported by Obasi and Ibe (2008) for BL and HG in CHC (25.05 and 17.41cm) and NZW (22.03 and 15.56cm) were higher than those obtained in this study for same breeds. Differences in method and time of measurement, breed, management and environmental influences could have been responsible for differences in results obtained (Zalla *et al*., 2007).

Generally, effects of breed of sire, dam and parity were found to be significant on some of the parameters measured in the three breeds at various ages. This is in line with the earlier submissions of McNitt and Lukefahr (1993) and McNitt and Moody (1990). In addition, the Chinchilla breed was found to be superior to NZW and CAW at all ages. This agreed with the reports of McNitt and Lukefahr (1993), who confirmed the superiority of Chinchilla over NZW and Dutch breeds in

terms of growth and body weight. Sex had no significant (P>0.05) effect on all growth parameters measured at all ages in the three breeds of rabbits.

5.3 General Combining Ability (GCA)

The significant effect (P<0.05) of GCA observed for body weight (BW), ear length (EL), body length (BL), heart girth (HG) and shoulder to tail-drop (STT) indicated that additive gene action is important in the expression of these growth traits. This suggests that traits with additive gene effects are expected to respond to selection for their genetic improvement. This is because their heritability values are also expected to be moderate to high. For other traits that showed positive but insignificant (P>0.05) effect of GCA, the implication is that additive gene action operates in their respective mode of expression but to a lesser extent. The observation in this study was in line with the reports of Obasi and Ibe (2008) who reported significant GCA estimates for EL, BL and HG. The authors also reported significant effect of GCA on tail length (TL), which contradicts the findings of this work.

The results also revealed that the Chinchilla breed (CHC) showed and maintained superiority over the New Zealand White (NZW) and California White (CAW) breeds for 8 traits; body weight (BW), ear length (EL), body length (BL), tail length (TL), nose to shoulder (NTS), shoulder to tail-drop (STT), length of front leg (LFL) and length of back leg (LBL). This was followed by the CAW which was superior to NZW for 5 traits (EL, TL, NTS, STT and LBL). The New Zealand White breed had the lowest estimates of GCA for 5 traits (EL, TL, NTS, STT and LBL). The implication of these results is that the CHC proved the best in terms of having the highest preponderance of genes which impart additive effects on growth traits. This agreed with the findings of Obasi and Ibe (2008) who reported that the CHC breed could possibly increase growth performance because of their higher GCA

values. Results by Afifi and Emara (1990) in Egypt indicated that breed differences in GCA for litter size at birth and weaning were non-significant. For litter weight at weaning however, Afifi (1971), cited by Afifi and Khalil (1992), reported highly significant differences ($P<0.01$) among the breeds studied, where the Californian kits had the highest litter weight, followed by the Bouscat and Giza white kits. Afifi *et al*. (1987) used four breeds of rabbits and observed that Baladi was highest in GCA for birth weight.

5.4 Specific Combining Ability (SCA)

The results of SCA indicated that the CHC x NZW cross was the best combination regarding the use of sire and dam breed to exploit non-additive genetic variance in 6 of the 9 examined traits (Table 4.2). It was observed also that the CHC breed performed generally well in crosses with either NZW or CAW. Cross performance was however low or almost poor for NZW x CAW cross, implying poor manifestation of non-additive gene action (Obasi and Ibe, 2008). The negatively non-significant SCA is an indication that crossing to utilize non-additive gene effects will result in depression of such traits (Nagpure *et al*., 1991). The findings of this study were in conformity with the reports of other workers (Brun *et al*., 1992; Krogmeier *et al*., 1994; Obasi and Ibe, 2008). According to Obasi and Ibe (2008), significant SCA is an indication of non-additive gene action for the traits concerned and can be improved genetically through appropriate crossing, utilizing non-additive gene effects such as dominance and epistasis. Improving the environment may also bring about improvement in the character (Obasi and Ibe, 2008). Carregal (1980) and Afifi and Emara (1990) reported non-significant differences due to SCA for kit body weight at several ages and litter size at birth or weaning, respectively. However, Emara (1980), cited by Afifi and Khalil (1992), found a significant effect for litter weight at birth

attributable to SCA, when utilizing Bouscat, Giza White, White Flander and Baladi Red rabbits.

