

UNIVERSITY OF CAPE COAST

THE EFFECT OF A 3X3 FULL DIALLEL CROSSING ON THE GROWTH  
AND REPRODUCTIVE PERFORMANCE OF THREE RABBIT BREEDS  
REARED WITHIN THE COASTAL SAVANNAH AGRO-ECOLOGICAL  
ZONE IN GHANA

LOUIS OPOKU-MENSAH

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BY

LOUIS OPOKU-MENSAH

A thesis presented to the Department of Animal Science of the School of  
Agriculture, College of Agriculture and Natural Sciences, University of Cape  
Coast, in partial fulfilment of the requirements for the award of a Master of  
Philosophy degree in Animal Science

MAY, 2017

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University of Cape Coast

**DECLARATION**

**Candidate's Declaration**

I, hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature ..... Date.....

Name: Louis Opoku-Mensah

**Supervisors' Declaration**

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast

Principal Supervisor's Signature ..... Date .....

Name: Julius Kofi Hagan (PhD)

Co-Supervisor's Signature ..... Date .....

Name: Moses Teye (PhD)

## ABSTRACT

Data on a full diallel cross involving three rabbit breeds and its effects on some growth and reproductive traits were studied. Data on two thousand and thirteen (2,013) rabbits comprising eight hundred and five (805) purebred bunnies kindled in 60 litters and one thousand, two hundred and five (1,205) crossbred bunnies from 86 litters bred from 2010 to 2014 in five parities were first corrected for the fixed effects of sex, season of kindling and the does' age using the least significant differences (lsd) before the analysis was run using the Generalised Linear Model. Of the three breeds, the Chinchilla showed superior performance in both the reproductive and growth performance while the BV X CH crossbred showed superior performance in most of the economic traits that were assessed compared to the other crosses. The BV X NZ and NZ X CH crossbreds recorded significantly ( $p = <0.05$ ) higher litter size at birth ( $6.8 \pm 0.1$ ) and at weaning ( $6.9 \pm 0.1$ ) respectively. The heterotic effects of both the main and reciprocal crosses were quite desirable for most of the economic traits. Notable among them was the age at sexual maturity, kindling interval and mortalities which recorded varying levels of negative heterosis. The reciprocal crosses exhibited some level of superiority in the growth traits (bunny weight at birth and the post-weaning growth rate) that recorded positive heterosis. The Chinchilla and BV X CH crossbred comparatively exhibited a higher level of superiority in the general and specific combining abilities in a number of the economic traits that recorded significant differences. The positive heterotic effects encourage the application of crossbreeding schemes in rabbit production for improved productivity within the coastal savannah agro-ecological zone of Ghana.

**KEY WORDS**

Diallel crossing

Heterosis

General combining ability

Specific combining ability

Crossbreeding

Reproductive

Breed complementarity

Crossbred

Agro-ecological

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**DEDICATION**

To my siblings and the lecturers of the Department of Animal Science of the School of Agriculture, College of Agriculture and Natural Sciences, University of Cape Coast.



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## LIST OF ACRONYMS

CH	Chinchilla
BV	Blue Vienna
NZ	New Zealand White
BWB	Bunny weight at birth
LWB	litter weight at birth
BWW	bunny weight at weaning
LSB	litter size at birth
LSW	litter size at weaning
ASM	age at sexual maturity
KIN	kindling interval
BW8wks	body weight at 8 weeks
BW10wks	body weight at 10 weeks
BW12wks	body weight at 12 weeks
PGR	post weaning growth rate
MT	mortality

## CHAPTER ONE

### INTRODUCTION

#### **Background of the Study**

Globally, there has been an increasing demand for animal protein; more significantly, in the developing countries of sub Saharan Africa. This soaring demand for animal protein has been attributed not only to the ever-increasing global human population, but is also an acknowledgement of the essential role of animal protein in human development and well-being. Improved economic status, urbanisation and industrialisation, particularly in the developing economies have all contributed to the increased demand for protein from animal sources (Karikari, Darkoh & Deku, 2011). There have been several interventions geared towards meeting this increasing demand. These interventions include improved management and production systems, improved nutrition, efficient utilisation of genetic resources and agro-industrial by-products, as well as rise in backyard or non-commercial animal production (Onifade & Tewe, 2010). More importantly, these interventions also seek to guarantee security in food supply for the marginalised in society (Fayeye & Ayorinde, 2010).

Over the period, poultry in particular has played a significant role in this regard, although the persistent and ever-widening gap between demand and supply of animal protein has not yet been bridged. This has necessitated the need to make more use of alternative sources of animal protein via the development of non-conventional livestock. The rabbit, in recognition of its high prolificacy, rapid growth rate, early sexual maturity, short gestation



period (28-31days), good ability to utilise forage feed, high meat yield, comparatively low production cost, lower space requirement, limited cultural and religious prohibitions on its production and consumption, as well as the high nutritive value of its meat, has been identified as a promising food animal (Fayeye, 2013; Obiajulu, Eze, Amadi, & Odoemena, 2016; Sivakumar et al., 2013).

Considering the potential for rabbit production in Ghana, and the success story of some neighbouring West African countries, the National Rabbit and Grasscutter Projects were initiated by Newlove Mamattah, in 1971. With the introduction of some improved rabbit breeds, breeding herd was approximately 1,478 by 1978 (Lukefahr, 1998; Lukefahr, 2000). Individuals, particularly women, children and rural folk who showed keen interest in this species, recorded tremendous successes. This initiative notwithstanding, performance records of rabbits have over the period not only been sub-optimal, but also continued to follow a downward trend. With time a number of individuals and governmental institutions (like the Rabbit Unit of the Animal Research Institute of the Council for Scientific and Industrial Research) abandoned the programme entirely, focusing only on the traditional livestock species. It is thus not surprising that efforts primarily geared towards enhancing the general performance (reproductive and growth) of rabbits through improved nutrition and management practices, have not yielded the expected results.

An important intervention or tool that has greatly influenced output of not only livestock species but also plant species as well has been crossbreeding. Crossbreeding is basically the mating of individuals of different

breeds. The exercise results in the alteration of genetic variance, and allows combining the valuable traits of parent lines in their progeny. It has also been found to be a major tool for the full exploitation of genetic variation in rabbits (Lukefahr, 1998), being identified as one of the best options to increase profits of the warren or colony because of its particular impact on productivity and adaptation to the environment (Akinsola et al., 2014; Fayeye & Ayorinde, 2010; Mbanasor, & Wogu, 2006; Obiajulu et al., 2016). Baselga (2004) has indicated that due to the nature of their productive traits, rabbits offer a higher degree of kindness (productivity) when improved via cross breeding.

Diallel crossing is a crossbreeding system that involves crossing each of several individuals with two or more others in order to determine the relative genetic contribution of each parent to specific characters or traits in the offspring. It has been identified as one of the best approaches to facilitate the selection of an ideal genotype, primarily because of the combining ability of the genotypes. Likewise, diallel crossing permits the estimation of heterosis among all pairs of breeds. This has been found to be useful in the evaluation of breeds which are already indigenous to a region or for a limited number of breeds chosen on the basis of prior top cross evaluation (García, Ponce de León & Guzmán, 2012). Aside offering the opening to assess the varied genetic aspects of the parents' performance, diallel crossing helps in taking objective decisions in the different improvement programmes right from the identification of superior genotypes and promising combinations for the desired economic traits (Ramos et al., 2006). It is thus not surprising that the diallel crossing is considered as an efficient means of assessing the full genetic and heterotic potential of different breeds or lines.

### **Problem Statement**

Rabbit production has gained much popularity in both the developed and particularly in developing economies in the tropics in recent times. This has been linked to the rabbits' potential as a reliable source of healthy meat, its' economic and genetic value. However, it appears that much has not been achieved with the existing rabbit breeds in Ghana. This is very evident in the suboptimal performance of the existing breeds of rabbit, a condition that has been linked to the effects of high levels of inbreeding. There is substantial evidence that this problem (inbreeding depression) can be effectively resolved through well-planned crossbreeding programmes. There is thus the need to exploit the full genetic potential of the existing rabbit breeds through a diallel cross. This would ultimately help in identifying and selecting best performing breeds and phenotypes for the Ghanaian environment.

### **Justification**

A number of success stories of rabbit production in some developing economies within the tropics and particularly within the West African sub-region have demonstrated that it is a reliable source of meat for the increasing population (Akinola & Ironkwe, 2012; Lukefahr, 1998). A series of studies that have been carried out in some of the developing economies within the last decade have actually confirmed the economic, genetic and more importantly the nutritional value of rabbit meat (Akinola & Ironkwe, 2012; Dalle Zotte & Paci, 2014). The performance of rabbit breeds within the tropics in particular however have been found to be suboptimal. This has inspired a number of interventions (improved nutrition, housing, selection and breeding of ideal breeds for specific agro-ecological zones, healthcare, adoption strategies,

educational fora, etc.) aimed at enhancing rabbit productivity within tropical environments (Adedeji, Osowe & Folayan, 2015; Ghosh, Das, Bujarbaruah, Das Asit, & Singh 2010; Oke, & Iheanocho, 2011; Onyiro, Ibe, & Anigbogu , 2008; Oseni & Lukefahr 2014; Rajapandi et al., 2015). The impact from such interventions have however been minimal to average successes. What has been established from the hand full of studies conducted in Ghana in this regard (improved productivity) has not been much different from what has been reported in the developing economies of sub-Saharan Africa (Ansah, Francis, Joejoe & Rockson, 2014; Appiah, Nimoh, Tham-Agyekum, & Tracoh, 2011; Apori, Hagan & Osei, 2014; Karikari et al.; 2011; Mensah et al., 2014; Osei, Apori & Osafo, 2012).

It has however been observed that quite substantial successes have been made through the genetic approach (crossbreeding, screening, identification and selection of best performing breeds and genotypes for various agro-ecological zones, breed development, etc.) than the other approaches have. Surprisingly, there is very limited information on any work(s) that have been carried out in this regard in Ghana. There is paucity of information on the genetic potential of the existing meat breeds, not to mention crossbreeding and diallel cross to be specific. Diallel cross have actually been known to be very effective in the genetic improvement of livestock species in general because it makes possible, the optimum use of the nicking ability of the breeds crossed. This is achieved by either bringing the overall traits relative to the dam and the offspring, or a favourable combination of additive effects on the components of an overall trait (Zeveloff & Boyce, 1980). Not only does diallel crossing aid in the conservation of

genetic resources but among other benefits, it aids in obtaining varied information of the parental population. The procedure is thus important in taking important in the different improvement programmes, from the identification of superior genotypes and crossings, or promising combinations (Mohammed, 2012; Momoh, Unung & Attah, 2015, Ramos et al., 2006). It has actually been identified as an efficient method for assessing the genetic and heterotic potential of different breeds and lines.

### **Research Objectives**

#### **General objective**

The study was aimed at evaluating the effect of a full 3x3 diallel cross on the reproductive and growth performance of three rabbit breeds namely, the New Zealand White, Blue Vienna and Chinchilla, and their crosses.

#### **Specific objectives**

The study specifically sought to

- compare the mean reproductive and growth performances of purebred and crossbred rabbits
- estimate the heterotic effects of crossbreeding on some reproductive and productive traits in crossbred rabbits
- estimate the general and specific combining abilities of some growth and reproductive traits

### **Relevance of the study**

The study will offer the opportunity to identify, select and develop high performing breeds and breed combinations from existing breeds for improved reproductive and growth performance within one of Ghana's coastal

savannah agro-ecological zone. According to Khadiga, Saleh, Nofal and Baselga (2008), Falconer and Mackay demonstrated that a cross between two base populations would show heterosis if they differ in the frequency of genes affecting a given trait. Considering some of the unique traits of rabbits such as prolificacy, fast growth rate and the possibility of all-year production especially in the tropics, the added general benefits of crossbreeding and more particularly diallel crossing would offer the alternatives to increased productivity in different rabbit populations.

The study will ultimately make significant contribution in ensuring food security in the face of the changing climate, particularly for the majority rural poor, women and children who most often are the disadvantaged in society. Having been identified and established in recent times as a potential source of employment, rearing rabbit would help considerably in reducing unemployment (with a little start-up), as well as the migration of the youth from the rural areas to the urban centres for non-existing jobs, with its accompanying social vices.

Likewise, a careful selection of rabbit breed(s) and crossbred(s) suitable for the various agro-ecological zones and for various traits would obviously be a very good response to the advocacy for climate-smart agriculture as a solution to the threatening food insecurity due to climate change.

## CHAPTER TWO

### LITERATURE REVIEW

#### **Domestication, Spread and Potential of Rabbits**

Rabbits, one of the small mammals, belongs to the family *Leporidae*. According to Matthee, Van Vuuren, Bell and Robinson (2004), the *Leporidae* (rabbits and hares) is made up of 11 genera and over 56 species. They, along with the pikas, make up the order *Lagomorpha* found in several parts of the world. Although fossil records suggest that the *Lagomorpha* evolved in Asia about 40 million years ago, wild rabbits are said to have been first domesticated in the 5th Century by the Monks of the Champagne Region in France (Carneiro, 2012; Carneiro et al., 2014, Queney et al., 2002). True domestication according to Gono, Dube, Sichewo and Muzondiwa (2013), occurred however in middle of the 16th Century, in remote monasteries. The Monks were thus almost certainly the first to keep rabbits in hutches and cages as a readily available food source, and to experiment with selective breeding for economic traits such as market weight or fur quality. The selective breeding of rabbits meant that distinct breeds arose in different regions, and the origins of many old breeds can be traced back to several centuries (Queney et al.).

Up until the 19th Century, domestic rabbits had been bred purely for their meat and fur. But during the Victorian era, many new 'fancy' breeds were developed through the hobby of breeding rabbits for shows or sports (Hardy et al., 1994; Queney et al., 2002). Although rabbits were characteristically connected with the countryside, with the advancements in industrialisation,

many of the people who moved from the countryside to the expanding towns and cities, brought rabbits along with them. With the exception of poultry, rabbits were the only farm animals that were convenient to keep in urban areas. Although many of these rabbits were bred for meat, it became increasingly common among the rising middle classes to also keep rabbits as pets (Hardy et al.).

The European wild rabbit (*Orytolagus cuniculus*), the only specie that is widely domesticated evolved around 4,000 years ago in Spain, developed by the Romans during the Second Punic War (Carneiro et al., 2012). The Romans upon their arrival in Spain around 200BC began to farm the indigenous rabbit breeds primarily for their fur and meat. With a rapid reproduction rate, increased cultivation of land and providing ideal habitats, rabbits soon established large populations in the wild (Lebas, Coudert, Rouvier, & De Rochambeau, 1997). The spread of the Roman Empire, increasing trade among countries and the break-up of continents during this period played significant roles in introduction of the European rabbit into many parts of the world, with the exception of Australia (Matthee et al., 2004). According to Lebas (2005), backyard production of hatched-raised rabbits for family consumption had become a common practice. When industrial production of rabbits for meat was finally introduced, it was perceived as a route out for poverty-stricken developing economies that needed a quick supply and cheap source of healthy protein and employment, without adversely affecting the local environment. To a far greater extent, it turned out otherwise because the meat did not end up only on the tables of the low and middle income earners but the higher income earners of both developing and developed economies



(Matthee, et al.). There are currently more than 60 recognised breeds of domestic rabbits

The production of rabbit as a reliable source of meat has over the period received much attention in both the developed and developing economies, particularly in sub-Saharan Africa (Opoku & Lukefahr, 1990; Oseni, 2012). The high adaptability of the rabbit to a variety of agro-ecological zones, existence of several agroecology-specific breeds (Hardy et al., 1994; Mathee et al., 2004; Oseni, 2008) and the rabbits' potential for high genetic improvement makes it an ideal livestock specie. The contribution of the rabbit in climate-smart agriculture and towards ensuring food security, particularly in developing economies in the face of the threatening climate change (Ajayi, Oseni & Papoola, 2014; Oden, 2009; Oluwatusin, 2014; Oseni, 2008). Rabbits are currently exploited on an industrial scale globally primarily for its meat, and to a much lesser extent for its fur, leather, wool, medical research, education, pharmaceuticals and pet breeding (Owen, Morgan, & Barlow, 1977).

### **Benefits of Rabbit Production**

Rabbits have been identified as one of the unconventional livestock in recent times endowed with some unique traits that makes it both an ideal source of meat and very significant in helping bridge the persistent and widening gap between production and demand for protein from animal sources. Its consumption has lately received high acknowledgement among all strata for both the developing and developed economies of the world (Abdel-Hamid, 2015; Adzitey, 2013; Assan, 2013; Oseni, 2008; Oseni, 2012; Owen et al, 1977). This new development is almost entirely attributed to the

exceptional nutritive value and high quality of its meat (an all-white meat, high protein yield, fewer calories, relatively rich in essential fatty acids, certain vitamins and minerals, and low to medium cholesterol levels) compared with most of the traditional sources like poultry, beef, mutton, chevon and pork (Cheeke, 1980; Lebas. 2005; Dalle Zotte & Paci, 2014; Guauy, 2011; Khan et al., 2016). The meat has an added advantage of not just having a very pleasant taste but is more easily digestible than some other proteins (Akinola & Ironkwe, 2012; Nistor et al., 2013; Wu, Gu & Li, 2012; Zeferino et al., 2011). Unlike some of the conventional livestock species like pig and cattle whose consumption has religious limitations, rabbit meat is reported to have considerably limited religious restrictions. Rabbit meat is acceptable by Moslems and Hindus (Dalle Zotte & Szendrő, 2011)

The rabbit is also known to be highly prolific (an average of 5-9 bunnies per kindling and 25-30 bunnies per year in both temperate and tropical regions), has early sexual maturity (4-5months), rapid growth rate (3 months mature size) and high feed conversion efficiency (Baruwa, 2014; Baselga, 2004; Cheeke, 1980; Kabir et al., 2014) The rabbit has high genetic potential for selection, relatively short gestation period and reproductive cycle (Hassan, Elamin, Yousef, Musa & Elkhairey, 2012). The rabbits' ability to rebreed shortly after kindling makes it possible to have high number of litters per year, (4-5litters); and when well-managed, it can be bred throughout the year particularly within the tropics (Ghosh et al., 2010). Another peculiar and unique attribute favouring rabbit production over monogastrics, is the possibility of raising the rabbit on an entirely grain-free diet depending on the production/management decision (Karikari et al., 2011; Olowofeso,

Adejuwon, Ademokaya & Durosawo, 2012). This is truly an added advantage for rabbit keepers, especially in developing economies like Ghana where there has been a continual and rising demand for grain such as maize, millet and sorghum, as food for humans. The rabbits' ability to even subsist on low quality feed such as kitchen leftovers, highly fibrous ingredients and agro-industrial by-products, is an added benefit (Appiah et al., 2011; Karikari et al.; Moreki & Seabo, 2012; Niba et al., 2012; Oseni, 2012).

Likewise, the rabbits' efficiency in feed utilisation, high carcass yield or dressing percentage, ease of raising, requiring a comparatively small space and little start-up capital for production makes it one of the most economical farm animals to raise (Hassan et al., 2012.; Olowofeso et al., 2012; Onifade & Tewe, 2010). Besides its judicious space utilisation, the establishment of the rabbitry requires low inputs and is thus, an alternative and viable means to empower particularly women who live in poverty in developing economies in Africa (Baruwa, 2014; Gono et al., 2013; Lukefahr et al., 2000; Obiajulu et al., 2016). The rabbits' small size does not only make them easy to raise and handle, even by vulnerable members of the household including women and children, but their low individual value compared to cattle, sheep, goats and pigs also limits risk of investment (Adedeji et al., 2015; Baruwa.; Borter & Mwanza, 2011; Cheeke, 1986; Karikari & Asare, 2009, Moreki & Seabo, 2012). This makes its production less sophisticated such that not only the majority rural poor and landless people but the marginalised in society particularly women and children in most developing economies to also raise rabbits to meet their nutritional needs (Mamattah, 1978; Oluwatusin 2014). Their small body size also makes it easy to transport and market them.

According to Oseni et al. (2008) it makes the recurrent costs for maintaining rabbit beyond the optimum low compared to other livestock species

A considerable number of people in developing countries south of Sahara often engage in rabbit production on a backyard system essentially to meet the meat or protein requirements of the household. It has been established that it sometimes serves also as an additional source of revenue for the household from the occasional sale of some of the rabbits (Karikari et al; 2011; Appiah et al., 2011; Oseni, 2012; Owen et al., 1977; Serem et al., 2013). This makes it a viable venture for all scales of commercial production (Gono et al., 2013; Hassan et al., 2012). It is thus not surprising that throughout the world, cuniculture is seen as a lifesaver especially for the rural poor, lower-income classes, peasants, school dropouts, etc. When compared to other livestock enterprises such as poultry, sheep, goat and cattle for meat and dairy production, rabbit farming poses quite minimum economic risks. This, according to Serem et al. (2013), makes it possible for not only landless but resource-poor famers to either downscale or upscale the enterprise without incurring heavy losses. Unlike the manure from conventional livestock like poultry and cattle which require composting, the seemingly odourless rabbit manure can be applied directly to cultivated vegetables. A few publications in recent times (Mailafia, Onakpa & Owoleke, 2010; Gono et al.) have confirmed the findings of Casady who in 1975 reported that the manure is also relatively rich in phosphorus and nitrogen compared to the manure of other livestock.