5.5 Heterotic effects for birth and weaning traits

For litter size and weight at birth and at weaning (Table 4.3), higher percentages for heterotic effect were obtained from NZW x CAW cross than those from CHC x NZW and CAW x CHC crosses. Similarly, for litter size at birth and at weaning, litters from CHC x NZW cross showed better performance than those from CAW x CHC. Henry (2007) reported that crossbreeding has helped to improve litter size at birth, litter weight at birth and gestation gain substantially in all the matings used. The positive and high heterotic effects obtained in this study agreed with the reports of other workers (Sheridan, 1986; Afifi and Emara, 1990; Brun *et al*., 1992; Afifi and Khalil, 1992). Carregal (1980) found significant differences for body weight of kits at 28 and 70 days of age attributable to maternal heterosis in favour of New Zealand and Californian does, when compared to Dutch and Blanc du Bouscat does. Afifi and Emara (1990) reported that the best maternal heterosis was exhibited by white Flander and Baladi red does at birth and at weaning respectively. Afifi (1971) and Emara (1982), cited by Afifi and Khalil (1992), reported significant differences for litter weight at weaning due to breed of doe. Brun *et al*. (1992) found differences for litter size between strains of rabbits attributable to maternal heterosis. The superiority which some breeds of doe exhibit for maternal ability can be attributed to increased milk production, maternal behaviour and care of the litter.

Results for %H' for all weaning traits were positive and substantial for all mating groups except for weaning mortality, which showed lower estimate. Higher estimates of %H' for a given trait indicated that crossbreeding has improved the performance of that trait in the mating concerned. Fayeye and Ayorinde, (2000)

reported that the most promising crossbred for the exploitation of heterotic effect was the NZW x CHC. The authors added that the cross had improved litter size, litter weight, kit weight and rate of body weight increase (birth to 21 days postpartum).

The performance of some traits reported herein showed that crossbreeding was associated with negative effects. Hoste (1989) had earlier reported negative heterosis with a significant increase across generations for age at 1st egg in the domestic fowl. Recently, Yahaya *et al*. (2009b) working on layer type chickens reported negative heterosis for age at sexual maturity across generations and said that this is desirable, because crossbred groups will reach age at 1st egg earlier than their purebred counterparts.

Heterosis or hybrid vigour for a certain trait exists when the average performance of the crossbred progeny is superior to the average performance of the two parents (Ahmed, 2003). This means that the magnitude of non-additive (mainly dominance) is comparatively substantial. The magnitude of heterosis can vary practically, depending on the environment and on the populations being crossed. Theoretically, the magnitude of heterosis is inversely related to the degree of genetic resemblance between parental populations (Willham and Polak, 1985) and it is expected to be proportional to the degree of heterozygousity of the crosses (Sheridan, 1981; Hill, 1982). However negative heterosis might be attributable to directional dominance of genes affecting traits. In this regard, Falconer (1989) showed that a cross between two base populations will show positive heterosis if they differ in the frequency of genes affecting a given trait. The author further explained that negative sign of heterosis could be attributed in some cases to the nature of the measurement (i.e if the trait is expressed in another way, such as the reciprocal of the present, then the heterosis would be positive in sign) and may also be due to the size of dataset.