## **Reproductive and Growth Performance of Rabbits in the Developed Economies**

The rabbit, since its domestication, has been raised for varied and diverse uses (laboratory or experimental animals, pets, showing, sports, etc.) depending on the social status and the objective of the farmers or breeders. They have however been raised extensively for meat production in a variety of settings (backyard, commercial, extensive, semi intensive) and at different times around the world. Upon the realisation of the rabbits' role in meeting the ever-increasing global demand for animal protein, especially in the developing countries in the tropics, several interventions have been implemented to ensure enhanced reproductive and growth performance. Notable among such interventions have been improved nutrition and husbandry practices, identification, selection and breeding of high performing breeds and genotypes for specific agro-ecological zones, and the advocacy and introduction of cuniculture in both the developed and developing countries in particular (Akinsola et al., 2014; Alves et al., 2015; Carneiro et al., 2014; Corbet et al., 2006; Emlen & Oring, 1977). A good number of these interventions which were primarily aimed at ensuring increased animal protein supply and ensuring food security, particularly for the marginalised and malnourished in society, have greatly contributed to enhanced performance in rabbits (Assan, 2014). The realisation of the nutritional value of the meat has really encouraged large-scale production and export of rabbit meat in some developed economies. This has significantly contributed to an increased global rabbit population and consumption, in both the developed and developing economies (Lukefahr, 2008; Oguike & Okocha, 2008, Wu et al., 2012). In the

United States for instance, both processors and producers in the commercial rabbit meat industry have been focusing on improving the supply, consistency and market outlets for rabbit meat. Most of the top rabbit producing countries happen to be located mostly in Europe, Asia and America. China happens to be the largest producer and consumer of rabbit meat; together with Italy, Spain and France (which happens to be the origin of the modern domestic rabbit). These countries alone produce 75% of the world's rabbit meat (Lebas, 2005; Lukefahr et al, 1998).

In spite of the several meat breeds of rabbits often raised in the characteristic small scale production and backyard production systems mainly in the developing economies, most of the industrial farms of the top producing economies use primarily the New Zealand White, Chinchilla, California White, Flemish Giant and sometimes, their crossbreds (Abu, Onifade, Abanikannda & Obiyan, 2008; Cheeke, 1986; Lebas et al., 1997; Lukefahr, 2000). The climatic conditions in the temperate regions coupled with the years of intensive selection and breeding of rabbits have significantly influenced reproductive performance as well as growth rates. The major challenge in most parts of Europe and Asia has been the impact of the distinct seasonal variation that does not encourage an all-year production (Ghosh et al., 2005; Ghosh et al., 2010, Sivakumar et al., 2013). This notwithstanding, the litter size at birth and at weaning, from a number of studies involving the major meat breeds of rabbits from the developed economies, have ranged between 4.5-13.0 and 4.0- 6.9 respectively (Dige, Kumar, Kumar, Dubey & Bhushan, 2012; Tůma, Tůmová & Valášek, 2010). Breeds of rabbits from these regions tend to also have heavier bunny weight both at birth and at weaning (45.9-

54.2g and 572.5-858.8g) respectively, low mortalities and fast growth rates (Sivakumar et al.) This is attributable to the comparatively favourable climatic conditions within the temperate regions which the rabbits like most livestock species are able to adapt to or withstand compared to the hot tropical conditions (Oluwatusin, 2014; Tembachako & Mrema, 2016; Zeferino et al., 2011) Moreover, the extensive level of selection and breeding of rabbit breeds that are ideal for such agro-ecological zones and the scale of production in those economies cannot be overemphasised (Oseni & Lukefahr, 2014).

### **Reproductive and Growth Performance of Rabbits in sub-Saharan Africa**

The commercial production of rabbits on the continent seems to be still emerging although its introduction has been quite long. The focus of most of the rabbit production systems in sub-Saharan Africa has notably been on the backyard system. They are often managed to serve as a backup to supplement the family's protein requirement, and not as a profit-making venture (Abu et al., 2008; Ansah et al., 2014; Karikari & Asare, 2009; Mailafia et al., 2010; Mensah et al., 2014;). That notwithstanding, sales from rabbits occasionally serve as an additional source of revenue to meet some household needs (Akpo et al., 2008; Gono et al., 2013; Hassan et al, 2012; Oseni, 2012; Serem et al., 2013). As a result, most of the farmers are not much concerned about the profitability of the enterprise which is informed by the litter size at birth and weaning, growth rates, mortality, etc. (Jaouzi, Barkok, Bouzekraoui & Bouymajjane, 2004; Oden, 2009; Osei et al., 2012)

The backyard operations which have characterised rabbit production in a majority of African communities are likewise well-noted for the use of normally poor performing indigenous dwarf breeds which are generally small

in size, have slow growth rate, high mortality and low litter size (Osei et al., 2012). It is thus not surprising that in spite of the characteristic favourable climatic conditions of the tropics that promotes an all-year production, it has not contributed significantly to enhance growth and reproductive performance (Akpo et al., 2008; Apori et al., 2014; Thornton, 2010). For more obvious reasons, either little or no proper identification and selection of favourable breeds have been carried out in most developing economies in sub-Saharan Africa for ideal breeds for the different agro-ecological zones. There is also either the lack of or limited institutional support for rabbit farmers in most of the developing countries in the tropics compared to other livestock species. The characteristic small scale of operation, poor nutrition, limited facilities and infrastructure, overuse of breeding animals and other factors have contributed to low output (Akpo et al., Oseni, 2008; Oseni 2012; Szendrő, Szendrő & Dalle Zotte, 2012).

Similarly, the few breed improvement programmes that are targeted at improving the reproductive and growth performance of nonconventional livestock like rabbits in particular, are highly limited. Even with conventional livestock species like poultry, such programmes have often been the preserve of a few individuals and occasionally some internationally recognised non-governmental agencies like the FAO, IFAD, AGRA, CGAIR, AgUSAID and other partner organisations that may partner the government in such programmes. It is thus not surprising that the reproductive and productive potential of rabbit breeds in Africa has not yet been fully exploited, in spite of its confirmed potential. An evaluation and sustainability of a number of rabbit projects that became widespread on the continent a couple of decades back,



have proven to be more or less great failures. Lukefahr (2000) did indicate that for optimum benefit, rabbit farming required a bit of detailed training and continual governmental support, in not only farming but marketing as well. A number of studies have confirmed that rabbit breeds in tropical environments have demonstrated higher reproductive and growth performance. This has greatly encouraged its production in developing economies, particularly in Africa (Mailafia et al., 2010; Oluwatusin, 2014; Osei et al., 2012; Oseni & Lukefahr, 2014; Owen & Amakari, 2010; Thornton, 2010).

Cuniculture in a number of the economies in sub-Saharan Africa in recent times is seen not just as a solution to hunger and malnutrition for the less privileged in the society (particularly women and children) but as a useful tool for poverty alleviation (Adedeji et al, 2015; Akpo et al., 2008; Amin, Taleb, Bangladesh & Rahim, 2011; Owen & Amakiri, 2010). This has greatly encouraged the use of comparatively high performing and improved breeds. Likewise, the use of crossbreds, adoption of improved management practices, training and workshops occasionally organised for farmers among other things, in most developing economies who have particularly embraced rabbit farming, have contributed significantly to their progress. For instance, the litter size at birth and at weaning of most of the commercial purebreds (both local, and exotic) and in some cases, their crossbreds have ranged from 2.6-8.3 and 2.6-8.1 respectively, with the crossbreds performing comparatively better than the local and exotic breeds (Abdel-Azeem, Abdel-Azim, Darwish & Oma, 2007; El Rahman, Elagib & Babiker, 2012; Khalil & Bolet, 2010; Olowofeso et al., 2012; Pragya & Eady, 2001). In addition to the increased attention gained by crossbreeding programmes over the past decade, there

have been efforts at identifying, characterising and developing breeds that are ideal for the various agro-ecological zones (Khadiga et al., 2008; Khalil, 1999; Youssef, Baselga, Khalil, Gad-Alla & Garcia, 2008).

### **Reproductive and Growth Performance of Rabbits in Ghana**

Rabbit production in Ghana, like most African countries, began with local meat breeds that were either captured from the wild or brought in by expatriates from neighbouring West African countries like Nigeria, Liberia, Sierra Leone, Cote D'Ivoire and Cameroun, having realised the essential role of rabbits in meeting the country's protein demand (Karikari & Asare, 2009; Lukefahr, 2000). Like most of the developing countries in sub-Saharan Africa, they are kept as part of the backyard livestock by a comparatively few individuals in the villages, and on a few occasions in the peri urban and urban areas. In recognition of the several unique traits of the rabbit which makes it an ideal source of meat in developing countries, Mamattah in his contribution to the governments' quest to attain food self-efficiency began what later became the National Rabbit and Grasscutter Project in 1971 at Kwabenya (near Accra) with some foreign breeds from Australia, Belgium, New Zealand, Holland and the United States of America (Opoku & Lukefahr, 1990; Lukefahr, 2000). The project was targeted at improving the reproductive and productive performances of the meat breeds of rabbits in the country so that Ghana could become self-sufficient in meat production. With the exception of the initial support that the project received from the government via the Food and Agricultural Organisation of the United Nations, there has virtually been very minimal input from the government of Ghana. It is thus not surprising that although the initial performance records of the rabbit breeds in the country

were very promising, their performance over the years has been declining. The project was supported upon the realisation of the rabbits' role in meeting the country's increasing protein demand, as had been realised for some of the developing countries in the tropics that were also limited in their protein resource (Lukefahr). The performance records of the earlier breeds from the project, coupled with the adoption of improved husbandry practices, yielded very significant results which was however not sustained.

An assessment of Ghana's Rabbit Project revealed that the challenges it encountered were not much different from what was reported in other developing countries on the continent (Gono et al., 2013; Lukefahr., 2000; Mensah et al., 2014; Moreki & Seabo., 2012; Oden, 2009; Oluwatisin., 2014). This was partly attributable to the abandonment or non-sustenance of the project. Information on some aspects of rabbit production such as available feed resources, the genetic composition of the exotic breeds received, housing and management prior to their introduction was quite limited (Lukefahr; ; Osei et al., 2012). A detailed study of their performance under the prevailing local conditions (like the available forage species as influenced by the various agro-ecological zones), the economic status of the few farmers and their ability to adopt the improved management systems would have been very helpful. This is on the basis of the essential roles these play in making well-informed decisions. As it has been established with similar projects, its sustainability is informed by primarily its affordability by the majority of the people for which the project is designed (Apori et al, 2014; Mensah et al.; Osei et al.) Aside the meat breeds being the major breeds that have been kept, any other breed that has found its way into Ghana has served the same purpose. Notable among

these breeds are the New Zealand White (which happens to be the most-farmed meat breed), the Flemish Giant, Chinchilla, Blue Vienna, California White and in some cases, their crosses (Apori et al; Karikari & Asare., 2009; Mensah et al., 2014.Osei et al.)

Unlike the other unconventional livestock species like the grasscutter, and snail production which have received much attention, rabbit production in Ghana do not seem to have gained the needed market in spite of decades of its introduction into the country. Quite similar to what have been reported in some countries, knowledge about it as a reliable source of healthy meat, its production and consumption is still limited to the production areas although there have been studies to establish that (Lukefahr, 2000; Mamattah, 1978). This challenge could be attributed to its economic viability that was probably not considered or emphasised by the then National Rabbit and Grasscutter Project. However, there have been few studies lately to establish its economic viability under the prevailing conditions; limited feed resources, adaptable breeds, and veterinary services among others (Appiah et al., 2011; Karikari & Asare, 2009; Mensah et al., 2014). Although some of the studies have actually confirmed that rabbit production can be very useful in reducing poverty and child and infant malnutrition, particularly in areas where women have quite limited employment opportunities, their performance has not been any better than what has been reported in some of the neighbouring West African countries like Togo, Cote D'Ivoire and Nigeria (Mailafia et al., 2010; Oseni, 2012; Owen & Amakiri, 2010; Saha et al., 2013;).

### **Limitations to Rabbit Production in Developing Economies**

The major limitations to rabbit production in developing economies ranges from environmental factors (poor nutrition, heat stress, housing, stocking density), genetic (poorly adapted genotypes, breeding system) limited institutional support, etc. These factors have serious implications on both the growth and reproductive performance of rabbits. Interestingly, these factors most often than not are intertwined and their effects can be very detrimental (Lazzaroni, Biagini, Redaelli & Luiz, 2012; Olawumi, 2014; Pascual, Savietto, Cervera & Badelga, 2013).

#### **Poor Nutrition**

In most of the resource poor economies where special efforts have either not been made towards improved nutrition or the cost of nutritious ration is very expensive partly due to the erratic or seasonal availability of feed ingredients or the high competition between humans and livestock for such feed ingredients (Apori et al., 2014; Assan, 2014; Egena, Akpa, Alemede, & Aremu, 2014; Osei et al., 2012; Safwat, Sarmiento-Franco, & Santos-Ricalde, 2014, Xiccato, 2010). Farmers within such regions are compelled to depend mainly on available forage and sometimes kitchen leftovers and agro industrial by-products (Mailafia et al., 2010; Osei et al.; Oseni and Lukefahr, 2014). These resources have been found to significantly affect the performance of rabbit breeds in developing economies. Besides, these resources have been known to be inadequate (quantitatively and qualitatively) and are also not fed properly (Paci, Dalle Zotte, Cecchi, Marco & Schiavone, 2014; Xiccato, 2010). As a result, the output of the available breeds have most often been suboptimal. Their performance in the developing

economies have always mimicked the seasonal availability of such forage resources (Apori et al.; Osei et al.). Poor nutrition has actually been identified as one of the main reasons why the performance records on rabbits in most of the countries within the tropics has not been very encouraging, although climatic conditions have been found to be favourable for an all-year production (Apori et al.; Assan, 2013; Baruwa, 2014; Mailafia et al.; Oluwatusin, 2014; Paci et al.).

Much as the effects of poor nutrition on the productivity of rabbits can in no uncertain terms be under estimated, its effect on the doe and bunnies can be detrimental. For instance, poorly nourished does may either become infertile, may abort or re-absorb foetuses, give birth to very weak bunnies that may die before weaning, show late sexual maturity, slow growth rate and so on (Pascual et al., 2013; Poigner, Zs, Lévai, Radnai, & Biró-Németh; 2010; Safwat et al., 2014). Pascual, Cesvera and Baselga (2012) likewise have made comments on the negative consequences of a deficient foetal nutrition on the development and adult reproductive performance. In some jurisdictions, nutrition is not seen as a key component because unlike monogastrics (poultry and pigs) which depend mainly on grains (maize) which is a major feed component in developing economies, rabbits can subsist on forage and kitchen waste although the effects have been quite detrimental (Osei et al., 2012). On the other hand, the high cost of the scarcely available concentrates in most of the developing economies does not serve as an incentive for the majority of resource-poor famers (Owen & Amakiri, 2010).

## **Climate**

The climate of countries in the developing economies of the tropics are characterised by high ambient temperature and humidity which are very stressful for most of the high performing exotic breeds. Although cold stress has been known to have effect on rabbits, the effect of heat stress is more detrimental (Akinsola, 2014; Owen & Amakiri, 2010; Zefererino et al., 2013). To an extent, the poor performance of rabbits within the tropics have been linked to the heat-stressed climate. According to Oseni (2012), climatic effect is comparable to poor nutrition, disease and pest that have bedevilled rabbit production in the tropics. The negative implications of heat stress is very disturbing and varying; reduced fertility and fecundity, growth rate, feed intake and quality of forage, high neonatal and pre-weaning mortality, etc. (Castellini et al., 2010; Prayage & Eady, 2001; Zeferino et al. 2011).

## **Management of Rabbits**

The general handling of rabbits, like any livestock species, can have implications on its performance. The management of rabbits in most rabbitries in developing economies are very stressful. The animals are often not properly fed (qualitatively and quantitatively), watered, housed or rested prior to mating and so on (Assan, 2013; Castellini et al., 2010; Oguike & Okocha, 2008). Due to the does' ability to be rebred shortly after kindling, they are often rebred at a comparatively shorter interval and thus wean the bunnies early. Xiccato and Trocino (2010) have reported that the early weaning of bunnies can adversely impact the fertility and prolificacy in multiparous livestock species like the rabbit. The weight and age at which especially the doe is first bred, or its condition prior to mating, can have significant influence on the litter size at

birth. This has been linked to the limited uterine space and nutrient supply to the foetuses. Likewise, the rebreeding interval and the rabbits' physiological status at mating have also been found to have significant influence on the output of most rabbitries in the developing economies (Moce & Santacreu, 2010; Saha et al, 2013).

### **Institutional Support and Policies**

Cuniculture in general has not received the needed attention in developing economies. When the prospect of the rabbit as a reliable source of meat gained attention, most institutions with the support of other international organisation like the FAO, World Bank and other development partners, began various projects in countries that showed interest. The rationale for the initiative was to provide institutional support for the rabbit farmers in these countries. However, a good number of these projects have been abandoned due to the government's disinterest in such projects; the abandonment of Ghana's National Rabbit Project is a classic example (Oseni, 2010; Oseni & Lukefahr, 2014). The lack of institutional support and policies is not just in terms of limited resource availability (breeds, nutrition, vaccines, financial support, etc.), its production is wrongly perceived (disease conditions are scares, depend entirely on forage and kitchen waste, meat for poor people). Rabbit farming is perceived as the preserve of poor and low-income earners, school dropouts, villagers, etc. It is thus not surprising that its husbandry in most developing economies have become the responsibility of women and children within the household (Lukefahr, 2000).



## Breeds

Although most of the local breeds in developing economies are comparatively adapted to their agro-ecological zones, they are normally bedevilled with small litter size at birth, low birth weight, slow growth rate ( $10\text{-}20\text{gd}^{-1}$  in the developing economies compared to  $35\text{-}40\text{gday}^{-1}$  in developed economies), high mortalities particularly prior to weaning, high levels of inbreeding and so on (Apori et al., 2014; Mailafia et al., 2010; Osei et al., 2012). Several studies on rabbit productivity have established that breed has significant effect on a number of economic traits and thus performance (Ghosh et al., 2010; Jaouzi et al., 2004; Prayaga & Eady, 2001; Wajanla, 2015). For instance, breed has significant effect on mothering ability, body weight, growth rate, etc (Sivakumar et al., 2013).

In a majority of the developing economies, little has been done in screening, identifying and selecting best performing indigenous breeds for enhanced performance. Attempts at improving on the performance of the local breeds (via crossbreeding with high performing exotic breeds) have been quite minimal. It has been reported that a good number of the foreign breeds that are often offered to farmers in developing economies by NGOs are culled rabbits that have outlived their reproductive usefulness (Lukefahr, 2000; Oseni & Lukefahr, 2014). Due to the finite population size and selection, there are often high levels of inbreeding. This has detrimental effect on the performance of the rabbits (Akinsola et al., 2014, Baruwa, 2014, Egena et al., 2014; Kabir et al., 2014)

### **Major Interventions in Rabbit Production in Developing Economies**

Although rabbit production (and more so commercial production) undisputedly remains a comparatively new enterprise in sub-Saharan Africa, there have been on-going interventions aimed at improving production. A number of publications have revealed that a number of such interventions and discoveries have made significant improvements in rabbit production in most of these economies (Assan, 2013; Karikari et al., 2011; Mailu, Wanyoike, Serem, & Gachuiri, 2014; Moreki & Seabo, 2012; Nwakpu, Ogbu, & Ugwu, 2015; Pascual et al., 2012; Serem et al., 2013). Notable among them have been the introduction of high performing exotic breeds, crossbreeding programmes, identification and selection of adapted breeds for various agro-ecologies, grading up of local and existing breeds (Baselga, 2004; Youssef et al., 2008) and development of nutritious rations from agro industrial by-products among others.

### **Improved Nutrition**

Previously, most of the rabbit enterprises in Africa like in most developing economies depended entirely on forage, kitchens leftovers, and in some case, agro-industrial by-products from the cottage industries as the source of feed for rabbits. Some studies however established that such systems were highly limited due to the poor nutritional function and toxicity of some of the common forages, and the seasonal variations that affect their availability (Gidenne, 2000; Lukefahr & Cheeke, 1990; Onifade & Tewe, 2010). The impact is often not just limited to meat production but the growth and reproductive performance of rabbits (Apori et al., 2014; Oseni, 2012). These findings have actually contributed to the formulation of comparatively high

nutritious rations from agro-industrial by-products for rabbits which unlike poultry would require maize and fishmeal as major components in their ration formulation (Cidenne, García, Lebas, & Licois, 2010; Mensah et al., 2014, Momoh et al., 2015; Safwat et al., 2014). This improvement in their nutrition has contributed significantly to their growth. The growth performance records of some meat rabbit breeds fed commercially prepared rations under tropical conditions have reportedly increased by  $0.45\text{-}1.23\text{gday}^{-1}$  (Ansah et al., 2014; Carabaño Luengo et al., 2009; Karikari et al., 2011; Thornton, 2010).