5.6 Reciprocal effects for birth and weaning traits

The high reciprocal effects observed (Tables 4.3 and 4.4) for LSB, LWB, LSW and LWW in the CHC x NZW cross agreed with the earlier reports of Fayeye and Ayorinde (2000). The authors reported that reciprocal effect was higher in the NZW x CHC crossbreds than in NZW x CAL and CAL x CHC crossbred for litter size at birth. Ponce de Leon and Menchaca (1974) found significant effect for litter size at birth which is attributable to reciprocal effects. The highest averages in their study were found where the Semi-giant breed was included as the sire in the mating. Nagpure *et al*. (1991) observed from their study that the use of New Zealand White males on White Giant females can be made to exploit reciprocal effects (maternal and sex-linked) in obtaining higher body weights from birth to 6 months of age. Carregal (1980) found that the use of Dutch males on New Zealand, Californian and Bouscat does produced the highest individual kit body weight at 28 days of age. Emara (1982), cited by Afifi and Khalil (1992) reported a highly significant effect ($P<0.01$) on litter weight at birth attributed to reciprocal effects.

5.7 Genetic parameter estimates

5.7.1 Heritability estimates

The low to moderate heritability estimates from sire (h^2_S) and dam (h^2_D) components observed for reproductive traits in all the breeds (Tables 4.8a and 4.8b) was an indication that non-additive and additive gene action operates for the expression of these traits. Characters that are lowly heritable can be improved upon by crossbreeding, considering the strong non-additive gene action which determined the expression of such characters (Akanno and Ibe, 2005). Moderately heritable traits

on the other hand would be improved upon by combining pedigree and individual selection. The heritability estimates for gestation length at birth reported herein were lower than values (0.59±0.26) reported by Chineke and Raheem (2009).

In the CHC breed, heritability estimates for litter size from birth to weaning were high, while the estimates for litter weight were moderate to high. Similarly in the NZW and CAW breeds, estimates of heritability from birth to weaning for litter size and weight were observed to be moderate to high. The high heritable characters can be improved upon by individual selection. Odubote and Somade (1992) obtained heritability estimate of 0.33±0.08 for litter birth weight in the Chinchilla, California, New Zealand and their crosses. The estimates previously reported by Odubote and Somade (1992) were lower than the values reported in this study. Differences in estimates of heritability could arise from differences in breeds, environment, management as well as method used in data analysis. For litter size, the estimates observed in this study were in conformity with other reports in literature. Odubote and Somade, (1992) reported a heritability value of 0.38±0.02 in different breeds and their crosses. Khalil *et al*. (1988) reported an estimate of 0.24±0.15 in Bouscat breed of rabbit. Similar values for litter traits had been reported by other workers (Ndjon and Nwakalor, 1998).

The heritability values obtained for body weight in the three breeds of rabbits at various ages were similar to the 0.42 for body weight at 90 days of age reported by Lukefahr *et al.*, (1992) and the 0.29 for body weight at 11 weeks of age by Ferraz and Eler (1994) under tropical conditions. In addition, the heritability estimates obtained herein for body weight are similar to those reported in temperate environments (Szendro *et al*., 1988; Castelline and Panella 1988; Lukefahr *et al.,* 1996). On the other hand, the estimates obtained in this study for body weight in the three breeds of

rabbits at 6, 8 and 10 weeks of age were higher than those reported by Akanno and Ibe (2005) at 6 (0.43), 9 (0.11) and 12 (0.36) weeks of age. Working on the Rhode Island breed of layer birds (male and female lines) Adeyinka (1998), Nwagu (2004) and Kabir *et al.* (2006) reported high heritability from the sire component of variance for body weight. Characters that show high heritability estimates reflect on the fact that additive gene action is important in such characters. This suggests that if the improvement of such trait is desired, either pedigree or individual selection method could be adopted.