### **Genetic Improvement**

Most of the local or traditional rabbit breeds were bedevilled with poor reproductive and growth performance, a condition which among other factors has been linked to the small body size of the local breeds though an adaptive feature (Lebas et al., 1997; Mamattah, 1978). This led to the introduction of high performing temperate breeds such as the California, Chinchilla, New Zealand White, Flemish Giant and Blue Vienna. However, the exotic rabbit breeds like other livestock species failed to meet the expectation of rabbit keepers within the tropics due to their inability to adapt to the harsh climatic conditions of the tropics (El-Raffa, 2004; Guauy, 2011, Maria, Habeeb & Gad., 2002). As has been the practice with conventional livestock production in the developed economies, crossbreeding programmes that have engaged the use of local and exotic rabbit breeds have contributed significantly to the genetic make-up of local breeds (Kabir, Akpa, Nwagu & Adeyinka, 2012; Lavanya, Mahender, Rajanna & Gnanaprakash, 2016, Olawumi 2014; Youssef et al., 2008). Occasionally, a number of research institutions in these developing countries also collaborate by grading up of the local breeds via the

free delivery of higher performing crossbreds to local rabbit farmers. These undoubtedly have contributed to improvement in the performance of the local breeds. Similarly, there has been studies on the effect of mating on the reproductive and growth performance of rabbits (Heba-T-Allah, Osman, Elsheikh & Chen, 2016).

### **Growth and Litter Traits**

Crossbreeding projects, coupled with other improved husbandry practices (improved nutrition, housing and health) in rabbit production have contributed to the improvement in growth performance and litter traits of rabbit breeds in developing economies of the tropics (Bora et al., 2010). According to Momoh et al. (2015); the average daily gain of most crossbred rabbits in developing economies is reported at ranging from 3.7-13.8g. These developments have been linked to the ability of the various breeds to nick or complement each other by effectively combining their unique traits or strengths in the progeny that is produced (Amin, 2014; Kabir et al., 2012; Mocé & Santacreu, 2010; Wakchaure et al., 2015). The progenies from the crossbreeding programmes have been known to have a comparative advantage of purebred parents in their performance, a phenomenon known as hybrid vigour (Iraqi et al., 2006; Kabir et al., 2014; Khadiga et al., 2008). These interventions have significantly contributed to the meat production, yield and quality (Bora et al., 2010; Prayaga & Eddy), and the selection of ideal crossbreds for various agro-ecological zones and production systems. A cross between the California White and New Zealand White according to Kabir et al. for instance have been found to have better heterotic effect and combining abilities for litter traits (litter size at birth and at weaning) than other crosses.

## **Production Systems**

Until recently, a significant number of rabbit producers in Africa had adopted the backyard system. With the establishment of the economic worth of rabbit production in a number of the countries in Africa, there has been a boost in the commercial production of rabbits, although they have typically been under the small holder system. In spite of the predominantly smallholder and backyard system, these systems have been found to have advantage over the traditional livestock species, a condition which has been attributed to the small body size, high rate of reproduction and utilisation of agro-industrial by-products by rabbit (Mensah et al., 2014; Osei et al., 2012; Safwat et al., 2014). Khan, Khan, Khan and Ahmad (2017) for instance confirmed the comparative advantage of the intensive production systems over the traditional systems in Pakistan. In acknowledgement of the influence of the environment, phenotype and their interaction on the performance of rabbit breeds, most productions systems now take into consideration, the selection of ideal breeds for specific agro-ecological zones and the creation of an ideal environment for optimal output (Apori et al., 2014; Oke & Iheanocho , 2011; Onyiro et al., 2008)

## **Human Welfare and Empowerment**

One of the major challenges in most of the developing economies, particularly within the tropics, have been the issue of inadequate food supply, and malnutrition particularly among pregnant women, nursing mothers and children. According to Karikari and Asare (2009) and Assan (2014), rabbit production can make significant contribution to human welfare by ensuring food security. This has encouraged the involvement of women in rabbit production in some of the African countries. Rabbit production in developing

economies have been identified as one of the effective tools for the economic empowerment of women in particular and the less privileged in society at large (Oseni & Lukefahr, 2014). Some researchers have revealed that unlike crop production and some livestock species whose production is restrained due to scarcity of land or land tenure systems, rabbit production in such regions would be an ideal avenue for the generation of extra income particularly low income earners and source of employment for the jobless (Karikari et al., 2009; Lukefahr, 2000; Lukefahr et al., 2000; Lukefahr, 2002; Maass, Musale, Chiuri, Gassner, & Peters; 2012; Szendrő et al., 2012). Such financial independence has the potential to help in building a better self-esteem.

#### **Some Meat Breeds of Rabbits**

The rabbit, since its domestication, has gone through series or phases of breeding over the years, depending on the production objectives (meat, fur, pet, showing, hobby, etc.). The breeding of meat breeds has however received more attention than the other objectives, especially in the less developed and developing economies, for the purpose of helping solve their meat deficit challenge (Lebas et al., 1997; Lukefahr, 2000). Rapid and uniform growth rates, good mothering ability and high prolificacy (large and frequent litters) have been identified as some of the unique traits of meat breeds of rabbits (Asamt, Costa, & Polastre, 2010; Maria et al., 2002; Marai, Ayyat, & El-Monem, .2010, Abu et al., 2008) These have thus been the focus of breeding work involving such meat breeds. All the breeds of rabbits currently raised for meat production are descendants of the European wild rabbit (Carneiro et al., 2012; Ferrand & Branco., 2007). Among the major breeds of rabbits developed for the meat industry are the Chinchilla, Californian, New Zealand,

Flemish Giant, Himalayan, Champagne and Blue Vienna. Other breeds of rabbits that have been developed for commercial meat production are the Florida White, Dutch Rex, and Altex. Of these breeds, the New Zealand White, California White and their crossbreeds have been extensively used in most of the commercial rabbitries of both the well-established and developing economies of the world (El-Raffa, 2004; McNitt, Lukefahr, Cheeke, & Patton, 2013; Moreki, 2007; Ozimba & Lukefahr, 1991).

To a very large extent, this has been attributed to their comparatively high adaptability to a wide range of agro ecological conditions. Some are known to have performed credibly well in some countries than others have, for reasons attributable to variations in climatic factors, husbandry practices, expertise, etc. (Appiah et al, 2011). The meat breeds are normally categorised into three major groups; light, medium and heavy breeds, based on their market or slaughter weights. The light breeds for instance weigh 2-3kg; they have been known to have good mothering abilities and fast growth rate. The medium breeds weigh between 3-5kg; they are the most abundant and are widely used in intensive rabbit production in Europe (McNitt et al., 2013, Moreki, 2007). The heavy breeds normally weigh more than 5kg. The growth potential of these breeds can ideally be exploited via cross-breeding programmes.

### **Chinchilla**

Chinchilla rabbits originated from France in the early 1900s, and were named for the similarity of their fur to the South American rodent, the Chinchilla. The breed was developed using Himalayans, Beverens and wild-coloured Agouti rabbits, and was first shown in France in 1913. Chinchilla rabbits, aside being

one of the very successful commercial meat breeds were originally bred and farmed for their soft and silky fur. They are small to medium in size, weighing around 2.5-3kg. The Chinchilla has a compact body, short neck and fairly broad head with short, erect ears. Chinchillas have agouti colouring, where the hairs have different colour bands along their length. The belly, neck, flanks and eye-circles have pale, pearl ticking, and the ears are laced with black. Their coat colour vary from slate blue, pearl to black. Chinchilla rabbits are excellent mothers and very playful. They are generally quite docile, good natured and very gentle. They are intelligent, curious and enjoy company and attention. Chinchillas are usually good with children and are also well-suited as house rabbits. They are popular for their good temperament and luxuriously soft coat. They are raised for their meat, showing and as pets (Ferrand & Branco, 2007; Ferrand 2008; Lebas, 1997; McNitt et al., 2013; Monnerot et al., 1994).



*Figure 1:* Chinchilla breed of rabbit (Field Data, 2016)



### **Californian**

The Californian is an excellent meat breed which was developed in the early 1920s by George West in Southern California by initially crossing the Himalayan breeds with the Chinchilla; and then the crossbred with the New Zealand White. The Californian was bred to be a meat breed, and for its high quality pelt and good fur. It is thus not surprising that the California White is currently second to the New Zealand White rabbit as the most popular meat breed in the world. The Californian is fairly large (3.5-4.75kg), usually calm and very friendly. They are pure white with characteristic dark markings (usually near black although some may be blue and chocolate) on the nose, ears, feet and tail, and are well noted for their large litter size and fast growth rate. Their eyes are pinkish due to a lack of pigmentation; have large ears, bulky in build, with firm plump body and short neck (Ferrand & Branco, 2007; Ferrand 2008; Lebas, 1997; McNitt et al., 2013; Monnerot et al., 1994; Moreki, 2007)



*Figure 2: California White breed of rabbits (Field Data, 2016)*

### **New Zealand White**

The New Zealand White which happens to be the best meat breed actually originated from the United States and was bred in 1916 by W.S. Preshaw, a Californian breeder, in his quest to develop a valuable rabbit for the meat and fur trade. It is unknown which breeds of rabbit he used but the name is thought to stem from wild New Zealand rabbits; but the texture and quality of the fur suggests the use of Angoras. The New Zealand White is a large rabbit with an average weight of 4-5kg, has a substantial built body, well-rounded broad bodied and short, powerful legs. The head is broad with very full cheeks and thick, upright ears. New Zealand Whites have a dense coat of medium-length hair and red-eyed. White is most common or dominant coat colour although grey, black, red and broken pattern are recognised in the USA. They are exceptionally calm and docile rabbits, well noted for their good mothering ability, large litter size (8-12 bunnies) and fast growth rate. Due to its great qualities, many breeding programmes use the New Zealand White rabbit breed as the foundation stock for hybrid rabbits (Ferrand & Branco, 2007; Ferrand 2008; Lebas, 1997; McNitt et al., 2013; Monnerot et al., 1994; Moreki, 2007).



*Figure 3: New Zealand White rabbit breed (Field Data, 2016).*

### **Blue Vienna**

The Blue Vienna happens to be one of the rabbit breeds that is also raised primarily for their meat and fur. It is an old breed believed have been originally bred in Austria in the 19th Century and is the result of crossing the Flemish Giant with older Moravian breeds. The Blue Vienna has soft, silky fur that is generally deep slate blue that lightens to a paler grey on the underside but may also be white or agouti. It is medium-sized with an average weight (3.6-5.4kg), a long body, an average litter size (6-8 bunnies) and a good dressing percentage (about 58%). They are well known for easy acclimatisation and happen to be one of the most popular of all exhibition breeds. (Ferrand 2008; Lebas, 1997; McNitt et al., 2013).



*Figure 4:* Blue Vienna breed of rabbits (Field Data, 2016).

### **Flemish Giant**

The Flemish Giant originated in Belgium and is thought to have been derived from the large Flanders and the Patagonian rabbits. It was originally bred in its wild natural agouti colouring but now has grey, black and white as the main colours. The Flemish Giant which happens to be one of the most popular utility breeds in Europe are also bred for meat and fur. It is the known largest breed of rabbit in the world (7-8kg). They have very long bodies, wide back with well-rounded and solid-fleshed hindquarters, strong powerful legs of average length, with their large ears held in a V-shape above the head. They have a glossy sheen and a dense undercoat, very friendly, calm and docile (Ferrand 2008; Lebas, 1997; McNitt et al., 2013; Monnerot et al., 1994; Moreki, 2007)

### **Dutch**

The Dutch rabbit which happens to be one of the oldest breeds. It is believed to have originated from Holland but was actually bred in Great Britain. It is a descendant of the Petite Brabancon, from the Brabant region in Flanders. It is one of the primary meat breeds, very calm, fairly built, with a well-rounded body and is small to medium in size (2.0-2.5kg). This distinct well-marked out rabbit is coloured from about the middle of the back to the tail, with a straight dividing white line running up the front of the face. The feet and hind legs are white while the head and ears are black. Although the initial breeds were black, many other colours have been introduced via crossbreeding (Ferrand & Branco, 2007; Lebas, 1997; McNitt et al., 2013; Monnerot et al., 1994; Moreki, 2007).



*Figure 6:* Dutch breed of rabbits (Field Data, 2016).

### **Mating Systems in Animals**

Mating systems have basically got to do with how individuals (animals) are grouped in relation to mating and the dynamics involved; the characteristics of mate acquisition or obtaining a partner and the associated mating behaviour. It essentially has to do with how the animals are structured in their sexual behaviour or the process that determines which specific male(s) have the opportunity to mate with which female(s) (Ajayi et al., 2015). Although male mammals in particular have been known to exhibit an array of sexual behaviour (mating bond, defence of the feeding and mating territories or individual receptive females) both sexes naturally exhibit specific sexual behaviour to ensure they succeed in leaving as much progeny as possible in the next generation of animals. This is informed by the number of mates an individual has access to during the breeding season, the ability to mate successfully during the season and to a much greater extent, the environmental

conditions (Bonsall, 2010; Gamble, Lindholm, Endler & Brooks, 2003; Jiang, Bolnick & Kirkpatrick Klug, 2013;).

Mating systems have been known to be very important to genetic improvement because they are behavioural representations of the result of natural selection on mate choice, and they affect the reproductive success of all individuals (.Alvariño, 2000; Alvariño, Del Arco, & Bueno, 2010; Gosling & Roberts, 2001; Isvaran, 2005; Klein, 2000; Rommers, Boiti, De Jong, & Brecchia, 2006; Verga, 2000). This knowledge is highly acknowledged in the matching of males and females from the selected group of animals to ensure the production of animals with higher breeding value. According to Zeveloff and Boyce (1980), mating systems reflect the strategies or approach in maximising individual reproductive success. Mating systems in animal production are broadly categorised under natural (in which there is no human interference in the selection of mating partners) and artificial systems (for which the breeder or farmer has influence on the mating partners).

### **Natural Mating Systems**

Although mating systems have been known to be very dynamic and change through time, mating systems in livestock, depending on the number of partners an individual (animal) has access to and defends during the breeding season have broadly been categorised into three; monogamous, polygamous or promiscuous.

Monogamy or pair bonding is a mating system in which a single male is exclusively bound or paired with another female. This partner exclusivity can last for a breeding season, a little longer or a lifetime. Such animals become life-long and parenting partners. In addition to the shared parental

care, territorial resources are maintained. The challenge with this mating system however is the occasional high fitness cost; for example, when a poor partner is chosen. The system also reduces the potential for genetic variation among the offspring of the female. This is very typical of birds like the dove, parrot, pigeon and some species of eagles (Jiang et al., 2013; Westneat, Sherman & Morton, 1990)

Polygamy is a mating system in which an animal has exclusive relationship with two or more partners during the breeding season. Depending on which of the partners has exclusive relationship to multiple partners. There are two recognised types of polygamy; polygyny and polyandry. Polygyny is a mating system in which a male has exclusive relationship with two or more females. The female is almost entirely responsible for the parental care of the young. The females may associate with the male for varied reasons such as resource availability, attraction and defence or influence. This is very typical of mammals and a few birds and insects (Gosling & Roberts, 2001; Zeveloff & Boyce, 1980). Polyandry on the other hand, is a mating system in which a female has exclusive relationship with two or more males. This system of mating is comparatively rare but it has been found to ensure high reproductive success as it offers the female multiple mating options (Krasnec, Cook & Breed, 2012).

Promiscuity is a mating system in which both males and females have multiple partners. Depending on which of the partners is more successful, it could be polyandrogyny in which case the female mating success is more variable, or polygynandry in which case the male mating is more variable. Very unique of this mating system is the care provided to the young by the

generally fewer available males in the group. This is very typical of apes like the chimpanzees and bonobos (Emlen & Oring, 1997; Gosling & Roberts, 2001; Krasnec et al., 2012).

### **Artificial Mating Systems**

This is a mating system in which the breeder or farmer interferes with the selection of the mating partner and he does so based on the available resources and management decision (Rommers et al., 2006). There are quite a number of artificial mating systems in animals. Notable among them are hand mating, pen mating and artificial insemination.

Hand mating is the commonest artificial mating system employed in farm animals like rabbits, grasscutters and pigs. The males and females are often kept in separate pens or cages. Very typical of the system, unlike in the natural mating system, the farmer or breeder determines which sire is mated to which dam. In this system, a dam (or vice versa) is brought at a specific time primarily for mating. Not only does this allow the farmer to decide which animal gets the chance to leave its progeny in the next generation of animals but also eliminates unhealthy social competition. It allows for better timing of the servicing in order to allow the sires' fertility to be at its peak with each subsequent mating (Ajuogu, Herbert & Yahaya, 2015; Westneat, 1990)

Pen mating is a mating system in which one or more dams are placed in a confined pen with one male for a period of time. In this practice, the dam is brought to the sires' pen and is serviced at will. It is commonly practised in monogastrics (Levis, Reese & Ness, 2011).

Artificial insemination (AI) is the process of collecting active or living sperm cells from a sire and manually depositing them into the reproductive



tract of a dam. AI happens to be the most extensively used artificial mating system in recent times. This has been attributed to the several benefits or advantages it offers over natural mating which is more stressful. Increased efficiency has been one of the key benefits of AI (the possibility of using a single dam for breeding purposes and not requiring the physical presence of the sire on the farm either). There is also reduced risk of genital and non-genital infections and disease transmission, improved genetics due to the opportunity to use only sires of superior genetic merit, and reduced postpartum interval. The approach however requires skill and special equipment. It is also time consuming, quite laborious compared to natural mating, and there is selective advantage only if the best male is accurately determined (Ajuogu et al., 2015; Dimitrova, Angelov, Teneva, & Uzev, 2009; Jiang et al., 2013)

### **Breeding Strategies in Livestock Production**

Since the era of animal domestication, man has continuously observed some degree of variation in the performance of animal species. The practice or approach to animal breeding, is linked to their domestication since humans primarily selected and kept animals that met their needs (Blasco, 2013; Carneiro et al., 2011; Carneiro et al., 2014; Monnert et al., 1994). Although humans have contributed significantly to selection through intuitiveness or what best served his interests, it is interestingly to note that it is one natural phenomena which is not peculiar to domesticated animal species but those in the wild as well ( Queney et al 2002). To a greater extent, these variations have been both specie and environment or agro-ecology specific, depending on the genetic make-up.

According to Adenaike et al. (2013), the species' genetic make-up informs its fitness and ability to adapt to the prevailing environmental or climatic conditions; and more importantly, its ability to tolerate, survive, develop and reproduce. It is quite obvious that at the core of this variation in the performance of domesticated animal breeds (as informed by their genetic make-up) is the change in the gene frequency and the degree of heterozygosity in a given population. This variation is influenced by either uncontrolled or deliberate selection of animal breeds over a period of time for adaptation to specific environmental condition (Abdel-Hamid, 2015). The changing climate which has been characterised by increased pest and disease, extreme temperatures, drought, flooding and poor seasonal nutrition has necessitated the need to develop and adopt efficient breeding systems. Moreover, the ever-increasing demand for superior animal species or breeds, products and services have justified the need to identify, select and give the opportunity to the well adapted and best performing breeds of animals to produce the next generation.

Animal breeding as a discipline is basically concerned with the production of superior animal breeds. It is the process of strategic and purposeful or selective mating of domesticated animals with desirable genetic traits aimed at either maintaining or improving such traits in the next generation. In very basic terms, animal breeding has got to do with producing improved breeds of domesticated animals by improving their genotypes through selective mating; that is, producing new or superior breeds of animals with improved or increased productivity, resistance to disease and high adaptability to specific agro ecological conditions, etc. This is achieved

through improving their genotypes through selective mating or identifying and introducing unique and desirable traits in domesticated animals (Kabir et al., 2014; Piles, Rafel, Ramon & Gómez, 2010). The deliberate selection of animals in different environments and for different traits has been the basis for modern animal breeding. With respect to livestock, this involves principally, the accurate estimation of the genetic value of the individual traits that are of interest to the breeder. The impact of this deliberate selection of animals (animal breeding) has been found to be very effective and economical (Abdel-Hamid., 2015; Adenaike et al., 2013; Piles et al.)

### **Types of Animal Breeding**

According to Leymaster (2002), the diversity in animal breeds offers producers the opportunity to identify and use breed(s) that perform at a level consistent with the marketing goals and production resources such as the availability of feed, labour, facilities and managerial skills. Depending on the set objective(s) of the breeder, a breeding method or approach is adopted. There are principally three methods of breeding; inbreeding, line breeding and crossbreeding.

#### **Inbreeding**

Inbreeding is primarily the crossing of best performing and closely related animals over a period of time. It has been identified as one of the best methods of improving the performance of animals. Inbreeding is primarily aimed at conserving or maintaining the integrity of superior genes and is thus often used in the development of pure breeds mainly for breeding purposes. It also happens to be one of the best options for the re-creation of breeds that are

near extinction as well as in the creation of entirely new breeds. Due to the considerable number of the desirable traits that are maintained or preserved in the selected animal, it makes it neither laborious nor time consuming (Carneiro et al., 2012; Piles & Blasco, 2010; Piles et al., 2010). However, with the continuous transmission of the superior genes to the next generation of animals, homozygosity is increased.

### **Effects of Inbreeding**

Inbreeding makes more pair genes homozygous regardless of the kind of gene action involved. That is, inbreeding does not change the gene frequency in the population, but causes an increase in the frequencies of the homozygous genotypes and a decrease in the heterozygote genotypes (Charlesworth, 2003; Edmands, 2007). It is thus a useful tool in the detection of carriers of recessive genes and in the development of pure or inbred lines. However, inbreeding can expose the recessive genes which were previously concealed in the heterozygous state. Such genes normally have undesirable effects on the traits, a condition often referred to as inbreeding depression (Kristensen, & Sørensen, 2005). Inbreeding depression is the gradual lowering in the performance of traits due to the interaction of homozygous recessive genes and is normally seen in characters like fertility, growth, survival and size (Nagy et al., 2012). Such interactions, most often than not, negatively impact the animals' performance. Hybrid vigour, fertility and productivity are adversely affected in such breeding programmes (Iraqi, Afifi, Baselga, Khalil & García, 2008).