For linear body measurements, the estimates of heritability for ear length obtained in this study at 6 weeks of age in the CHC breed (0.14), NZW breed (0.11) and CAW breed (0.22) were low and found to be similar to 0.11 reported by Chineke and Adeyemi (2001) and by Akanno and Ibe, (2005). Lowly heritable traits are determined by non-additive gene effect, which means that the environmental influence plays a major role in the expression of such traits. The importance of ear length to the rabbit in heat dissipation cannot be overemphasized (Lukefahr and Ruiz-Feria, 2003 as cited by Akanno and Ibe, 2005). If there would be any need to improve the ear length of the rabbit, considering the strong non-additive gene action playing a vital role in its expression, crossbreeding might be a better option to make use of heterosis.

The moderate to high estimates of heritability obtained in this study for STT, BL, LFL and LBL were in line with the values reported by Chineke and Adeyemi (2001) and Akanno and Ibe (2005). These traits reflect the length of long bones, which have been observed as good predictors of live weight and carcass composition (Tiamiyu *et al*., 2000). The traits whose heritability values were not estimatable could be due to negative sire component of variance in the analysis of variance (ANOVA).

Negative variance components are regarded as an indication of negligible contribution of additive genes to variation of the traits concerned. Although theoretically impossible, negative variance components may result with the analysis of variance procedure used of the estimation (Akanno and Ibe, 2005).

5.7.2 Repeatability estimates

The estimate of repeatability (Table 4.12) obtained from this study for gestation length (GL) at birth was higher than the values (0.17±1.24) reported by Chineke and Raheem (2009). Similarly, the estimates of repeatability obtained from this study for litter size and weight at birth in the CHC breed (0.72±0.32 and 0.86±0.37), NZW breed (0.50±0.28 and 0.74±0.32) and CAW breed (0.70±0.33 and 0.69±0.30) were higher than 0.22±2.42 and 0.12±1.12 reported by Chineke and Raheem (2009). Akpa and Alphonsus (2008) reported repeatability values of 0.67 and 0.80 for litter size at birth and gestation length, respectively. In a study conducted on non-descript rabbits in the South-Eastern part of Nigeria, Okoro *et al*. (2007), reported estimates of repeatability of 24% and 34% for litter size and weight at birth, which were lower than estimates of repeatability observed herein. Reporting on Chinchilla rabbits, Lukefahr *et al*. (1983a) gave an estimate of 3.7% for litter birth weight, while Nwagu *et al*. (2000) obtained a high repeatability estimate of 45% for litter size in locally adapted breeds of rabbits in Shika-Nigeria. Ndjon and Nwakalor (1998) reported moderate to high estimates of repeatability for litter weight at weaning. Traits with moderate to high repeatability imply that great reliability can be put on selection or culling of does and bucks for that trait, based on 1 or 2 records.

The low estimate of repeatability observed in the NZW breed for HG (0.18±0.12) was in conformity with the reports of Chineke and Adeyemi (2001). The authors obtained repeatability estimate of 0.11±0.08 for HG at 35 days of age and

regarded it as low. This confirmed that heart girth could be lowly repeatable indicating that the likelihood of repeated performance is relatively low. The implication is that, traits with low repeatability cannot be selected based on its performance (Okoro *et al*., 2007). The moderate to high estimates of repeatability observed from this study agreed with the submission of Chineke *et al*. (2001) for body weight and linear measurements at various ages. According to Akpa and Alphonsus (2008), moderate to high estimates of repeatability for litter size and gestation length as well as high correlated relationship amongst them suggest that selection of rabbit for increased litter size and shorter gestation length can be done using the first or second record of the rabbit.

Repeatability is the proportion of total phenotypic variance for a trait attributable to permanent difference among individuals (Falconer, 1989). It indicates the extent to which selection will influence future animal performance. The improvement of lifetime record would require selecting for early records so as to exploit shortened generation intervention that can lead to increase in genetic progress (Ibe, 1995). Repeatability estimates should be higher than estimates of heritability because of the values contained in their numerator genetic variance, variance due to permanent environments, provided by the doe during prenatal and post natal periods as well as covariance between genetic value of a trait and the maternal environment.