This adverse effect of inbreeding can however be curbed or corrected via selection; mating with either another superior from an unrelated breeding

population or by the prudent culling of animal breeds exhibiting the negative effects (Iraqi et al., 2008; Kristensen, & Sørensen , 2005; Ragab, Sanchez & Baselga, 2015).. In a situation where the breed is relatively free of such deleterious recessive genes, although that is quite rare, the process can continue. Considering the effects of the extremities or intensification of inbreeding, it becomes very essential to be particularly critical in the selection of breeds and more importantly, when it becomes the only option or means of obtaining the set breeding objective(s).

### **Line Breeding**

Line breeding is a milder form of inbreeding that involves the mating of animals that are related by a common ancestor, but are not closely related. Considering the advantage it offers in the production of more consistent progeny, a thorough knowledge of the pedigrees of the parents, particularly the desired sire, are key in maintaining the desired breeding objective. This is due to the comparative advantage of the sire in passing the desired trait to more offspring than the dam would. This system of breeding helps in maintaining the uniformity of the trait without succumbing to the effects of inbreeding or outbreeding (Assan, 2014; Bijma & Woolliams, 2000; Charlesworth & Willis, 2009; Osei et al., 2012; Ragab et al., 2015).

### **Crossbreeding**

Crossbreeding is the mating of individual animals from two or more different breeds or genotypes. It is principally aimed at combining and producing some valuable traits in the new breed or crossbred. That is, the primary objective of crossbreeding is to essentially produce a comparatively

better or superior animal with increased and enhanced performance, as well as greater adaptability to variable and difficult environmental conditions. This is achieved through their ability to take advantage of hybrid vigour (a merge up of the distinct traits of the parents in the progeny) which often manifests as an improvement in fitness, growth and fertility traits (Abdel-Hamid, 2015). To a much greater extent, this primary objective of crossbreeding is only realised when the breeds are able to successfully combine their unique and desirable traits, such that the crossbred is comparatively better or superior to the pure breed parents (Alves et al., 2015; Blasco, 2013; Thornton, 2010; McAllister, 2002). It has been established that, this superiority of the progeny relative to the parental groups is also due to their ability to successfully combine their unique traits; this is attributed to the complementary paternal and maternal effects, changes in the non-allelic interaction and increased heterozygosity. This is however dependant depending on how genetically distinct the two parental breeds used are or may be.

Ajayi et al. (2015) reiterated that the optimisation of crossbreeding; increased heterozygosity due to the effect of nicking ability or interbreeding, is achieved when the breeds or genotypes used are distinctively unique from each other. This is in spite of the fact that very similar breeds or genotypes equally make genetic contributions to the progeny that is produced. Hakima et al. (2013) together with other authors (Iraqi, Ibrahim, Hassan & El-Deghadi, 2006; Lalev, Mincheva, Oblakova, Hristakieva & Ivanova, 2014, Piles et al., 2010) have confirmed crossbreeding as one of the fastest approaches that breeders have over the years used to improve various economic traits in livestock. However, the system is quite expensive because the comparative

advantage or superiority of the hybrid or crossbred over the parents is maintained until the hybrids are mated inter se. This implies that parental stock of the pure breeds must be maintained from time to time to ensure that the desired hybrid vigour or heterosis in the crossbred is maintained.

Crossbreeding has also been identified as a tool that has also contributed to the formation of new “composite” breeds from a combination of pre-existing breeds selected for superior adaptation (Iraqi et al., 2008; McAllister, 2002). It is likewise an opportunity for incorporating climatic adaptability and performance (reproductive and growth) traits in the crossbred that is in harmony with the production environment and market requirements. The system has offered a much better alternative for improving on performance of local or exiting breeds compared with the introduction of high performing foreign breeds into new environments (García et al., 2010; Jaouzi et al., 2004; Kahi, Rewe, & Kosgey, 2005; Lalev et al., 2014). Not only does crossbreeding help in improving the performance of poor performing local breeds particularly in the developing economies in the tropics, but an avenue to ensure the preservation of valuable genetic resources; for instance, disease and pest tolerance. This is because the introduction of improved breeds into new agro-ecological zones for instance can result in the wiping out of the poor performing but genetically adapted existing breeds.

### **Crossbreeding Approaches**

The primary objective of crossbreeding has been to improve on the performance of a comparatively poor performing existing or local breed and thus increase heterozygosity. Depending on the objective of the breeder or

farmer, the crossbreeding can take varied approaches. Notable among them are outbreeding, outcrossing, grading-up, rotational crossing and crisscrossing.

### **Outbreeding**

This basically involves the crossing of distantly related animals, or animals that are less closely related than the average of the population from which they came. Owing to the different backgrounds or purpose of the breeds that are often used in outbreeding, it has been viewed as one of the surest means of widening the genetic and phenotypic variation of any population (Weaver, 2015). This has actually been one of the best means of not only ensuring an enhanced general fitness and adaptability of newly introduced breeds, but to also step up the performance of existing breeds (Dayo et al., 2009; McAlister, 2002). However, a major challenge has got to do with the introduction of new genes into the population. This can delay or frustrate the breeding objective(s) considerably (Snelling et al., 2010)

### **Outcrossing**

This is the mating of either unrelated animals, or animals within the same breed but without a common ancestor within at least 4-6 generations. Outcrossing helps in introducing some new genetic variation into the existing stock. Ultimately, the desired genetic diversity is maintained. It has been identified as the best breeding method for animals that are below average in productivity (Chamberlain., 2012; Grisart et al., 2002). Although crossbreeding is aimed at increasing the degree of heterozygosity in the flock or herd, the uniformity of the outcrossed F1 can be considerably conspicuous, depending on the extent of inbreeding in the existing flock; this is however, not very consistent. Much as outcrossing is not a surety or guarantee against



genetic disorders, the degree of hereditary disorders, such as inbreeding depression is reduced (Chevalet & Gillois, 1978; Schirm, 2007; Notter, Sanders, Dickerson, Smith, & Cartwright, 1979).

### **Top-crossing or Grading-up**

Top-crossing or Grading-up is a crossbreeding system or approach in which the purebred males of a particular proven breed are crossed with indigenous females. The female crossbred are continuously bred with the purebred males of that proven breed over a season. Depending on the value or quality of the indigenous female, offspring of the F<sub>2</sub> exhibits 75% of hereditary material of the proven breed, and the proportion of inheritance of the indigenous breed is halved in each subsequent generation (Gandini, Pizzi, Stella, & Boettcher, 2007). This system of crossbreeding ensures rapid transformation of the indigenous breed to the desired pure breed. This approach is normally used when a few individual males of the desired breed are available (Gosey 2005; Kahi et al., 2005; Weaber, 2015).

### **Rotational Crossing**

Rotational Crossing is a crossbreeding system which systematically uses three or more breeds. For instance, in a rotational cross involving three breeds (A, B and C), breeds A and B are crossed, and the crossbred AB female is crossed by C. The sequence is repeated with males of A, B and C and this sequence ensures that the offspring continues to have 57%, 29% and 24% of the immediate, second and third sire respectively (Gandini et al., 2007; Kahi et al, 2005; Olson, Peacock & Kog, 1993). Unlike the other approaches, this system of crossbreeding requires only sires of pure breeds and it has been found to be very efficient for species with low reproductive rates and facilitates the use of

sires of the crossbred females (Syrstad, 1996). However, the management system can be quite complex, considering the number of males or semen from males that would be required. Unlike the other forms or approaches, it can neither be practised on the framers' farm, backyard or under smallholder conditions (.Leymaster, 2002, Madalena, 1993; McAllister, 2002; Schirm, 2007). It is carried out at research stations

### **Crisscrossing**

Crisscrossing is a crossbreeding system in which males of the pure breed are alternately crossed with the crossbred females. This system requires just two pure breeds because it fully exploits hybrid vigour, and has been found to be very productive. This system of breeding, just like rotational crossing, inhibits gene recombination. It is however demanding, requires considerable space in a situation of natural servicing, and can likewise not be practised on the farmers' farm (Leymaster, 2002; Schirm, 2007).

### **Effects of Crossbreeding**

Crossbreeding which involves the use or mating of at least two distinct pure breeds has a comparative advantage (increased production levels) over the use of a pure breeding (Abdel-Hamid, 2015; Alves et al., 2015; Blasco, 2013; Kahi et al., 2005; Lalev et al., 2014; Piles et al., 2010; Piles, Tusell, Lavara, & Baselga, 2013; Thornton, 2010). It has been identified to offer two primary or distinct advantages. These are (i) heterosis or hybrid vigour; the increase in performance of an offspring above what is expected on the average of its parents and (ii) breed complementarity; the ability to combine desirable characteristics or traits of two or more breeds into one animal.

## Heterosis

Breeders have over the years exploited heterosis by mating two different pure-bred lines with unique and desirable traits so that such admirable traits will be shown in the products or progeny of the first generation. It has actually become an acceptable approach or means of enhancing the performance of most local breeds. Heterosis has been variously defined to mean basically, the comparative advantage in performance that crossbred animals express above the average of the purebreds. Baranwal, Mikkilineni, Zehr, Tyagi and Kapoor (2012) explained that heterosis or hybrid vigour is a phenomenon that describes the survival and performance superiority of a hybrid offspring over the average of both its genetically distinct parents. A number of authors (Goldman, 1999; Hallauer, 1997; Lamkey & Edwards, 1998) among others have established that Shull in 1914 coined the term to refer to an increase in vigour or other related traits which are usually associated with fitness such as yield, tolerance, resistance, fertility, growth rate etc. Shull (1952) later indicated that the physiological vigour of an organism as manifested in its rapidity of growth, its height and general robustness, is positively correlated with the degree of dissimilarity in the gametes by whose union the organism was formed. According to Kaeppler (2012) and Baranwal et al., heterosis is the increase in vigour that is observed in progenies of mating diverse individuals from different species, which may either be isolated populations or selected strains within species or populations. To an extent, heterosis is the measure of the degree of difference between the average performances of the progeny or the crossbred and that of the parents which is not always revealed by the phenotypic study of the pure breeds. It is

primarily the phenotypic superiority of a hybrid over its parents with respect to traits such as growth rate, reproductive success and yield (Madalena, 1993; Rege, Marshall, Notenbaert, Ojango & Okeyo, 2011). Heterosis has actually been found to be the ideal means of improving on reproductive traits such as conception rate, mothering ability and growth rate, which have been known to be lowly heritable (Auldish, Pyman, Grainger & Macmillan, 2007; Charlesworth, 2003; Charlesworth and Willis, 2009 Piles et al., 2013; Schiermiester, Thallman, Kuehn, Kachman, & Spangler, 2015).

One of the primary objectives of most crossbreeding programmes have been the maximisation of heterosis, or the performance of the crossbred being comparatively better or superior to that of the purebred parents. This has been extensively exploited in a number of crossbreeding programmes in both plants and animals for different economic traits, and the results have been very impressive in most instances (Abdel-Hamid, 2015; Al Lawati, Pierce, Murray & Ray, 2010; El-Bayomi, El-Tarabany, Abdel-Hamid, 2012; Fayeye, 2013; García, 2010; Ouyed & Brun, 2008). In order to satisfy this primary objective however, it has been advised to ensure that the parental breeds that are crossed are as much as possible genetically 'clean' and distinct or divergent (Bahari, Rafii, Salh & Latif, 2012; Baselga, García, Sánchez, Vicente, & Lavara, 2003; Willham & Pollak, 1985, Sprague, 2013). That is, there is the need to ensure the genetic purity and distinctiveness of the pure breeds that are to be crossed. This is due to the fact that heterosis is not heritable or passed on from parent to progeny.

Although heterosis can impact a number of traits, it has actually been identified as the ideal or best means of improving economic traits with poor

heritabilities (Gosey, 2005; Khalil & Bolet, 2010; Madalena, 1993; Mocé & Santacreu, 2010). Heterosis is thus maximised via a well-planned and monitored crossbreeding programme. However, the basis of assessment have been found to be biased. In reality, aside the performance of the crossbreds being an improvement on the parents' performance, these crossbreds are normally raised and assessed in a comparatively more favourable environment (management, housing, nutrition, etc.) that ultimately offers them a comparative advantage. It is quite obvious that the performance of such crossbred cannot be entirely attributed to the animals' own performance. Strictly speaking, the optimisation of hybrid vigour can only be confirmed or ensured when both the parents and the progeny of the crossbred have been assessed under a common or same environment, and the data has been collected concurrently. This is in appreciation of the effects of some environmental factors such as year, season, parity, feed, housing and their interactions on the animal's performance (Apori et al 2014; Dalle Zotte & Paci, 2014; Fayeye & Ayorinde, 2010; Ghosh et al., 2010; Lazzaroni et al., 2012; Rege et al., 2011; Tuma et al., 2010).

Both animal and plant breeders have confirmed that for almost all the economic traits, hybrid vigour is maximised in the F1 because a backcross with either of the parents, records a decline (Madalena, 1993; Mocé & Santacreu, 2010; Willham & Pollak, 1985). Several studies of heterosis have revealed that heterosis is not only enhanced or higher when the parents used in the crossbreeding are as much as possible genetically distinct or unique in the traits of interest, but also for traits that are lowly heritable and, in such animals with higher combining abilities. It is quite obvious that to an extent, hybrid

vigour is proportional to the number of dominant genes that are contributed by the parents (Demuth, & Wade, 2005; Kaeppler, 2012; Khalil & Bolet, 2010; Lalev et al., 2014; Taha & El-Ghany, 2013; Ouyed & Brun, 2008; Ouyed, Rivest, & Brun, 2011).

### **Estimation of Heterosis**

Mathematically, heterosis can be defined as the difference in the performance between the average of both reciprocal crosses and the average of the two corresponding pure breeds or lines. This may be expressed either as a (i) fraction,  $H = \frac{AB - (0.5A + 0.5B)}{(0.5A + 0.5B)}$  or as most often than not been the case, as (ii) a percentage,  $H\% = \frac{AB - (0.5A + 0.5B)}{(0.5A + 0.5B)} \times 100$ , where A, B and AB are the mean performance of parents A, B and the mean performance of the F1 crossbred respectively. However, heterosis can is often estimated in three different ways depending on the basis or point of reference in assessing the performance of the crossbred or hybrid. These are the mid-parent, better parent and standard heterosis

Mid-parent heterosis is when the heterosis is estimated over the performance of the mid parent. It is also known as average heterosis or relative heterosis and it is calculated by using formula,  $H\% = \frac{F1 - MP}{MP} \times 100$  where F1 is mean of the crossbred and MP is the mean of the two parents (Rasul, Khan & Ali. 2002).

Better parent heterosis is when the heterosis is estimated over the better parent. It is also known as heterobeltiosis and it is calculated by using

formula,  $H\% = \frac{F1-MP}{BP} \times 100$  where F1 is the performance of the crossbred and BP is the mean of better parents (Rasul et al., 2002)

Standard heterosis refers to the superiority of F1 over the standard breed. It is also called as economic heterosis or useful heterosis and it is calculated by using formula,  $H\% = \frac{F1-Check}{Check} \times 100$  where the check is the mean output of the standard commercial breed and the F1 is the performance of the crossbred (Rasul et al., 2002)

### **Types of Heterosis**

It is worth noting that heterosis which is otherwise referred to as hybrid vigour can be either positive or negative and depending on the economic benefit trait(s) being considered, it may be desirable to either positive or negative heterosis. Positive heterosis results when the average performance of the crossbred or the progeny of the cross is found to be comparatively better than the average of both parents. Negative heterosis on the other hand, is when the average performance or output of the offspring is comparatively lower or worse than the average performance of the two purebreds. According to (Baselga et al, 2003), there could also be zero or absence of heterosis. This arises when the breeds or lines that are crossed are either genetically close or related or the frequencies for the genes affecting the trait under consideration are either low or very close. Even in such instances or scenarios the crossbred or progeny is known to have the added benefit of complementarity compared to the parents based on theory of dominance for heterosis (Kaepler, 2012; Khalil & Bolet, 2010). As much as the primary objective of animal breeders have always been to achieve 'positive' heterosis for most economic traits,

what is often measured as hybrid vigour have under some situations been found to be erroneous (Kaepler).

### **Forms of heterosis**

Heterosis can take three forms relative to the nature of the trait considered in the study. These are the individual, maternal and paternal heterosis.

Individual heterosis is the superiority of the crossbred progeny or the advantage of the crossbred individual relative to the purebred individual. Individual heterosis is revealed in enhanced weight at weaning, growth rate and carcass traits (Madalena, 1993; Ouyed & Brun, 2008; Schneider, 1978)

Maternal heterosis is the combined improvement in traits from the dam that positively contributes to her performance and an enhanced performance of its progeny. That is, the advantage of the crossbred dam over the average of the purebred dam. Maternal heterosis results in better reproductive traits such as litter size at birth and at weaning, milking ability, the age at sexual maturity and maternal ability of the crossbred dam (Ouyed & Brun, 2008; Schneider, 1978).

Paternal heterosis is the basically improvement in productive and reproductive characteristics of the sire or the advantage of the crossbred sires over the average of the purebred sire. The effect of paternal heterosis is felt only on conception and the potency of the sire. It is quite obvious that unlike individual heterosis which is measurable in both sexes, maternal and paternal heterosis are sex limited (Madalena, 1993; Schneider, 1978)

### **Breed Complementarity**

Aside heterosis which ensures increased heterozygosity in any given population, breed complementarity has been known to be the other added



advantage crossbreeding offers in livestock production. Complementarity in very simple terms is when two or more desirable traits identified in two distinct breeds or lines are incorporated in the crossbred. Studies over the years have demonstrated that each breed of animal may exhibit some level or degree of superiority in a trait(s). It thus makes it very rare, if not impossible, to have an excellent breed irrespective of its degree or level of superiority. To ensure the optimum benefit, the crossing is designed to mask the weakness of the breeds and thus capitalise on or merge the unique traits or superiority of the different breeds in the crossbred that is produced. Thus, complementarity is attained when the breeds that are crossed successfully exploit their relative traits to realise maximum efficiency of production. For instance, a breed (sire) with very good growth and carcass traits is mated to a breed (dam) with good maternal qualities (high litter size, high milk yield and mothering ability) to ensure fast growth and high litter size at weaning of its bunnies. Alternatively, a medium-size breed with good maternal traits is crossed by a large-size breed so that their unique abilities are realised in the crossbred (Assan, 2013; Cassel, 2009; El-Bayomi et al., 2012; Leymaster, 2008; Piles & Baselga, 2012, Piles et al., 2013)

It is quite evident that breed complementarity has basically got to do with the ability of the crossbred to combine the strengths or advantages of the different parental breeds used. In principle, it offers the breeder the chance to capitalise on the advantages of the different breeds that are crossed. As earlier established, the crossbred produced however, will not outperform the parent breeds in all the identified economic traits. This actually forms the basis of crossbreeding programmes involving local or indigenous breeds and exotic

breeds. In most of the crossbreeding programmes involving indigenous breeds that are for instance highly adaptable to the existing climatic or environmental conditions, and the highly productive exotic breeds, the crossbred that is produced ends up combining both unique traits in the parents. The crossbreds produced from such crossbreeding programmes are comparatively highly adapted and productive under the existing or prevailing local conditions compared to the exotic and the local breeds respectively. The breeds are said to complement each other by contributing their unique or desirable traits in the crossbred produced. It should however be noted that when the crossbreeding is not well planned or structured, just like heterosis, complementarity can have detrimental effects on productivity (Fargione & Tilman, 2005; Piles et al., 2013; Tilman & Snell-Rood, 2014)

### **Diallel Crossing**

There are quite a number of possible crosses a breeder can adopt based on the primary objective(s) of the breeder, the reproductive biology of the species and the available resources such time, number of animals, skill or exposure. For best results however, the breeder has to carefully consider the breeds that would make significant contributions to the objective. The most extensively used cross breeding approach in livestock unlike crops has been diallel crossing. Diallel crossing is genetic design employed in the study of quantitative traits that are polygenic in nature. According to Viana, Cruz and Cardoso (1999), it is a mating scheme or design that permits all the possible crosses among a group of parents or genotypes being considered. It has actually been found to be an important tool used in evaluating the performance of breeds in their various combinations, especially for those breeds already

indigenous to the agro-ecological area (Dickerson, 1992; Syrstad, 1996). Schmidt is credited as the first to use diallel cross in animal breeding when crosses were made between two males and two females at different times (Sughrue, 1995). According to Adenaike et al. (2013), it has actually become a common method of analysing genetic variability among combinations of breeds and their crosses. It is currently acknowledged as a standard procedure in genetic research.

The theory and statistical analysis of the diallel mating design since its introduction has been investigated in-depth by several outstanding researchers. Notable among them is Griffing, a leading authority on the subject who in 1956 developed four models that can be used in analysing diallel crosses. This is informed by the categories or the classes of animals used in the evaluation; parents, their reciprocal crosses or both. Kempthorne and Curnow in 1961 also developed the partial diallel, while Gardner and Eberhart developed a model to investigate the genetic properties of open-pollinated varieties and their crosses in 1966. Depending on the objectives of the breeder, the resources his/her disposal (time, experience and number of breeds involved), how the animals are mated and the type of data to collect, diallel cross or mating has been broadly categorised into four (Griffing, 1956; Hayman, 1958; Kempthorne & Curnow, 1961; Syrstad, 1996). These are the (1) Full diallel in which parents, crosses and reciprocals are involved, (2) Full diallel involving only the crosses and the parent, (3) Half diallel involving parents and reciprocals and (4) Half diallel involving only the crosses. Considering the fact that all the available breeds are crossed in all the possible combinations in a full diallel, it is

practically feasible when a few breeds are considered; while the half or partial diallel makes it possible to increase the number of parents used.

Due to the varied information this genetic design provides on the breeds involved, it actually makes it possible to estimate heterosis among the various breed combinations, the general and specific combining abilities of the breeds, inheritance of traits and the identification of superior breeds among others (Adenaike et al., 2013; Al Lawati et al., 2010; Ramos et al., 2006; Syrstad, 1996). Such information are relevant in taking very objective decisions in the various improvement programmes (Ghosh & Das, 2004; Saadey, Galal, Zaky, & El-Dein; 2008). The diallel mating system has not only been found to be unique and ideal for the evaluation of existing indigenous breeds, but also for a limited number of breeds chosen on the basis of top-cross evaluation (Kabir et al., 2012). A number of studies on economic traits of livestock within the tropics in recent times have explored the benefits of diallel crossing (Razuki & Al-Shaheen, 2011; Taha & El-Ghany, 2013; Zeferino et al., 2013).

### **Combining Abilities**

As earlier mentioned, one of the benefits the diallel cross has offered breeders in general has been the ability to estimate the combining abilities. It is actually a basis of establishing the breeding value of an animal or breed because a good estimation of the combining ability suggests the appropriate use of the line or breed in a breeding programme (Olfati, Samizadeh, Rabiei & Peyvast, 2012). Combining abilities defined as the ability of parents to combine among each other valuable or favourable traits or genes during the process of fertilisation, so that the most favourable genes or characters are

transmitted to their progenies. According to (Amin, 2015, El-Bayomi et al., 2012; Lalev et al., 2014; Olfati et al.), the combining abilities in no uncertain terms provide useful information on the best lines, breed, genotype or strain combinations required for optimum performance of the crossbred animal and the best combiner that exhibits the highest heterosis or hybrid vigour. It is thus obvious a good estimation of the combining ability could guarantee or be the basis for determining the value or usefulness of the purebred in the hybrid combinations or diallel cross, particularly in the F1 generation.

General Combining Ability (GCA) has been defined as the average performance of an inbred line or individual in a series of hybrid combinations or the performance of all the crosses derived from a particular breed (Sprague, 2013). The GCA gives a description of the parents' ability to transfer a trait averagely to its half-sib progeny. In other words, it is the deviation of the mean performance of a line from the mean of all crosses. That is, it is an indication of the ability of the inbred line or purebred to combine with the other breeds; this helps in the identification and the selection of the best genotype to use in crossbreeding programs as parents (Bora et al., 2010; Griffing, 1956; Kabir et al., 2014; Ramos et al., 2006). Kabir et al. (2014) applied the principle of the GCA in the identifying the best parents for the for fast growth rates in rabbits. Kabir et al. (2012) among other authors had earlier identified the best parents for litter traits in a 3 X 3 diallel cross in rabbits.

Specific Combining Ability (SCA) on the other hand considers the performance of an inbred or purebred in a particular cross or the combined attribute of the two breeds. According to Griffing (1956), it is the genetic interaction of the two parents which manifests in the full-sib progeny. It is

actually a measure of the uniqueness of the crossbred to its parents, or how a crossbred performs better than expected, based on average performance of the breeds or lines involved. That is, the SCA contributes significantly in the identification and selection of the best cross combination on the basis of the desired output or product. Kabir et al. (2012) for instance have used the principle of SCA in identifying the best crossbreds for litter traits in 3 X 3 diallel cross. Similarly, Bora et al. (2010) applied the principle in the assessment of growth performance in some rabbit crossbreds. Adebambo et al. (2010) also employed the principle of SCA in identifying the meat type chickens (crossbreds) with the best carcass traits.

Since the domestication of livestock species, there has been a number of successful interventions (selection, breeding, improved nutrition, housing, and healthcare, etc.) primarily aimed at meeting the specific needs of man. These interventions have however not been devoid of setbacks (inbreeding depression, loss of viability, wiping out of genetic resources). Nonetheless, the search for safe and appropriate technologies or approaches have continued. It is quite obvious that crossbreeding has been one of the safest and efficient means of improving the performance of livestock species in both developed and developing economies particularly in sub-Saharan Africa. Crossbreeding has contributed tremendously in managing the challenge of poor adaptability in high performing exotic breeds in new environments. It also offers the opportunity to introduce useful economic traits (high litter size, fast growth rate, heavier bunnies) in the highly adapted local but poor performing breeds. The diallel which offers the possibility of all pairwise crosses have become a useful tool in this regard as it offers the opportunity to select various cross

combinations for specific economic traits or benefit. Nonetheless, for optimal results (better heterotic effect), there is the need for a careful and proper planning; thorough screening of breeds (local and exotic) within the agro-ecological area. That would not only help in establishing the genetic background of the local breeds in particular and their unique traits, but the preservation of valuable genetic resources.

## CHAPTER THREE

### METHODOLOGY

#### Location of the Study

Data for the study were obtained from the Rabbitry of the Farmer Brown Livestock Farm, a private breeding farm situated at Amanfro in the Awutu-Senya District of the Central Region of Ghana. Data from three main breeds; the Blue Vienna, New Zealand White and Chinchilla, and their crosses, were studied. All the animals were reared on the farm under similar management conditions. The climate in the study area was generally hot, semi-arid and tropical in nature, with an average annual rainfall of between 400mm and 500mm, mean annual minimum and maximum temperatures of 22°C and 28°C respectively.

#### Source of Animals

The New Zealand White, Blue Vienna and the Chinchilla which constituted the base population for the study were obtained from the Animal Research Institute (ARI) of the Council for Scientific and Industrial Research (CSIR) at Amrahia in the Greater Accra Region. The replacement bucks were however secured from good and reputable farms from Togo and Cote D'Ivoire. This strategy of obtaining the replacement bucks from reputable farms from neighbouring Togo and Cote D'Ivoire was primarily aimed at reducing the effects of inbreeding to the barest minimum



## Management of the Experimental Animals

### Housing

The rabbits were housed in cages under open-sided roofed structures. Each breeding does were provided with nestling boxes in their cages. The litters were fed and watered together until the bunnies were weaned at six weeks. The weaned rabbits were however kept in groups of four and five in standard galvanised iron cages measuring 75 X 45 X 35cm, and were managed in a similar manner. The breeding buck were however kept individual cages. No artificial light was provided.

### Feeding and watering

In the morning, pelleted feed containing 19% crude protein and 2400 kcal per kilogram of feed metabolisable energy was fed to the rabbits at the rate of 75  $\text{gd}^{-1}$  up to the 6th week of age; and 100 $\text{gd}^{-1}$  from the 7th up to the 12th week of age. Relative to the body weight and litter sizes, the lactating does were offered 200 to 250  $\text{gd}^{-1}$  of the pelleted feed. The rabbits were fed from earthenware bowls. In ensuring that the lactating does were well nourished to provide the needed nutrition for the bunnies, the does were fed *ad libitum*. The does were supplemented with some nutritious green fodder and shrubs like *Moringa oleifera*, *Desmanthus virgatus*, *Euphorbia sp* and *Megathyrsus maximus* late in the afternoon. Fresh, cool and clean drinking water was provided from nipple drinkers *ad lib*. A standard prophylactic endo- and ectoparasitic control schedules were strictly followed to ensure that the rabbits were always in good condition.

## **Mating**

The experimental rabbits consisted of straight or main and their reciprocal crosses generated from the crossing of the three different breeds. Thirty does (comprising ten does per breed) with an average age of 24 weeks and weighing 1200 g, and six bucks (comprising two bucks per breed) with an average age of 24 weeks were selected. They were however made to begin their reproductive life when they were 25 weeks averagely. The hand mating system was employed in the mating of the rabbits and a mating ratio of a buck to five does was maintained. The males and females were randomly selected from each of the breeds and used as parents. The mating was well strategised to ensure that the principle of a complete diallel cross which gave an opportunity for each of the rabbit breeds to become a parent. The breeding bucks were culled after a year of reproductive function while the does were replaced after two years of reproductive function. In a bid to also ensure that the does were not stressed unduly, their breeding was strategised to ensure that a doe kindled five times in a year. The bunnies from these crosses were classified according to the genotype/ breed of the sires and dams.

### Categories of Main Crosses

#### 1. New Zealand White X Blue Vienna

NZ

X

BV



X



*Figure 7: New Zealand White buck*    *Figure 8: Blue Vienna doe*

#### 2. Blue Vienna X Chinchilla

BV

X

CH



X



*Figure 9: Blue Vienna buck*

*Figure 10: Chinchilla doe*

#### 3. Chinchilla X New Zealand White

CH

X

NZ



X



*Figure 11: Chinchilla buck*

*Figure 12: New Zealand White doe*

### Categories of Reciprocal Crosses

#### 1. Chinchilla X Blue Vienna

BV                      X                      NZ



X

Figure 13: Chinchilla buck

Figure 14: Blue Vienna doe

#### 2. New Zealand White X Chinchilla

NZ                      X                      CH



X

Figure 15: New Zealand White buck

Figure 16: Chinchilla doe

#### 3. Blue Vienna X New Zealand White

BV                      X                      NZ



X

Figure 17: Blue Vienna buck

Figure 18: New Zealand White doe

### Categories of Pure Crosses

#### 1. Chinchilla X Chinchilla

CH

X

CH



X



Figure 13: Chinchilla buck

Figure 14: Chinchilla doe

#### 2. New Zealand White X New Zealand White

NZ

X

NZ



X



Figure 15: New Zealand White buck

Figure 16: New Zealand White doe

#### 3. Blue Vienna X Blue Vienna

BV

X

BV



X



Figure 17: Blue Vienna buck

Figure 18: Blue Vienna doe

### **Source of Data**

Secondary data on eight hundred and eight (808) purebred bunnies kindled from 60 litters and one thousand, two hundred and five (1,205) crossbred bunnies from 86 litters used for the study were secured from the rabbitry unit of Farmer Brown. The crossbred group was made up of 800 and 405 bunnies from the “straight” (or “main”) and the “reciprocal” crosses respectively. That data secured for the study comprised of a total of two thousand and thirteen (2,013) offspring bred from 2010 to 2014 in five parities.

### **Data Collection**

Data on the reproductive performance of the three main breeds, and their crossbreds, in terms of litter size at birth and at weaning, age at sexual maturity, kindling interval and the percent mortality were determined. Likewise, growth performance data from the pure breeds and their crossbreds in terms of bunny and litter weights at birth and at weaning, bunny weight at 8, 10 and 12 weeks respectively, as well as the pre-and post-weaning growth rates under the prevailing environmental conditions were determined. The age at first kindling was calculated as the age at which the doe had its first bunnies, while kindling interval was calculated as the time that elapsed between two successive kindling. Gestation length was determined as the period between conception and kindling. Litter size at birth and weaning were determined by counting the number of bunnies per litter. The bunny weights at birth in each litter were obtained within twenty-four hours after kindling. The bunnies from a doe from a particular kindling cage were carefully picked with gloved hand and weighed on a 500g capacity top-loading balance. The litter weight was determined as the weight of all the bunnies from a particular doe

per kindling. The weaning weight was however taken individually when the bunnies were weaned using a 2.0 kg capacity top-loading balance. After weaning, the body weight of each of the rabbits was taken fortnightly (8th, 10th and 12th week respectively) with a 3.0 kg capacity top-loading balance. The growth rate was calculated as the weight gained over a given period. Mortality was determined as the difference between the litter size at birth and the reached market weight

### Data Analysis

The data were first corrected for the fixed (significant) effect of sex, the season of kindling and the does' age using the least significant difference (lsd) before the analysis was run. A fixed effect model was then fitted using the Generalized Linear Model (GLM) procedure of GenStat (Discovery Edition 2016) for the diallel analysis. This was used to estimate the General Combining Abilities (GCA), Specific Combining Abilities, (SCA), heterosis (H%) and the reciprocal effect (RE), for the reproductive and growth performance of the three rabbit breeds and their crosses.

Estimates of the GCA, SCA and RE for both reproductive and growth performance data were based on the widely used Griffings' (1956) method II, model 1. The model for the assumed combining ability analysis is as follows:

$$Y_{ijk} = \mu + g_i + s_j + r_k + e_{ijk}$$

where  $Y_{ijk}$  = variable analysed

$\mu$  = overall mean

$g_i$  = the effect of the general combining ability of the  $i$ th breed.

$s_j$  = the effect of the specific combining ability of the  $j$ th breed.

$r_k$  = the reciprocal (sex-linked) effects of the crosses (I and j).

$e_{ijk}$  = random error.

Heterosis and reciprocal effects for the growth and reproductive performance data were estimated using the mid-parent approach or formulae.

$$H\% = \frac{AB - (0.5A + 0.5B)}{(0.5A + 0.5B)} \times 100$$

where A is the mean performance of parent A, B

is the mean performance of parent B and AB is the mean performance of the F<sub>1</sub> crossbred (Rasul et al., 2002).

The GCA and SCA for both the growth and reproductive performance were estimated using the mathematical formulae below:

$$GCA = 0.5n (Y_i + Y_i) - 0.5nY$$

$$SCA = 0.5 (Y_{ij} + Y_{ji}) - 0.25n (Y_i + Y_i + Y_j + Y_j) + 0.5n$$

where

n is the number of records considered

Y the sum of the observations

$Y_1 + Y_2 + Y_3 + Y_4 + \dots + Y_n$  are the respective breeds (i and j) of rabbits

(Griffings, 1956).



## CHAPTER FOUR

### RESULTS

#### **Reproductive Performance of Purebred and Crossbred Rabbit Breeds**

Mean reproductive performance of the purebred and crossbred rabbits used in the study are presented in Table 1. The results recorded significant effects on a number of the traits that were considered in the study. The litter size at birth (LSB), litter size at weaning (LSW) and mortality (MT) before weaning were all significantly ( $P < 0.05$ ) influenced by the breed combinations. The LSB for the pure breed, the main cross and the reciprocal crosses ranged between 5.9 to 6.4, 6.4 to 6.8 and 6.3 to 6.9 respectively. The LSW on the other hand ranged from 5.1 to 5.9, 5.8 to 6.2 and 5.9 to 6.5 respectively and that is comparatively good for the agro-ecological zone. The performance of the crossbreds (main and reciprocal cross combinations) for the LSB and LSW which recorded significant difference were superior to those of the purebreds. Although there was no particular trend in the performance of the various cross combinations, the average performance of the reciprocal cross in both the LSB and LSW were superior to the other cross combinations. Mortality varied from 6.5 to 6.9% in the purebred, 5.0 to 6.3% in the main cross and 5.5 to 6.4% in the reciprocal cross combinations. Similarly, there was no clear trend in the percentage mortalities recorded even though the crossbreds generally recorded lower mortalities than the purebreds. The age at sexual maturity (ASM) for the various breed combination which ranged between 157-159 days recorded no significant effect. Neither was the kindling interval (KIN) influenced by the

breed combinations although the average performance of the purebreds (94-95days) were superior to that of the crossbreds (93-97days).

**Table 1:** Least Square Means  $\pm$  s.e of the Reproductive Performance for the Purebred and Crossbred Rabbits

Trait	Pure Breed			Cross Breed					
				Main cross			Reciprocal cross		
	CH x CH	NZ x NZ	BV x BV	NZ x BV	CH x NZ	BV x CH	CH x BV	NZ x CH	BV x NZ
N	(206)	(305)	(297)	(332)	(201)	(187)	(267)	(115)	(103)
LSB, N <sub>0</sub>	6.4 $\pm$ 0.1 <sup>b</sup>	6.3 $\pm$ 0.2 <sup>b</sup>	5.9 $\pm$ 0.1 <sup>c</sup>	6.8 $\pm$ 0.1 <sup>a</sup>	6.4 $\pm$ 0.1 <sup>b</sup>	6.4 $\pm$ 0.2 <sup>b</sup>	6.6 $\pm$ 0.1 <sup>b</sup>	6.3 $\pm$ 0.1 <sup>b</sup>	6.8 $\pm$ 0.1 <sup>a</sup>
LSW, N <sub>0</sub>	5.9 $\pm$ 0.1 <sup>cd</sup>	5.9 $\pm$ 0.2 <sup>cd</sup>	5.1 $\pm$ 0.2 <sup>e</sup>	6.2 $\pm$ 0.2 <sup>b</sup>	5.9 $\pm$ 0.1 <sup>cd</sup>	5.8 $\pm$ 0.1 <sup>d</sup>	6.3 $\pm$ 0.1 <sup>c</sup>	6.9 $\pm$ 0.1 <sup>a</sup>	5.9 $\pm$ 0.2 <sup>cd</sup>
ASM, days	159 $\pm$ 0.3	158 $\pm$ 0.1	xxx $\pm$ 0.1	159 $\pm$ 0.2	157 $\pm$ 0.1	158 $\pm$ 0.3	158 $\pm$ 0.1	157 $\pm$ 0.1	159 $\pm$ 0.3
KIN, days	95 $\pm$ 0.1	94 $\pm$ 0.4	94 $\pm$ 0.2	94 $\pm$ 0.2	93 $\pm$ 0.3	97 $\pm$ 0.3	94 $\pm$ 0.3	96 $\pm$ 0.3	95 $\pm$ 0.3
MT, %	6.5 $\pm$ 0.1 <sup>ab</sup>	6.8 $\pm$ 0.3 <sup>a</sup>	6.9 $\pm$ 0.3 <sup>a</sup>	5.3 $\pm$ 0.1 <sup>d</sup>	5.0 $\pm$ 0.3 <sup>d</sup>	6.3 $\pm$ 0.1 <sup>ab</sup>	5.5 $\pm$ 0.1 <sup>cd</sup>	6.0 $\pm$ 0.1 <sup>bc</sup>	6.4 $\pm$ 0.3 <sup>ab</sup>

Key: Chinchilla (CH), New Zealand White (NZ), Blue Vienna (BV), Litter Size at Birth (LSB), Litter Size at Weaning (LSW), age at Sexual Maturity (ASM), Kindling Interval (KIN), Mortality (MT) and Number (N<sub>0</sub>).

Means within a row with different superscripts are significantly different at 5% level of significance ( $P < 0.05$ ), n, numbers in brackets represents the number of animals that were used.

### **Growth Performance of Purebred and Crossbred Rabbit Breeds**

Mean growth performance of the purebred and crossbred rabbits used in the study are presented in Table 2. With the exception of the body weight at weaning (BWW) and the post-weaning growth rates (PGR) which did not record any significant differences in the various cross combinations, all the other growth parameters (BWB, BW8wks, BW10wks, BW12wks) considered in the study recorded significant differences ( $P < 0.05$ ). The BWB for the pure breed, main cross and reciprocal cross combinations varied between 54.1-55.2g, 56.1-58.0g and 56.0-57.1g respectively with a number of the crossbreds exhibiting some level superiority. The CH X NZ crossbred recorded the highest BWB of 58.0g and that was significantly different ( $p < 0.05$ ) from the performance of the BV X CH, CH X BV and BV X NZ crossbreds which recorded BWB ranging from 57.0-57.1g. Likewise, the BWB of the NZ X BV and NZ X CH crossbreds did not record any significant differences. The litter weight at birth (LWB) similarly recorded significant effect ( $p < 0.05$ ) from the cross combinations; but unlike the BWB, there was no clear trend. The post-weaning growth performance that was recorded fortnightly from the eighth to the twelfth week (BW8wks – BW12wks) consistently recorded significant difference ( $p < 0.05$ ). The BW12wks (market weight) varied between for the major cross combination ranged from 2.0 - 2.1kg in the pure breed, 2.1 - 2.3kg in the main cross and 2.0 - 2.3kg in the reciprocal cross. However, there was no clear trend in performance even though the crossbreds were comparatively heavier at market weight.