5.8 Estimates of genetic and phenotypic correlations

The implication of the present findings is that for traits with positive and high genetic correlation, selection for one trait will lead to improvement in the other. This however, is the phenomenon of correlated response. These findings corroborated the

work on the chinchilla breed carried out by Okoro *et al.* (2008). The authors explained that growth in the chinchilla breed is asymmetrical with other body parts and that as this breed of rabbit grows, all the other parts are growing concurrently. The moderate to high coefficient of genetic correlation for growth traits at various ages observed in this study are in line with the works of Akanno and Ibe (2005), Abdullah *et al.* (2003) and Chineke (2000) in various breeds of rabbit.

The moderate to high phenotypic correlations observed in this study are consistent with the findings of Tiamiyu *et al.* (2000) and Okoro *et al.* (2008). Positive and significantly high association for HG, BL, NTS, STT and BW indicated that absolute height and frame size were complementary. Besides, selection for increased measurement for any trait and in any of the breed studied herein, would mean positive and significant influence on the other and therefore, increased skeletal stature with concomitant increase in other absolute body measurements. Wei and Vender Werf (1995) reported high genetic correlation for some important economic traits in layer type chickens.

Both genetic and phenotypic correlations are helpful as guides to selection. Akanno and Ibe (2005) explained that selection for a wider and longer body in an index could be effective in a breeding programme aimed at achieving increased body size, as long as linear body traits were very highly and positively correlated with body weight. The authors further concluded that linear body parameters could be used to predict body weight for selection purposes. Nwagu *et al.* (2000) reported that significant and positive correlation between two weights do not necessarily indicate that selecting for one of these weights will lead to the improvement in the other because a phenotypic correlation is not always a reliable estimate of genetic relationship existing between traits. For example an environmental effect upon two

weights could be so strong and positively correlated that a negative genetic correlation is masked (Nwagu *et al.,* 2000).

5.9 Carcass traits analysis

Variation among rabbit breeds and crossbreeding combinations of different origin for carcass traits exist (Rao *et al.,* 1978, Lukafahr *et al.,* 1982b, Lukefahr *et al.,* 1983a, Lopez *et al.*, 1990, Szendro *et al.*, 1994, Bawa *et al.,* 2009). The variation observed in the main-cross for preslaughter weight, carcass weight and dressing percentage is in line with the reports of Oke *et al.,* (2010) where they observed higher mean values for live weight, carcass weight and dressing percentage in the CHC x NZW crossbreds. Das and Bujarbarua, (2005) had earlier noted a higher live weight of these breeds compared to the Dutch breed. The relatively low and non-significant differences observed for heart, liver, kidneys, lungs and other visceral organs in the pure, main and reciprocal crosses could be explained by the environmental circumstances and feeding regime applied, which could influence the ability of the breeds. However, values of carcass traits are difficult to be compared objectively with those reported in literature, because of the different initial or pre-slaughter weights, breeds, method of slaughter and evaluations as well as the statistical model adopted.

5.10 Heterosis and maternal effects for carcass traits

Results obtained in this study for heterotic effects on carcass traits agree with those of Lukefahr, *et al.* (1983a). The authors reported that the proportions of carcass traits differed slightly between the straightbreds and crossbreds. According to Ahmed (2003), crossing does not only take advantage of traits with considerable non-additive genetic variations (ie dominance and epistasis), but also exploits differences in additive effects (ie differences in mean performance between populations as a deviation from the overall mean) between populations.

Maternal effect consists mainly from additive maternal and cytoplasmic-inheritance. However, the maternal effect herein is conceivably confounded with the reciprocal effect (ie sex linkage) since it is determined as the difference between the three reciprocal crosses (NZW x CHC, CAW x NZW and CHC x CAW). Sex linkage as an effect is due to additive effects of genes concerned with the trait and is carried on the sex chromosomes (Ahmed, 2003).