**Table 2:** Least Square Means  $\pm$  s.e of the Growth Performance for the Purebred and Crossbreed Rabbits

Trait	Pure Breed				Cross Breed				
					Main cross		Reciprocal cross		
	CH x CH (206)	NZ x NZ (305)	BV x BV (297)	NZ x BV (332)	CH x NZ (201)	BV x CH (103)	CH x BV (267)	NZ x CH (115)	BV x NZ (187)
BWB, g	55.2 $\pm$ 0.3 <sup>c</sup>	54.1 $\pm$ 0.2 <sup>d</sup>	55.1 $\pm$ 0.3 <sup>c</sup>	56.1 $\pm$ 0.1 <sup>b</sup>	58.0 $\pm$ 0.3 <sup>a</sup>	57.0 $\pm$ 0.3 <sup>a</sup>	57.1 $\pm$ 0.3 <sup>a</sup>	56.0 $\pm$ 0.1 <sup>b</sup>	57.0 $\pm$ 0.3 <sup>a</sup>
LWB, g	353.3 $\pm$ 0.1 <sup>cd</sup>	340.8 $\pm$ 0.3 <sup>d</sup>	325.1 $\pm$ 0.3 <sup>e</sup>	381.5 $\pm$ 0. <sup>ab</sup>	371.2 $\pm$ 0. <sup>abc</sup>	364.8 $\pm$ 0. <sup>bc</sup>	359.7 $\pm$ 0. <sup>cd</sup>	353.4 $\pm$ 0. <sup>cd</sup>	387.6 $\pm$ 0. <sup>a</sup>
BWW, kg	1.1 $\pm$ 0.1	1.2 $\pm$ 0.3	1.1 $\pm$ 0.3	1.1 $\pm$ 0.4	1.1 $\pm$ 0.3	1.2 $\pm$ 0.1	1.0 $\pm$ 0.4	1.2 $\pm$ 0.3	1.1 $\pm$ 0.3
BW8wks,kg	1.5 $\pm$ 0.5 <sup>ab</sup>	1.5 $\pm$ 0.5 <sup>ab</sup>	1.6 $\pm$ 0.5 <sup>a</sup>	1.5 $\pm$ 0.3 <sup>ab</sup>	1.4 $\pm$ 0.3 <sup>b</sup>	1.6 $\pm$ 0.3 <sup>a</sup>	1.5 $\pm$ 0.3 <sup>ab</sup>	1.6 $\pm$ 0.4 <sup>a</sup>	1.6 $\pm$ 0.3 <sup>a</sup>
BW10wks, kg	1.7 $\pm$ 0.5 <sup>b</sup>	1.8 $\pm$ 0.5 <sup>ab</sup>	1.8 $\pm$ 0.5 <sup>ab</sup>	1.8 $\pm$ 0.3 <sup>ab</sup>	1.5 $\pm$ 0.5 <sup>c</sup>	1.8 $\pm$ 0.3 <sup>ab</sup>	1.7 $\pm$ 0.5 <sup>b</sup>	1.9 $\pm$ 0.3 <sup>a</sup>	1.9 $\pm$ 0.4 <sup>a</sup>
BW12wks, kg	2.0 $\pm$ 0.1 <sup>b</sup>	2.1 $\pm$ 0.3 <sup>ab</sup>	2.1 $\pm$ 0.3 <sup>ab</sup>	2.3 $\pm$ 0.1 <sup>a</sup>	2.1 $\pm$ 0.3 <sup>ab</sup>	2.2 $\pm$ 0.3 <sup>a</sup>	2.0 $\pm$ 0.6 <sup>b</sup>	2.3 $\pm$ 0.6 <sup>a</sup>	2.2 $\pm$ 0.3 <sup>a</sup>
PGR gday <sup>-1</sup>	21.4 $\pm$ 0.	21.4 $\pm$ 0.	23.8 $\pm$ 0.	28.6 $\pm$ 0.	23.8 $\pm$ 0.	23.8 $\pm$ 0.	23.8 $\pm$ 0.	26.2 $\pm$ 0.	26.2 $\pm$ 0.

Key: Chinchilla (CH), New Zealand White (NZ), Blue Vienna (BV), Bunny Weight Birth (BWB), Litter Weight at Birth (LWB), Body Weight at Weaning (BWW), Body Weight at 8weeks (BW8wks) Body Weight at 10 weeks (BW10wks), Bunny Weight at 12weeks (BW12wks) and Post-weaning Growth rate (PGR).

Means within a row with different superscripts are significantly different at 5% level of significance ( $P < 0.05$ ), n, numbers in brackets represents the number of animals that were used

### **Heterotic Effects on some Reproductive Traits of Rabbit Crossbreds**

The heterotic effects on the reproductive performance of the crossbreds (main and reciprocal cross combinations) recorded varying degrees of positive but low heterosis on both the litter size at birth (LSB) and at weaning (LSW). The percent heterosis for the LSB varied between 0.8% - 7.1% in the main cross and 2.4 – 11.5% in the reciprocal cross. The LSW ranged for the various cross combinations (main and reciprocal crosses) ranged from 0.0-9.1%. Unlike the LSW for which there was a particular trend with the reciprocal cross recording comparatively higher percent heterosis, there was no particular trend in the LSB even though the highest percent heterosis for the LSB was recorded in the reciprocal. Both negative and positive heterosis were recorded in the age at sexual maturity (ASM), kindling interval (KIN) and mortality (MT) were not beneficial. The negative heterotic effect observed in the above mentioned traits although generally low particularly for the ASM and KIN, it is an indication of some improvement made in those traits. But for the BV X CH from the main cross which recorded a positive percent heterosis of 6.0 in mortality, the heterotic effect of the other cross combinations from the main cross was negative and comparatively higher than the percent heterosis recorded from the reciprocal crosses.

**Table 3:** *Heterotic Effect on some Reproductive Traits in the Main and Reciprocal Crosses*

Trait	Genotype					
	Main Cross (H%)			Reciprocal Cross (R%)		
	NW X BV	CH X NZ	BV X CH	CH X BV	NZ X CH	BV X NZ
	(332)	(201)	(103)	(267)	(115)	(187)
LSB, N <sub>0</sub>	7.1	0.8	4.1	2.4	3.3	11.5
LSW, N <sub>0</sub>	5.1	0.0	5.5	9.1	7.3	7.3
ASM, days	0.3	-0.9	-0.3	-0.3	-0.6	0.6
KIN, days	-0.5	-1.6	2.6	-0.5	2.1	1.1
MT, %	-20.3	-24.8	6.0	-17.9	-12.4	-6.5

Key: Chinchilla (CH), New Zealand White (NZ), Blue Vienna (BV), Litter Size at Birth (LSB), Litter Size at Weaning (LSW), Agee at Sexual Maturity (ASM), Kindling Interval (KIN) and Mortality (MT). Number (No). Numbers in brackets represents the number of animals that were used.

### Heterotic Effects on some Growth Traits of Rabbit Crossbreds

With the exception of the bunny weight at birth (BWB), the litter weight at birth (LWB) and the post-weaning growth rate (PGR) for which the heterotic effects were positive for all the cross combinations and thus an indication of some level of improvement made with respect to those traits, there were some negative heterosis recorded in the BWW and the body weight that was taken fortnightly after weaning. The heterotic effect on the BWW varied between 2.7 – 6.7% in the main cross and 2.6 – 3.5% in the reciprocal cross. However, there was no particular trend in the estimated heterosis for the various cross combinations. Similarly, the percent heterosis estimated for the PGR which varied from 5.3 – 22.4% and 5.3% - 26.5% in the reciprocal and main crosses respectively did not show any particular trend. The PGR of the various cross combinations from the study were high. The weight of the rabbits at weaning (BWW) recorded negative percent heterosis in all the cross combinations with the exception CH X BV cross from the reciprocal cross which recorded percent heterosis of 4.3. The percent heterosis for the BWW for the main cross was -4.3% while the reciprocal cross varied between -9.1 - 4.3%. The percent heterosis BW8wks ranged from -3.2 – 9.7% and -3.2 – 0% in the main and reciprocal crosses with the main crosses recording comparatively higher value. The percent heterosis for the BW10wks on the other hand ranged from -2.9 – 5.6% in the reciprocal cross and -8.6 – 2.4% in the main cross. With the exception of the CH X BV cross from the reciprocal cross which recorded negative percent heterosis (-2.4%) at slaughter (BW12wks), all the other crosses from the cross combinations recorded positive percent heterosis



**Table 4:** *Heterotic Effect on some Growth Traits in the Main and Reciprocal Crosses*

Traits	Genotype					
	Main Cross (H%)			Reciprocal Cross (R%)		
	NZ X BV (332)	CH X NZ (201)	BV X CH (103)	CH X BV (267)	NZ X CH (115)	BV X NZ (187)
BWB, g	2.7	6.7	3.4	3.5	2.6	4.4
LWB, g	9.9	7.0	7.5	6.0	6.1	14.6
BWW, kg	-4.3	-4.3	-4.3	-9.1	4.3	-4.3
BW8wks	-3.2	9.7	3.2	-3.2	0	0
BW10wks	2.9	-8.6	2.9	-2.9	5.6	5.6
BW12wks	12.2	2.4	7.3	-2.4	9.5	4.8
PGR gday <sup>-1</sup>	26.5	11.2	5.3	5.3	22.4	15.9

Key: Chinchilla (CH), New Zealand White (NZ), Blue Vienna (BV), Bunny Weight Birth (BWB), Litter Weight at Birth (LWB), Body Weight at Weaning (BWW), Body Weight at 8weeks (BW8wks) Body Weight at 10 weeks (BW10wks), Body Weight at 12weeks (BW12wks) and Post Weaning Growth rate (PGR). Numbers in brackets represents the number of animals that were used.

## **General and Specific Combining Abilities of some Reproductive Traits in Three Rabbit Breeds**

The values estimated for the general and specific combining abilities from the study were low. In some instances, there were obvious indications of poor nicking ability between some of the cross combinations. From the reproductive performance in Table 5, only the litter size at birth (LSB) and at weaning (LSW) recorded significant differences in their combining abilities. The general combining ability (GCA) for the LSB and LSW for the pure breed ranged between -2.10 to 0.53 and -1.10 to 3.25 respectively while the respective specific combining ability (SCA) of the above mentioned traits for the main cross ranged between -4.21 to 3.21 and -2.10 to 3.33. Unlike the SCA for which the BV X CH cross demonstrated superiority in both the LSB and LSW by recording highest values, the pure breed combinations from the Chinchilla (CH) and Blue Vienna (BV) rabbits breeds demonstrated superiority in their GCA for the LSB and LSW respectively. The CH and BV breed combinations recorded the highest values of 0.59 and 3.25 for the respective LSB and LWS. The New Zealand White on the other hand was inferior to the other breeds in both the LSB (-2.10) and LSW (-1.10) as it recorded negative values for both traits. Although some breeds and crossbreds recorded negative values for the age at which the does first kindled (ASM), the effect was not significant. Similarly, no significant effects were recorded in the GCA and SCA in the pure breed and cross breed with respect to the kindling interval (KIN) and mortality (MT)

**Table 5:** *Estimated General and Specific Combining Ability of some Reproductive Traits.*

Trait	GCA			SCA		
	NZ X NZ (305)	BV X BV (297)	CH X CH (206)	CH X NZ (201)	BV X CH (267)	NZ X BV (332)
LSB, N <sub>0</sub>	-2.10*	0.01*	0.53*	1.11*	3.21*	-4.21*
LSW, N <sub>0</sub>	-1.10*	3.25*	1.29*	-2.10*	3.33*	2.11*
ASM, days	-3.10	1.51	3.41	-1.01	4.31	1.88
KIN, days	0.11	1.61	1.11	1.12	3.21	3.68
MT, %	0.45	1.51	0.24	1.41	-6.10	6.31

Key: Chinchilla (CH), New Zealand White (NZ), Blue Vienna (BV), General Combining Ability (GCA), Specific Combining Ability (SCA), Litter size at birth (LSB), Litter size at weaning (LSW), Bunny weight at birth (BWB), Litter weight at birth (LWB) and Mortality (MT).

Means within a row with asterisks (\*) are significantly different at 5% level of significance ( $P < 0.05$ ), n, numbers in brackets represents the number of animals that were used.

## **General and Specific Combining Abilities of some Growth Traits in Three Rabbit Breeds**

The estimated values for the general and specific combining abilities for a number of the growth traits considered in the study were quite high and positive in a number of the cross combinations. In a few instances, some of the cross combinations recorded negative values which were obvious indications of poor nicking ability or combining ability between those cross combinations. With the exception of the bunny weight at weaning (BWW) and the tenth week body weight (BW10wks) for which no significant differences were recorded, all the other cross combinations recorded considerably high and significant differences in their respective GCAs and SCAs for the traits considered. Notable among them were the bunny weight at (BW8wks). The SCA and the GCA for the cross breed and pure breed recorded average values of 15.3 and 26.5 with the New Zealand White breed recording the highest GCA of 42.3. The CH X NZ cross on the other hand recorded the highest SCA of 18.5 for the BW8wks. Significant differences were also recorded in the body weight at birth (BWB) and the market weight (BW12wks). The SCA for the BWB varied between 1.2 to 4.4 while the GCA varied from -2.5 to 10.5. Similarly, significant differences were recorded estimated combining abilities of the various cross combinations. With the exception of the CH-NZ cross which recorded a negative SCA (-10.1) for the market weight (BW12wks) which is an indication of a poor combining ability between those breeds, the other cross combinations recorded positive values. The average GCA and SCA for the pure breed combination and cross breed combination for the BW12wks 6.8 and 1.1 while the PGR were 0.6 and -0.5 respectively.

**Table 6:** *Estimated General and Specific Combining Ability of some Growth Traits*

Trait	GCA			SCA		
	NZ X NZ (305)	BV X BV (297)	CH X CH (206)	CH X NZ (201)	BV X CH (267)	NZ X BV (332)
BWB	5.5*	-2.5*	10.5*	3.8*	4.4*	1.2*
BWW	18.5	-11.5	33.5	-8.6	-4.5	3.2
BW8wks	42.3*	28.5*	8.6*	18.5*	16.8*	10.5*
BW10wks	15.1	27.8	10.8	20.1	33.1	5.8
BW12wks	5.5*	2.3*	12.5*	-10.1*	10.8*	2.5*
PGR, gday <sup>-1</sup>	0.7*	0.1*	0.9*	-1.1*	-2.3*	1.8*

Key: Chinchilla (CH), New Zealand White (NZ), Blue Vienna (BV), Bunny Weight Birth (BWB), Litter Weight at Birth (LWB), Body Weight at Weaning (BWW), Body Weight at 8weeks (BW8wks) Body Weight at 10 weeks (BW10wks), Body Weight at 12weeks (BW12wks) and Post Weaning Growth rate (GR).

Means within a row with asterisks (\*) are significantly different at 5% level of significance ( $P < 0.05$ ), n, numbers in brackets represents the number of animals that were used.

## CHAPTER FIVE

### DISCUSSION

#### **The Reproductive Performance of Three Rabbit Breed and Crossbreds**

Litter size, particularly at birth and weaning in multiparous species like the rabbit, has been identified as one of the key economic traits in breed development and improvement programmes that is essentially targeted at meat production (Rajapandi et al., 2015). This is because according to Sivakumar et al. (2013), these litter traits are considered one of the most important economic components in intensive meat production. It has become very important and extensively used in recent times for selecting maternal lines because the litter size reflects both the prolificacy as well as the milking and nursing ability of the doe (Mocé and Santacreu, 2010). Ultimately, this has bearing on the significant role it has in contributing to the quantity of meat produced; and thus, ensuring a regular supply of meat, particularly in the developing economies where animal protein has been very limiting for the marginalised in society (children, expectant and nursing mothers). Considering the unique traits (reproductive) of the various breeds, and particularly of their crosses, the significant variations in their reproductive performance were expected. The results of the reproductive performance of the purebreds and crossbreds recorded significant effects on a considerable number of the traits that were considered in the study, as reported in Table 1. This is unlike Nwakpu et al. (2015) who recorded significant effect on only mortality at the pre-weaning stage. From Table 1, although there was no particular trend in the performance of the various breed combinations, the crossbreds comparatively, performed

better in most of the reproductive traits such as the litter size at birth, litter size at weaning and mortality. The results from this study is an indication that crossbreeding is linked to improvement in the LSB and LSW. Thus, the generally observed comparative advantage of the crossbreds over the purebreds can be attributed to the effects of the different genetic backgrounds of the rabbit breeds and the nature of the gene effect on the traits (Kabir et al., 2014; Oseni, 2012).

### **Litter Size at Birth (LSB)**

A number of studies on the litter size at birth of purebred and crossbred multiparous species like the rabbit, under tropical conditions particularly in sub-Saharan Africa, have varied from 3.5-7.4 and 6.2-8.7 respectively, with the crossbreds recording comparatively higher LSB (Abdel-Azeem et al., 2007; Fayeye, 2013; Iraqi et al., 2006; Kabir et al., 2012; Kabir et al 2014). The average performance of the pure breed, main and the reciprocal crosses were 6.2, 6.5 and 6.6 respectively. Similar to the findings made by other authors under tropical conditions, the performance of the cross breed combinations which ranged from 6.3 (CH X BV, NZ X CH) to 6.8 (NZ X BV, BV X NZ) among the crossbreds were superior to the performance of the pure breed combinations which varied between 5.9 (BV X BV) to 6.4 (CH X CH). Abdel-Azeem et al., Akpo et al. (2008), Khan et al (2017) and Oseni and Lukefahr (2014) among other authors have attributed the superior performance (LSB) of the crossbred to the purebred to differences in ovulation rate, uterine space and maternal effects informed by the number of matured fertilised and established ova. On the contrary, the average performance of the purebred and crossbreed recorded by Akinsola et al. (2014) were 6.51 and 6.42 for the LSB.

Although the NZ breed, unlike the CH, is not well noted for high LSB, the 6.3 bunnies from the NZ was not significantly different from the 6.4 the CH breed recorded from the present study. However, the LSB of the NZ in this study is lower than the 7.7 Mambiri (2013) recorded for the same breed of rabbits under tropical conditions. Similarly, the average performance of 8.2 of the crossbred from that study was higher than the 6.8 recorded in the present study. It could be argued that the comparatively small degree of variation in the LSB of the crossbreds from the study is due to the limited variation in the performance of the pure breeds that were used. The NZ X BV from the main cross as well as its reciprocal cross recorded the highest LSB of 6.8 among the cross combinations considered in the present study. This could be attributed to the comparative wide variation between these breeds (New Zealand White and Blue Vienna) rabbits in their LSB compared to the Chinchilla. The CH cross combination recorded the highest LSB of 6.4 among pure breeds even though it was not significantly differently from the 6.3 recorded by the NZ breed. The superior performance of the CH could be attribute to its comparative advantage its good mothering ability at the neonatal stage. The BV rabbit just like the CH is known to have good litter traits but this was not evident in the performance of the LSB of the BV rabbit. However, its performance is comparable to the other

It quite obvious that in spite of the comparatively improved performance in the LSB of the various cross combinations from the present study and particularly the 6.8 bunnies recorded by the NZ X BV and BV X NZ compared to the average LSB of 6.0 bunnies from meat rabbit breeds within the tropics, there still exist the potential for improved performance among all



the cross combinations (purebred, main cross and reciprocal cross) considered in the study. This can be achieved through rigorous selection and improved nutrition which has been identified as one of the major challenges in rabbit production particularly within the tropics. Such an improvement would not only contribute positively to the number of bunnies a doe may produce in its reproductive period, but the number of bunnies produced in the country per year. Ultimately, this would have a significant effect on food security, particularly in sub-Saharan Africa. It would also be a means of economic empowerment, mainly for the marginalised in society (Oseni & Lukefahr, 2014; Niba et al., 2012; Serem et al, 2013; Tembachako & Mrema, 2016). This is because, they can generate extra income from the sale of some of the rabbits either at weaning or at market weight to make it possible to meet other basic needs. For higher LSB, either the BV X NZ or NZ X BV crossbreds would be a better option within the coastal savannah agro-ecological zone.

#### **Litter Size at Weaning (LSW)**

The litter size at weaning have been identified as the most efficient tool in measuring or assessing the mothering ability of the doe. Just like the LSB, the LSW is of relevance to the availability of protein from animal sources, and thus its contribution towards food security in the developing economies (Assan, 2014; Oseni & Lukefahr, 2014; Szendrő et al., 2012). Thus, a doe that weans a greater proportion of its litter is considered as a “good mother” because the bunnies, until they are weaned, depend almost entirely on the nutrition provided by the doe. According to Moce and Santaereu (2010), LSW forms the basis for the selection of maternal lines because the trait reflects both the prolificacy and the mothering ability of the doe. The LSW within the

tropics, which have been generally low, have among other factors been attributed to breed effect, poor nutrition, stress and adverse climatic conditions (Oguike & Okocha, 2008; Szendrő, et al., 2012; Zeferino et al., 2011).

The LSW from the present study which was within the range of 5.1 to 6.9 falls within the upper quartile (3.9 to 7.3 bunnies) of the performance records of commercial meat rabbit breeds under tropical conditions (Abdel-Azeem et al., 2007; Apori et al., 2014; Kabir et al., 2014; Rajapandi et al., 2015). The mean performance of the various cross combinations from the study were 5.6, 6.0 and 6.1 bunnies for the pure breed, main cross and reciprocal cross respectively. Although the average performance of the reciprocal cross was considerably higher than that of the main cross and the pure breed crosses, there was no particular trend in the performance of the performance of the various cross combinations. The NZ X CH recorded significantly higher LSW of 6.3 bunnies and that comparable to the bunnies weaned by the other cross combinations considered in the study. This could be attributed to the good mothering of ability of the CH doe and not necessary the ability of those breeds (NZ and CH) to combine their unique traits in the provision of care for its bunnies. This is because, the average performance of the two breeds (CH and NZ) were equal. Neither was can it be attributed to the ability of two breeds to effectively and efficiently combine their unique traits in providing care for the bunnies because LSW is a sex-limited trait. This was evident in the 5.9 bunnies recorded by the CH X NZ cross compared to the 6.3 bunnies recorded by the NZ X CH cross.