Explaining maternal effect in terms of complementarity effects, certain crosses may show much more maternal effect than others depending on the extent to which the crossed populations differ in reproductive performance and in production characters. Therefore, this type of effect, according to Hill (1982) will rely on the direction of crossing, hence the negative signs obtained for some carcass traits in this study. The results obtained from this study may lead to the assumption that the three breeds of rabbit could be used as dam-line for carcass traits. In other words, the three selected populations do not seem to complement each other or aggregate the responsible genes regarding heterotic and maternal effect as well as reproductive efficiency of the studied carcass traits.

CHAPTER SIX

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

Reproductive performance of rabbit is an important feature that determines the efficiency of rabbit production. The reproductive performance can be measured by age at first kindling, litter size at birth, birth weight, litter size at weaning and weaning weight. The litter size at birth (6.05, 6.89 and 7.33 for Chinchilla, New Zealand White and California White does, respectively) obtained in this study were higher than litter size of 4.77 reported in literature for New Zealand breed in the Derived Savannah zone, and 4.4 reported for same breed at Shika in the Northern Guinea Savannah zone of Nigeria. The litter size was however lower than 8.0 reported for New Zealand White breed in the temperate regions and 7.49 in the Sudan.

For higher litter size at birth and weaning, the New Zealand White proved superior, but for higher individual weight at birth and weaning as well as for better milk yield and mothering ability, the Chinchilla breed is the best. This therefore, indicated that rabbit raisers in the Guinea Savannah zone of Nigeria would operate more profitably if they keep the Chinchilla breed rather than New Zealand White and/or California White breeds. The results of this study further showed that the Chinchilla breed maintained its superiority over the New Zealand White and California White breeds for eight traits out of the nine traits studied. This was followed by CAW and lastly the New Zealand White breed.

The results of SCA indicated that the CHC x NZW cross was the best combination regarding the use of sire and dam breed to exploit non-additive genetic variance in six of the nine traits examined. It was observed also that the CHC breed performed generally well in crosses with either NZW or CAW. Cross performance was however low or almost poor for NZW x CAW cross, implying poor manifestation of non-additive gene action. The heritability estimates for litter size in the CHC breed from birth to weaning were high, while the estimates for litter weight were moderate to high. Similarly in the NZW and CAW breeds, estimates of heritability from birth to weaning for litter size and weight were observed to be moderate to high.

The moderate to high coefficient of genetic correlation for growth traits at various ages observed in this study are in line with other literature reports. Positive and significantly high association for HG, BL, NTS, STT and BW indicated that absolute height and frame size were complementary. Beside, selection for increased measurement for any trait and in any of the breed studied herein, would mean positive and significant influence on the other and therefore, increased skeletal stature with concomitant increase in other absolute body measurements. For carcass analysis however, the CHC breed had the highest carcass weight (1214g) followed by NZW (1195g) and CAW (1174). In the crossbreds, the mean values obtained for pre-slaughter weight, carcass weight and dressing percentage were better for the CHC x NZW combination.

6.2 Conclusion

The following conclusions are drawn from this study:

- The CHC x CAW cross yielded the heaviest kittens (26.53±2.22g) followed by kittens from CAW x CHC (25.51±2.77g) and NZW x CAW (19.9±1.31g), probably due to high exploitation of heterosis from both parents. The result of specific combining ability was a pointer to the fact that, the CHC breed performed generally well in crosses with either NZW or CAW. Body linear measurements were improved and growth as well as the general performance was high. The CHC x NZW cross showed superiority over NZW x CAW and CAW x CHC crosses for BW (13.271), EL (0.242), BL (4.331), HG (0.782), NTS (0.172) and STT (0.360). Cross breed performance was however low or almost poor for NZW x CAW cross, implying poor manifestation of non-additive gene action.