The average performance of the crossbreds from the present study were found to be similar to the findings of Abdel-Azeem et al (2007), El-

Bayomi et al. (2012), Kabir et al. (2012), Kabir et al (2012) and Szendrő et al (2012) all of whom have reported that the performance of the crossbred combinations (main and/or reciprocal crosses) are generally higher than the performance of the pure breeds or *straight cross*. However, the average performance of the crossbreds from the present study was inferior to the average performances of 7.0 and 6.7 bunnies Abdel-Azeem et al., Jaouzi et al (2004) and Sivakumar et al. (2013) recorded in their respective studies. The comparatively higher performance recorded in those studies could be attributed to the wide variance in the performance of the rabbit breeds used in that study. In their respective studies for instance, Abdel-Azeem et al. crossed the New Zealand White with the California while Jaouzi et al crossed local Moroccan breeds with the California rabbit breed under tropical conditions. Similarly, the extent of work that have been conducted in the selection for better performing local or existing breeds within a given agro-ecological zone and the comparatively favourable climatic conditions, may account for this improved performance (Apori et al., 2014; Assan, 2014; Fayeye, 2013; Khadiga et al., 2008; Kumar et al., 2013; Onyiro et al., 2008; Youssef et al., 2008).

In spite of the superior performance the crossbreed combinations (main cross and reciprocal cross) in general exhibited over the pure breed even though there was no particular trend in their performance, the performance of some of the pure breed combinations were similar to that of the crossbred combinations. For instance, both the CH and NZ crosses recorded 5.9 bunnies at weaning just as the CH X NZ and BV X NZ crossbreds. In spite of the fact that the BV recorded the least number of bunnies (5.1) at weaning, it was

found to be better than the 4.4 bunnies Apori et al. (2014) recorded for the same breeds under similar conditions. Similarly, the LSW of 5.9 bunnies recorded in the NZ breed from the study was comparable to the 2.2 bunnies that Oke and Iheanocho (2011) recorded for the same breed. It is quite obvious that with continuous selection programmes for well adapted and better performing breeds, and the use of breeds that are quite varied in their reproductive performance (unimproved local breeds with exotic breeds), there will be some progress. For better LSW with respect to the various cross combinations considered in the study, the NZ X CH would be a better option within the agro-ecological zone.

### **Mortality**

Mortality has been identified as one of the major challenges the rabbit industry in the tropics faced with (Assan, 2013; Moreki & Seabo, 2012; Owen & Amakiri, 2010). These mortalities within the tropics is not peculiar to rabbits but livestock in general and have been attributed to the climatic conditions (Apori et al., 2014; Oseni & Lukefahr, 2014; Sivakumar et al., 2013). Almost all the studies on mortalities in the assessment of reproductive performance in rabbits have focused on the mortalities that occur from post-partum to pre-weaning. This is due to the fact that mortalities after weaning are quite rare and a number of studies have recorded 0% mortalities post-weaning. The several studies on pre-weaning mortalities within the tropics have ranged from 13.7- 46.8% (Abu et al., 2008; Apori et al., Hakima et al., 2013; Heba-T-Allah et al., 2016; Mambiri, 2013; Nwakpu et al., 2015; Oke & Iheanocho, 2011; Olowofeso et al., 2012). In spite of the considerably high mortalities a number of studies that have been carried out under tropical

conditions have recorded, the mortalities recorded in the present study were comparatively low. The average percentage mortalities recorded from the pure breed, main and reciprocal crosses were 6.7, 4.5 and 5.8 respectively and these are within the acceptable range (< 10%) for commercial production (El-Raffa, 2004; Maria et al., 2002; McNitt et al., 2013, Moreki, 2007)

The current study established significant differences in the percent mortalities among the various breed combinations (purebreds and crossbreds). It was observed from the study that the crossbreds (main and reciprocal crosses) comparatively recorded the least percent mortalities with the main cross recording the least average percent mortality (.4.5%) even though there was no particular trend with respect to the various cross combinations from the study. The CH X NZ recorded the least percent mortality (5.0%) while the BV recorded the highest percent mortality (6.9%) in the present study. The results from the study was comparable to other findings Hakima et al. (2013), Mambiri, (2013) and Nwakpu et al. (2015) with a variety of commercial breeds. Nwakpu et al. for instance, recorded average percent mortalities ranging between 13.4-21.7% while Mambiri recorded 24.1-31.8%. Although the purebreds from the study recorded comparatively higher percent mortalities (6.7%) it was comparable to the percent mortalities recorded both Abdel-Hamid (2015), Nwakpu et al. and Oke and Iheanocho (2011) recorded in both their pure breed and cross breed cross combinations. Oke and Iheanocho for instance recorded 45.8% and 46.8% for the New Zealand White and Chinchilla rabbit breeds while Nwakpu et al. recorded 25.1% and 16.5% for the respective breeds.

The comparatively higher mortalities (6.5, 6.8 and 6.9 %) recorded by CH, NZ and BV were not significantly different from the 6.3 and 6.4% recorded by the BV X CH and BV X NZ cross combinations respectively. Since more often than not the highest, and in some cases all the production mortalities recorded in rabbit production (like for most multiparous species) occur before they are weaned, any effort at reducing mortalities via cross breeding would be advantageous both to the farmer and in ensuring regular supply of animal protein (Assan, 2014; Fayeye & Ayorinde, 2010; Obiajulu et al., 2016; Oseni, 2012; Tembachako & Mrema, 2016; Thornton, 2010). The pre-weaning mortalities from the study can be attributed to a number of factors, such as poor mothering ability, choice of breed, unfavourable climatic factors, parity, poor nutrition and stress factors, as a number of studies have revealed (Abu et al., 2008; Apori et al., 2014; Baruwa, 2014; Heba-T-Allah et al., 2016; Jaouzi et al., 2004).

Aside from the above mentioned genetic factors, it could be argued that the recorded mortalities from the study could be attributed to poor selection. An interaction with Farmer Brown revealed that some of the New Zealand does, in spite of the comparatively low bunnies they kindled, lost consistently a number of the bunnies a few days after kindling. Investigations revealed that those does in particular had some blind teats which corresponded with the losses that occurred. Of the available breeds, the CH X NZ crossbred would be a better option so far as efforts at reducing mortality is concerned even though the mortalities recorded by the other cross combinations were within the acceptable range for rabbit production. This would ensure that farmers would have increased economic benefit from the number of rabbits

that can be slaughtered or sold at the end of the production compared to the BV X NZ crossbred that may have high litters and yet lose a good number of them.

### **The Growth Performance of Purebred and Crossbred Rabbit Breeds**

Growth traits in growing rabbits are important because heavier marketable body weight promotes the economics of rabbit production. Lukefahr (2010) observed that growth parameters are highly heritable traits, suggesting that differences among different genotypes are expected, and selection based on individual performance could successfully improve these traits. Data on the body weight (g) of the three rabbit breeds (New Zealand White, Chinchilla and Blue Vienna) and their crosses indicated significant effect ( $p < 0.05$ ) on all the growth parameters that were measured in the present study with the exception of the body weight at weaning and the post-weaning growth rate which indicated no significant ( $p > 0.05$ ) effects.

According to Olawumi (2014), non-significant ( $P > 0.05$ ) effect or breed differences suggests that breeds more or less have similar genetic background. Previous studies by Fayeye and Ayorinde (2010), Fayeye (2013) and Ouyed and Brun (2008) for instance, have shown that the growth performance (bunny weight at birth, body weight at weaning and market weight) of crossbred rabbits were significantly better than for the purebreds; this was not different from findings from the present study. Akinsola et al. (2014) have attributed the widely observed superiority of crossbred rabbits in growth traits to the heterotic effect of the crosses. Abdel-Azeem et al. (2007) on the other hand sided with Egena et al. (2014), Iraqi et al. (2006) and Oseni (2008) who attributed the superiority of the crossbred to hybrid vigour. The

mean bunny weight at birth and at weaning of the various genetic groups in the study were comparatively better than what some studies have reported as acceptable for tropical conditions in developing economies. The comparatively heavier weights at weaning and at market weight is indicative of the benefits of crossbreeding.

### **Bunny Weight at Birth (BWB)**

The bunny weight at birth (BWB) has actually been one of the key factors in any breeding work because aside ensuring and to a significant extent promoting faster growth rate because of the considerable resources they may have, it has the added benefit of ensuring good health (Abdel-Kafy et al., 2012; Iraqi et al., 2006; Momoh et al., 2015; Nwakpu et al., 2015; Poigner et al., 2010). The generally higher performance; heavier bunny weight at birth of the crossbreds in the study compared to the purebreds in the growth traits are not different from observations from other crossbreeding studies (Akinsola et al., 2014; Kabir et al., 2012; Piles et al., 2010; Wanjala, 2015). The birth weight of commercial breeds, according to Poigner et al. is normally between 60-70g, but this can range from 35-40g and 80-90g respectively. It is quite obvious that the BWB of the various cross combinations from the study were not within the ideal range (60-70g). That notwithstanding, the records from the study is not much different from what others have reported under tropical conditions (44.0-51.4g by Adeyinka et al., 2007; 54.4-57.7g by Oliveira et al., 2011 and 46.2-64.7g by Tuma et al., 2010).

Contrary to the observation made by Nwakpu et al. (2015) which indicated no significant effect ( $P>0.05$ ) in the weight of the bunnies at birth, there were significant differences ( $P<0.05$ ) in the BWB of the various cross



combinations considered in this study. Even though the average performance of the crossbreds were found to be superior to the BWB of the pure breeds, the average performance of the cross combinations (pure breed = 54.8g, main cross = 57.0g and the reciprocal cross = 56.7g) were not within the ideal range of 60 to 70 grams (McNitt et al., 2013, Moreki, 2007; Ferrand, 2008; Monnerot et al., 1994). The low birth weight of bunnies recorded to an extent may influenced by the breed, breeding system, the age at which the doe is bred and the condition or nutritional status of the doe prior to breeding and during the gestation (Chineke Agaviezor, Ikeobi & Ologun, 2002; Lukefahr et al., 2010; Prayaga & Eady, 2003). However, the performance of the crossbred from the present study is comparable to what other authors have reported under tropical conditions. For instance, Abdel-Azeem et al (2007), Nwakpu et al. (2015) Olowofeso et al. (2012) and Pragma and Eady (2001) have recorded 47.5-50.0g, 38.3-55.5g, 39.2-43.6g and 53.1-58.9g as the BWB from their respective crossbreds.

The CH X NZ cross from the present study recorded the highest BWB of 58.0g and this is comparable to the topmost performance (59.6 grams) Akinsola et al. (2014) recorded from their crossbred. The performance of the CH X NZ from the study was not significantly different from the 57.1 g recorded by the CH X BV cross and the 57.0g recorded by the BV X CH and BV X NZ crosses The BWB of all the cross breed combinations from the study were comparable to the 54.1g. Lavanya et al. (2016) recorded as the best performance from their crosses. Nonetheless, there still exists the potential for improving on the BWB of the various cross combinations from the study to at least attain the ideal range (60-70g) for commercial meat breeds under tropical

conditions. For selection purposes, the CH X NZ combination which recorded the highest BWB would be an ideal option for the improvement of the BWB within the coastal savannah agro-ecological zone even though its performance was not unique to the performance of some cross combinations. With identification of ideal breeds and breed combinations for the agro-ecological zone and improved nutrition particularly during the critical periods of its gestation, the birth weight of the bunnies can be enhanced (Chineke et al., 2002; Lukefahr et al., 2010; Poigner et al., 2010; Prayaga & Eady, 2003).

Although BWB of the purebreds (54.8g) from the study was comparable to the performance of the crossbreds, the performance of the pure breeds from was comparable to what a number of authors have recorded under tropical conditions. Akinsola et al. (2014) and Kabir et al. (2012) for instance recorded 42.6g and 50.8g respectively as the average performance from their pure breeds. The 55.2 and 55.1g BWB of the CH and BV rabbit breeds were significantly different from the 54.1 g for the NZ. The significantly low performance of the NZ from the study compared to the other pure breeds was uncharacteristic of the NZ breed which is known to normally compensate its low litter size at birth for comparatively heavier bunnies at birth. The performance of the NZ breed from the present study is comparable to the 58.2 Oke and Iheanocho (2011) recorded for the same breed. However, the performance of the CH and BV breeds from the study were comparatively superior to the 54.2 and 51.3 grams Apori et al. (2014) recorded for the same breeds within a similar agro-ecological zone (coastal savannah). Similarly, the BWB of the CH rabbit breed from the study (55.2grams) was quite

comparable to the 50.7grams Oke and Iheanocho recorded for the CH rabbit breed.

Considering the immense contribution of crossbreeding in improving the growth traits of particularly poor performing tropical breeds, and even exotic breeds, it is quite obvious from the study that the BWB of the existing pure breeds can be enhanced via crossbreeding with any of the available breeds (Kabir et al., 2014; Onyiro et al., 2008; Wanjala, 2015). This will also contribute to the growth rate of the rabbits, contribute to food security and the profit margin of the farmer since the animals would spend a comparatively shorter time in reaching market weight (Assan, 2014; Safwat et al., 2014). The BWB of multiparous species in general have been found to be inversely proportional to the litter size at birth (Pongier et al., 2010). This general observation have been associated with normally limited resource of the dams; small uterine space particularly of small-sized breeds (Oseni, 2012; Oseni & Lukefahr, 2014). In developing economies of the tropics however, nutrition has been identified as a major contributing factor to growth performance of livestock (Baruwa, 2014). Obviously, an improvement in the nutritional status of the dam, particularly during the gestation period, will affect the nourishment of the foetus and consequently, the bunny weight at birth (Baruwa; Fayeye, 2013; Oseni & Lukefahr, 2014).

#### **Bunny Weight at Weaning (BWW)**

The body weight at weaning which is one of the essential economic traits in the assessment of the mothering ability of dams, the potential for fast growth rate and ultimately higher economic returns. However, the study did not record any significant differences in the performance of the various cross

combinations. It could be reasoned that, each of the does was able to provide the needed resources; nutrition and care to meet the requirements of the bunnies as of the time they were weaned. Records on several studies regarding the weight at which commercial breeds of rabbits (purebreds and crossbreds) under tropical conditions are weaned, are quite wide and varied. The BWW within the tropics have ranged between 0.3-1.8kg (Abdel-Hamid, 2015; Kabir et al., 2012; Nwakpu et al., 2015; Rajapandi et al., 2015). The observed variations to a greater extent have been influenced by the breed, breeding system, nutrition, the age at which the bunnies are weaned, the litter size, agro-ecology and seasonal variation, among others (Chineke et al., 2002; Lukefahr et al., 2010; Prayaga & Eady, 2003).

The BWW of the various breeds and their crosses which varied from 1.0 - 1.2kg did not record any significant differences ( $P>0.05$ ). Olowofeso et al. (2012) likewise did not record any significant differences in the various genetic groups. The non-significance for the BWW could be attributed to the high litter sizes, body weight of the doe and birth weight of the bunnies (Gyovai et al., 2004; Mocé, & Santacreu, 2010; Poigner et al., 2010; Rommers, 2004; Szendrő et al., 2006). Similarly, the poor nutritional status of the does could account for the comparatively low and non-significant effect in the BWW (Castellinin et al., 2010; Carabaño Luengo et al., 2009; Cidenne et al., 2010; Fortun-Lamothe, 2006; Gidenne, 2000; Martínez-Paredes et al., 2012; Onifade & Tewe, 2010).

However, El-Bayomi et al. (2012) recorded significant effects on the BWW in different cross combinations (1.0 - 1.3kg) involving the New Zealand White, California and Flander rabbit breeds. Abdel-Hamid (2015)

similarly recorded significant differences in the various cross combinations under tropical conditions (1.0 -1.3kg), with the performance of the crossbreds being better than the purebreds. Chineke et al. (2002), Nwakpu et al. (2015) and Obike & Ibe (2010) have equally recorded significant differences ( $P<0.05$ ) in the weaning weights of various rabbit breeds and their crosses. Most of these authors have attributed the higher performance of crossbreds to heterosis. This is indicative of the preponderance of non-additive genes for these growth traits. Nwakpu et al. attributed the superiority of the crossbred in the BWW to the smaller litters in which they were raised. Olowofeso et al. (2012) on the other hand opined the superiority of some of the does in the bunnies they weaned to either their good mothering abilities or their ability to acclimatise to the climatic conditions. Obike and Ibe on the other hand observed superiority of purebreds over crossbreds and reasoned that it was probably due to the low number of genotypes used or a preponderance of additive genes for the pre-weaning growth traits. This could be true, particularly in situations where either little or no selection have been carried out in the population from which the experimental animals are obtained.

The lack of significance from the present study could be attributed to the inability of the crossbreds to nick well or complement each other in ensuring heavier bunnies at weaning. It could likewise be argued that the breeds were limited in their ability to provide adequate resources (nutrition) during the critical periods of pregnancy and during lactation (milk). Nonetheless, the BWW was quite encouraging and with improved nutrition, particularly for the does during the critical period of its reproductive period, and probably with an additional source of nutrition (reconstituted milk) for the

bunnies, there exists the possibility of having heavier BWW. This is because according to Castellinin et al. (2010) and Nwakpu et al. (2015), although the basis of production is the genotype, the manifestation of the genetics depends on a number of factors such as nourishment to the foetuses, milk supply to the bunnies and the environmental condition during rearing; among others, can have significant influence on the performance of does.

### **Post-weaning Growth Performance**

Although, there were no significant effect on the BWW of the three breeds and their crosses, there were significant differences in their post-weaning performances (body weight taken fortnightly). Nonetheless, there was no particular trend in the performance of the various cross combinations. This observation is not peculiar to this study. A number of authors (Abdel-Hamid, 2015; EL-Bayomi et al., 2012; Lavanya et al., 2016; Alves et al., 2015) have made similar observations and have reported instances where some pure breeds have outperformed the crossbreds, particularly in the growth traits. For instance, the CH X NZ crossbred recorded significantly, the least weights in both the BW8wks (1.4kg) and BW10wks (1.5kg). However, the other crossbreds seemed to exhibit some level of superiority in both the BW8wks and BW10wks. For instance, the highest BW8wks of 1.6kg was not limited to only the BV X CH, NZ X CH and BVX NZ crossbreds but the pure New Zealand White breed as well. The performance of the above mentioned crossbreds was however not significantly different from the 1.5kg of the other purebreds and crossbreds.

There was quite a remarkable improvement in the general performance of all the cross combinations at market weight (BW12wks). To an extent, the

degree of significance in the market weight of the rabbits was quite milder than what was observed in the BW8wks (1.4-1.8kg vs 2.0-2.3kg). Both the CH and the BV X CH cross weighed 2.0kg at market weight, and this was not significantly different from the 2.1kg recorded by the other pure breeds (BV and NZ) and the CH X NZ crossbreds. Even though the 2.0 of the CH and CH X NZ was significantly different from the 2.3 and 2.2 BW12wks recorded by the NZ X BV and the BV X CH and BV X NZ crossbreds respectively, the performance of the latter was not significantly different from the 2.1 of the other cross combinations recorded at slaughter (BW12wks). Nonetheless, the trend was not different from what was observed in the body weight at the 8th and 10th weeks. It can thus be argued that with the exception of the CH breed of rabbit and CH X BV crossbred, there is the high possibility of the other pure breeds and crossbreds considered in the study to reach market weight (2.0kg) before the twelfth week. Even though there are quite a number of options for the selection of an ideal cross combination for the improvement of post-weaning growth performance or heavier body weight at slaughter, NZW X CH would be the most appropriate cross combination. This is on the basis of the consistency in the superior growth performance it exhibit post-weaning

The post-weaning performance in most of the cross combinations were quite remarkable. For instance, the market weight of the BV and CH from the study (2.1 and 2.0kg respectively) were comparable to the 1.3 and 1.4kg that Apori et al. (2014) recorded for the same breeds of rabbits under similar conditions. Similarly, the BW12wks recorded by Lavanya et al (2016) and Adenaike et al. (2013) showed some level of inferiority in the market weight of their crossbreds Adenaike et al for instance recorded market weights ranging

between 736.1 to 866.0g from the Californian White, New Zealand Red and Chinchilla rabbit cross combinations. Abdel-Hamid (2015) however, obtained similar results (2.0-2.3kg) by the twelfth week to what was recorded in the present study. Piles et al. (2010) however recorded significantly higher market weight (2.5 - 2.7kg). The significant variance between the genotypes, according to Adenaike et al., is an indication of the considerable genetic diversity among the straight crosses and their reciprocal crosses. Olawumi (2014) however, did not record any significance ( $P>0.05$ ) in the slaughter weight of rabbits and opined the breeds have similar genetic background. From careful consideration of the added benefits of crossbreeding, particularly hybrid vigour, which has been identified as one of the effective tools for increased productivity and profitability in livestock production (Gosey, 2005; Hakima et al, 2013; Onyiro et al., 2008), it is quite obvious the economic gains of most of the resource-poor rabbit farmers in the developing economies of the tropics would be significantly enhanced. (Adzitey, 2013; Dalle Zotte, 2014; Kari & Asare, 2009; Mensah et al., 2014). This is in addition to the added contribution or benefit it would make towards meat production and food security through enhanced growth rate (Mailafia et al., 2010; Mínguez et al., 2015; Oseni, 2012; Safwat et al., 2014; Tembachako & Mrema, 2016).

#### **Post-weaning Growth Rate (PGR)**

It was observed that in spite of the remarkable post-weaning growth performances of the three rabbit breeds and their crosses, there was no significant differences in their daily body weight (BW) gain. Nonetheless, the crossbreds in general performed better than the purebreds. This particular observation, which is not unique to this study nor the species considered in the



study, can be attributed to the inconsistencies in their weekly weight gain. Similar trends have attributed it to the variation or changes in the physiological age which is linked to the endocrine profile (Pascual et al., 2013). A closer look at their post weaning growth performance revealed that the rate of growth declined at the 10th week. Several authors (Estany, Camacho, Baselga, & Blasco, 1992; Piles & Blasco, 2010) have made similar observations with rabbits and other livestock species. That notwithstanding, the targeted market weight at the end of the study (12th week) was achieved for all the rabbit breeds.