- The reproductive performance of the purebred California White and New Zealand White does was higher than that of Chinchilla. The California White produced higher litter size at birth (7.33±0.19) with a corresponding litter birth weight of 155.94±4.34g. This was followed by New Zealand White breed which gave a litter size at birth of 6.89±0.25 weighing 149.25±3.92g. The Chinchilla breed gave a litter size at birth of 6.05±0.29 which had the heaviest litter birth weight of 163.68±5.76g. The Chinchilla rabbit gave the highest estimate for eight traits namely; BW (16.741), EL (0.374), BL (0.778), TL (0.226) NTS (0.317) STT (0.486), LFL (0.179) and LBL (0.331). The New Zealand White rabbit had the highest and significant ($P<0.05$) estimate for HG (0.596), while the California White rabbit showed the least estimate of GCA for six traits. Generally the Chinchilla breed performed

impressively higher than New Zealand White and California White, respectively.

- NZW x CAW cross produced the highest percent heterosis for litter size at birth followed by CHC x NZW and CAW x CHC crosses, respectively and therefore should be used for exploitation of hybrid vigour. Reciprocal effect was however not important in all crosses for almost all traits studied, because reversing the breed of sires used in the main-cross yielded no better advantage. Therefore, the combination of sire and dam used in the main-cross is the best cross for the exploitation of hybrid vigor.

- The highest estimate of general combining ability was from Chinchilla breed of rabbit for eight traits {BW (16.741), EL (0.374), BL (0.778), TL (0.226) NTS (0.317) STT (0.486), LFL (0.179) and LBL (0.331)}. New Zealand White breed was the second best while the California White breed had the least estimate of GCA for six traits. Effect of specific combining ability on the breeds studied revealed that the CHC x NZW cross performed better than NZW x CAW and CAW x CHC crosses for body weight and other linear body measurements (EL, BL, HG, NTS and STT). The CAW x CHC cross on the other hand was superior to NZW x CAW for EL, TL, HG, NTS and STT.

- Heritability values observed for reproductive traits in the three breeds were low to moderate, an indication that non-additive and additive gene actions operate for the expression of these traits. Heritability estimates for litter size from birth to weaning were high (0.49–0.64) in the CHC breed, while the estimates for litter weight were moderate to high (0.34–0.52). In the NZW

and CAW breeds, moderate to high estimates of heritability for litter size and litter weight (0.33–0.46 and 0.28–0.41); (0.31–0.42 and 0.32–0.41) were observed from birth to weaning. Characters that are lowly heritable can be improved upon by crossbreeding, considering the strong non-additive gene action which determine the expression of such characters. Moderately heritable traits on the other hand would be improved upon by combining pedigree and individual selection while highly heritable traits could be improved upon by individual selection.

6.3 Recommendations

1. The pure breed Chinchilla rabbit is hereby recommended to rabbit raisers in the Guinea Savannah zone of Nigeria, because it had the highest litter weight (163g) at birth where each of the 6 kits weighed 27g. The breed also successfully nursed 5 of the kits to weaning at 345g each. The Chinchilla rabbit gave the highest estimate of general combining ability for eight traits namely; BW (16.741), EL (0.374), BL (0.778), TL (0.226) NTS (0.317) STT (0.486), LFL (0.179) and LBL (0.331). The breed also had the least neonatal (3.7%) and pre-weaning mortality (14.6%) rates.

2. The pure breed California White rabbits could however, be used for higher litter sizes at birth (7.3) and at weaning (5.86). The breed also had relatively low pre-weaning mortality (18.2%) compared to NZW (29.6%).

3. For cross breeding purposes, it is recommended that the CAW does should be crossed with NZW sires for better litter size and weight. The NZW x CAW had the highest litter size of 8.5 at birth with a corresponding litter weight of

184.96g. This cross produced the highest percent heterosis for litter size at birth (63.24%) and therefore should be used for exploitation of hybrid vigour.

4. Further growth studies using various growth curves should be conducted to determine the pattern of growth in the three breeds of rabbits.

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