### **Heterotic Effects on Some Reproductive Traits in Three Rabbit Breeds**

According to Fayeye (2013), the use of breed combination to improve litter size is generating a lot of interest among rabbit breeders. The diallel cross has been identified as one of the crossbreeding systems that can be used to improve or enhance the performance of livestock species in general, of which rabbit pure breeds are not exception. This have been attributed to the genetic diversity of the breeds. This genetic diversity has been found to be larger or wider among breeds compared to what is observed within breeds, and it is thus just acceptable, compared with the performance of various breeds and their crosses as a basis for selecting superior rabbit breeds and crosses, for an enhanced performance. More importantly, diallel cross offers the opportunity of identifying the best possible combinations particularly of traits that are sex limited based on the estimated heterosis. The heterotic effect of most cross breeding programmes may be positive, negative or although that is quite rare (El-Bayomi et al., 2012; Fayeye, 2013; Nwakpu et al., 2015; Schiermiester et al., 2015). A positive heterosis is an indication of a progress made as a result

of the crossbreeding carried out while a negative heterosis mean otherwise. However, a positive estimated heterotic value may not necessarily imply an improvement with respect to the trait. Depending on the nature of the trait being considered a negative value will imply a 'positive' heterosis while a positive value will mean otherwise (Baranwal et al., 2012; Ouyed et al., 2011)

Of all the reproductive traits that were considered in this study, it was only the litter size at birth (LSB) and weaning (LSW) that recorded the expected positive values for the estimated heterosis for all the crossbred combinations. Abdel-Azeem et al (2007), likewise recorded positive heterosis both in the main and reciprocal cross combinations for the LSB and LSW but not for all the reproductive traits. Although all crossbreeding projects are aimed at recording positive heterotic effect for all the economic traits with the selected breeds of animals, it is quite rare, if not impossible, to record positive heterosis in all cross combinations. Kabir et al. (2012), for instance have maintained that the superiority which some breeds (does) exhibit for maternal traits or ability can be attributed to increased milk production, maternal behaviour and care of the litter. The above mentioned factors are have been known to be influenced by the genotype, environment and their interaction in most case (Apori et al., 2014; Egena et al., 2014; Obike & Ibe, 2010; Onyiro et al., 2008; Sánchez & Piles, 2012) All estimates of heterosis from the study in general confirmed that the crossbred does were associated with significant and favourable heterotic effects on the litter traits studied particularly in the LSB and LSW as well as some cross combinations that had positive heterotic effect(s) in the ASM, KIN and MT for all the cross combinations.

### **Litter Size at Birth (LSB)**

The percent heterotic effect for the litter size at birth was positive in all the cross combinations. It was however considerably low (0.8-11.5%), with the main crosses recording on average, lower heterotic effect (4.0%) than the reverse crosses (5.7%). The results from the present study is similar to observation that was made by Abdel-Azeem et al. (2007) who recorded percent heterosis of 1.1-6.3 and 0-3.4. Similarly, Nwakpu et al. (2015) recorded lower heterotic effect (0.1-0.2%) for the same trait, with the New Zealand, Chinchilla and Dutch breeds of rabbits. This was however contrary to the observations made by Kabir et al. (2012) who rather recorded higher percent heterosis in the main crosses (36.2-62.2% vs 7.4-25.1%). Besides the contrary observation made by Kabir et al. in the light of the heterotic effect on LSB, the heterotic effect from that study was higher (7.4-63.2%).

The comparatively wide and better variation recorded by Kabir et al., (2012) in the percent heterosis for the LSB compared to results from the present study, could be attributed to the degree of variance between the various breeds that were considered in the study with respect to the trait. The observed differences between the main and reverse crosses could be attributed to the contributions the different breeds or lines, particularly the does, are able to make for the LSB (a sex-limited trait). Nevertheless, it can be maintained that irrespective of the extent or value of heterotic effect on the LSB from the present study, the observed positive heterosis is an indication that the crossbreeding has contributed to an improvement in the performance of the LSB. This could be as a result of the specific combining ability which is attributed to the non-additive genetic variance. The highest heterotic effect in

both the main and reciprocal crosses (7.1 and 11.5% respectively) involved the New Zealand and Blue Vienna rabbit breeds. Obviously, this placed them ahead of the other cross combination for higher LSB. It would seem more appropriate to attribute this to their nicking ability (NZ X BV and BV X NZ) than the genetic potential of either the does (better mothering ability) or the buck. This is because, none of the combinations indicated superiority in the other crosses

For best result and selection purposes for improvement within Ghana's coastal savannah agro-ecological zone, the BV X NZ would be the best option. This is in the light of the influence of the dam during the embryonic and foetal development which is quite paramount because the paternal effect terminates at fertilisation. The maternal influence is however genetically inclined and thus the development will depend much on the genetics of the animal, but also on the environment. On the contrary, Kabir et al. (2012) and Fayeye and Ayorinde (2010) recorded the best effect when the Chinchilla was crossed with New Zealand White and thus recommended the NZ X CH crossbred rather for the exploitation of heterotic effect within Nigeria's tropical environment .

### **Litter Size at Weaning (LSW)**

Litter size at weaning just like the litter size at birth is a sex-limited trait, and thus, the role of the dam is quite significant in the selection making decision, and the worth of such an information is hinged on the relevance of maternal ability. According to Kabir et al. (2012), the breed of does that usually exhibit superiority in LSB is more often than not attributed to increased milk production, maternal behaviour and care of the litter. Similar to

the observation made from the LSB, the reciprocal crosses on the average offered a better response than the main cross did in the LSW. For instance, the CH X NZ recorded 0% heterosis in the main cross while its reciprocal cross recorded percent heterosis of 7.3. It is quite obvious that the Chinchilla doe exhibited better maternal effect than both the New Zealand White and Blue Vienna does. Both Abdel-Azeem et al. (2007) and Kabir et al. on the contrary estimated better heterotic effect in the main than the reciprocal crosses. Kabir et al. for instance, estimated 33.2 - 38.5% heterosis in the main crosses and 5.6 - 15.8% in the reciprocal crosses. Abdel-Azeem et al. also observed better LSW obtained from mating the local Baladi Red buck to the Chinchilla Giganta, French Giant Papillion and Sivenwar does than reverse mating, and thus opined it could be attributed to the better mothering and milking abilities of the exotic breeds

Nonetheless, the low estimated heterotic effect on the LSW from the present study (0.0-9.1%) is not different from the 2.9 – 14.9% Abdel-Azeem et al. recorded for the same trait. However, the 5.6-38.5% heterosis Kabir et al. (2012) obtained is comparable. Similarly, Hakima et al. (2013) recorded higher percent heterosis (21.9) in a cross involving the Algerian rabbit buck (local breed) and California rabbit doe. Hakima et al. attributed the heterotic effect to the ability of the crossbred to bear more difficult raising conditions than the pure individuals. The comparatively low estimated percent heterosis from the present study could be attributed to the limited variance the breeds that were used with respect to the LSW (Baselga et al 2003; Demuth & Wade, 2005; Olawumi, 2014). To an extent, it appears the effort of the farmer aimed at effectively ensuring maximisation of heterosis by securing the replacement

stock (either bucks or does) from reputable farms in neighbouring countries (Togo and Cote D'Ivoire) was not accomplished. This is in the light of the comparatively low level of positive heterosis that was recorded. It could be argued that those breeds were probably not genetically distinct or diverse from the existing breeds since they were not sourced from well breeding stations.

Since the theory of dominance effect has great influence on the degree of heterosis, high heterosis could have been achieved by crossing the existing local breeds with either high performing foreign breeds or breeds that were quite distinct in their litter traits, the LSB and LSW to be precise. Alternatively, the same breeds of rabbits from any of the sub-Saharan countries, aside those in the West African sub-region, could have been used to probably establish the effect of the environment (agro-ecological zone) on the trait (LSW). Considering the influence of environmental factors such as nutrition, ambient temperature and animal handling on the sex-limited trait like LSW, an improvement in the particularly but not limited to the nutritional plane of the does could have made a significant impact on their output. Nevertheless, the positive heterotic effect in all the cross combinations is an attestation to the fact that the crossbreeding yielded a positive result.

Unlike the LSB, where the NZ X BV and its reciprocal cross offered the best response in both the main and reciprocal crosses, the cross involving the Blue Vienna and Chinchilla breeds of rabbit from the present study had the best heterotic effect on the LSW, in both the main (5.5%) and reciprocal (9.1%) crosses. It could be argued that, although the cross involving the BV doe did exhibit superiority in the LSB in the main cross, but not the ultimate, the BV doe would have better fostering ability than the other breeds (CH and

NZ does). The exhibition of superiority or the comparative advantage of some of the dams for mothering ability, according to Kabir et al. (2012), can be attributed to the differences between the breeds in their genetic makeup with respect to the genes that control milk production, maternal behaviour and care for the litter, prior to weaning (Baselga et al, 2003; Mínguez et al., 2015; Niranjana et al., 2010; Ouyed et al., 2010). The comparative advantage of the BV doe for higher litter size at weaning compared to the other breeds, is an indication of its genetic diversity for the trait. For breeding purposes however, it would be appropriate to select the CH X BV cross for better LSW.

#### **Age at Sexual Maturity (ASM)**

There was some level of progress with respect to the age at sexual maturity (ASM) in almost all the crosses involving the three rabbit breeds considered in the study, and that is very encouraging. Unlike for the LSB, LSW and growth traits in general for which positive heterosis is beneficial, the negative heterosis effect that was recorded in the AMS of some of the crosses was advantageous. The comparative advantage of such crossbreds in the age at which the does successfully kindled is not limited to rabbit breeds, but to any other livestock species (Iraqi et al., 2008; Lalev et al., 2014; Razuki & Al-Shaheen, 2011). It is an indication of the significant improvement made in the F1 generation with respect to the trait (ASM) compared to the ASM of the purebred parents. In spite of the generally low heterosis estimated for the various cross combinations, the major limitation from the present study is the positive heterosis is the NZ X BV cross in both the main and reciprocal crosses recorded. At least, the negative heterosis that were recorded for the

ASM involving the other rabbit breeds were beneficial although their impact might be very (0.3-0.9%).

The observation made under the prevailing conditions was not much different from what was theoretically expected from the crosses made. This is on the basis of the significant effect of not only the breed (genetic) but the environment (nutritional plane, climatic conditions, health status, etc.). Several authors have established the combined effect of breed and the environment on the ASM of rabbits. (Apori et al., 2014; Baruwa, 2014; Olowofeso et al., 2012; Oseni et al., 2008; Oseni & Lukefahr, 2014) In fact, the environmental factors have been known to have significant effect on the ASM from a number of studies (Ghosh et al, 2010; Mocé & Santacreu, 2010; Oseni; 2012). Early sexual maturity has actually been identified as one of the unique traits of rabbits. This imply that the cross combinations that recorded negative value heterosis would reach sexual maturity or kindle earlier than the purebred parents and the cross combinations that recorded a positive value heterosis. On the basis of the observed negative estimated heterosis some of the cross combinations for the ASM, it could be argued that the lifetime productivity of such does would be enhanced This is because an early sexual maturity that would not compromise on the welfare of the does would contribute significantly to the number of litters and for that matter, the number bunnies a breeding doe would produce in its reproductive period (Apori et al.; Khan et al., 2017)

Considering the effect of age on the reproductive function of does, an earlier ASM from such cross combinations would ensure safer, healthier and comparatively longer reproductive performance in the does and the production



of healthier bunnies as well (Apori et al., 2014; Khan et al., 2017; McNitt et al., 2013; Onyiro et al., 2008). Such positive impact on the does and particularly, the bunnies from such cross combinations would most likely impact significantly the quality (survivability, birth weight, and growth rate) of the FI bunnies (Oseni & Lukefahr, 2014) On the basis of the percent heterosis the cross combinations from the main and reciprocal crosses recorded, it would be appropriate to select CH X NZ if the breeder seeks to improve on the age at does attain sexual maturity within the agro-ecological zone.

### **Kindling Interval (KIN)**

Shorter general interval is similarly one of the unique traits of rabbits and any attempt at reducing the period between two successive kindling without compromising on the welfare of the doe would be very beneficial to the farmer (Apori et al., 2014; Baranwal et al., 2012; Kargo, Madsen, & Norberg, 2012; Thornton, 2010). Similar to the ASM, in spite of the comparatively low heterotic effect that were recorded, some level of progress (beneficial heterotic effect) was made in the estimated heterotic effect in the kindling interval with some cross combinations. The negative values obtained from the estimated heterosis some of the cross combinations recorded for a reproductive trait like KIN was advantageous (El-Bayomi et al., 2012; García et al., 2012; Schiermiester et al., 2015) This comparative advantage is not only limited to the purebred parents but also the cross combinations whose estimated percent heterosis were positive. The average performance of the main cross was generally better than those of the reciprocal cross. The NZ X BV and CH X NZ from the main cross recorded - 0.5 and 1-.6 % (the highest)

while the CH X BV which happened to be the only cross combination from the reciprocal cross whose estimated percent heterosis was negative (-0.5%).

Nonetheless, the estimated percent heterosis for some of the cross combinations from the study were positive and considerably high. Although this is certainly not advantageous for such cross combination, the observation isn't limited to this study. Both El- Bayomi et al (2012) and García et al. (2012) made similar observations from some cross combinations. The NZ X CH and BV X NZ of the reverse cross recorded percent positive heterosis of 1.1 and 2.1% respectively while the BV X CH recorded the highest percent positive heterosis (2.6%). It could be argued that the comparatively low and poor heterotic effect on the KIN involving the various rabbit breeds could be as a result of the limited variation in the age at which they first kindled or probably, that their specific combining abilities for the trait is fairly weak or not as beneficial as the general combining abilities. This would contribute significantly in the decision making process of the possible effect(s) of enhancing the LSB and LSW of rabbit does via crossbreeding on their KIN.

Even though both the CH X BV and NZ X BV crosses for instance recorded low negative heterosis of 0.5%, this was undoubtedly advantageous compared to the comparatively high but positive heterosis that was estimated for BV X CH cross. This is because such does (does for which the estimated heterosis on KIN were negative) would ultimately have an increased number of bunnies in their reproductive period or cycle in a year in a situation where the does are culled, not on the basis of the parity, but per the calendar year as practised by most rabbitries within the African terrain. The highest beneficial heterosis (negative heterosis) that was estimated for the KIN was the -1.6%

the CH X NZ crossbred recorded. This makes it (CH X BV) an ideal option for selection aimed at ensuring shorter kindling or generational interval. Similar to the ASM, the low percent heterosis the various cross combinations recorded can be enhanced via improved management (nutrition and selection of ideal breeds). This on the basis to the significant effect of the nutritional plane of the doe among other factors particularly during the sensitive periods of its gestation period and after kindling have on the general performance of its bunnies right from birth (Khan et al., 2017; Oseni & Lukefahr, 2014).

### **Mortality (MT)**

Of all the reproductive parameters that were considered in the present study, mortality at pre-weaning stage recorded the best and highest negative heterosis in the three rabbit breeds, with the exception of the BV X CH cross that recorded a 6.0% positive heterosis. Similar to the observations made in the ASM and KIN, the comparably high negative heterosis that were recorded in both the main and reciprocal crosses is a clear indication of the positive effect (hybrid vigour) that crossbreeding the three rabbit breeds considered in the study would have on pre-weaning mortalities compared to the pure breeds. Obviously, the resultant effect would be beneficial because there would be a reduction in the mortalities recorded in the crossbreds compared to the purebred parents. The percent negative heterosis observed in the study ranged between 6.5-24.8; and that is very encouraging because there is a clear indication of a substantial non-genetic additive effect in enhancing the survivability of the bunnies before they are weaned (Fayeye, 2013; Lavayan et al., 2016).

Considering the high pre-weaning mortalities that are often recorded in the NZ does, which has been attributed to its poor mothering ability compared to the BV and CH does, it is not surprising that they (CH X NZ cross) registered the highest heterosis of -24.8% on mortality. A considerable improvement in the mortalities that are often recorded during that critical stage would not only impact positively on the lifetime productivity of the rabbit does, but likewise on the profitability of rabbitries since a considerable number of the bunnies would be available for sale either at weaning or market weight. Similarly, that would contribute to or guarantee a reliable supply of protein from animal sources for the vulnerable in the society and a significant contribution towards ensuring food security particularly in the developing economies of the tropics (Adzitey, 2014; Ansah et al., 2014; Appiah et al., 2011; Assan, 2014; Osei et al., 2012). A strong case can be made for the possibility of improving on the heterotic effect of crossbreeding in these rabbit breeds. This is on the basis of the confirmed reports of the contribution of nutrition which is very key in dictating the mortalities that are often recorded prior to weaning (Apori et al., 2014; Fayeye, 2013; Rajapandi et al., 2015; Onyiro et al., 2008). That is, combined effects of heterosis and improved environment for the does and bunnies cannot be underestimated. On the basis of the estimated heterosis for mortalities among the rabbit breeds considered in the present study, all the possible cross combination, with the exception of the BV X CH, would result in significant improvement (reduced mortalities) at the pre-weaning stage. For optimum results however, it would be appropriate to opt for the CH X NZ cross for breeding purposes or recommended to the local rabbit farmers within the coastal savannah agro-ecological zone where

the study was conducted. This would considerably enhance the output of their farms, the profitability of their rabbitries, contribute to Ghana's animal protein output and ultimately, to global food security (Assan, 2014; Safwat et al., 2014).

### **Heterotic Effects on Some Growth Performance of Three Rabbit Breeds**

In animal breeding, crossbreeding makes room for the exploitation of breed qualities from both the genetic and biological points of view. The heterotic effects of crossbreeding on growth parameters have generally been low and this has been attributed to the low heritability of such traits, due to the additive genetic effect on growth parameters of which the body weights of rabbits at birth, weaning and at slaughter are not exceptions (Fayeye & Ayorinde, 2010; Gosey, 2005; Piles & Blasco, 2010). Nonetheless, the level or degree of variance in the frequency of genes affecting a given trait has a significant effect on the heterotic effect (Falconer & Mackay, 1996). There were fluctuations in the post-weaning bi-weekly percent heterosis among the cross combinations. Nonetheless, the crossbreeding was generally favourable for the growth performance in all the crosses. Its contribution in the post-weaning growth rate was quite remarkable compared to the reproductive traits. Higher estimates of percent heterosis, according to Kabir et al. (2012), for a given trait is a good indication that crossbreeding has improved the performance of that trait.

### **Bunny Weight at Birth (BWB)**

The BWB is very significant in animal breeding programmes because of its considerable effect on the growth performance (weight at either slaughter or weaning and sexual maturity) and to an extent, the fertility of the

rabbits (Tablido & Revilla, 2012). A careful study of the effect of heterosis on the BWB from the study (2.6-6.7%), were not much different from what have been reported generally on growth or traits by other authors within the tropics (Abdel-Azeem, 2007; Fayeye, 2013; Hakima et al., 2013; Kabir et al., 2012; Nwakpu et al., 2015). Abdel-Azeem for instance, reported 2.2-8.4% heterosis for the BWB while Fayeye estimated 13-15% for the same trait. The findings of Nwakpu et al. (-14.1-25.1) are quite comparable to what was obtained in the present study.

The positive heterosis recorded in all the cross combinations (main and reciprocal crosses), with respect to the bunny weight at birth and the litter weight at birth (LWB) met the desired expectations of the crossbreeding that was carried out in terms of percent positive heterosis (Fayeye, 2013), unlike Nwakpu et al. (2015) who recorded a negative heterotic effect (-14.1%) on the BWB for the cross involving the New Zealand buck and Chinchilla doe. The percent heterosis for BWB for the main crosses was averagely higher, from 2.7% (NZ X BV) to 6.7% (CH X NZ), and thus better than what was recorded in the reciprocal crosses 2.6% (NZ X CH) to 4.4% (BV X NZ). The percent heterotic effect recorded in the present study is similar to the estimates (2.2-2.7%) by Abdel-Azeem et al. (2007) but quite comparable to estimates (-14.1-25.1) by Nwakpu et al.

Similarly, the percent heterosis for the BWB from cross combinations (main and reciprocal cross) in the present study were quite low compared to what Fayeye (2013) estimated (13-15%) for similar crossbreds. According to Abdel-Hamid (2015) such variations in addition to the genetic variance of the breed could be due to the effect of the environmental factors; primarily

nutrition, the age at which the does is bred and its' condition prior to breeding. In recognition of the significant effect of the BWB on the rabbits' growth performance prior to weaning, and even post-weaning, the crossbreds from the present study would most likely reach market weight earlier than the pure breeds. That is however not in the absence of the provision of an enabling environment or appropriate resources such as good nutrition and proper housing, which would among other things create a thriving and conducive environment for the optimum performance of the bunnies.

Although all the crossbred bunnies demonstrated the desired advantage over the purebreds in their BWB, the CH X NZ crossbred from the main cross (which recorded a 6.7% positive heterosis) would be a better option of all the crossbreds considered. The considerable performance of the New Zealand White breed of rabbit, in both the main and reverse cross for the BWB, can be attributed to its unique advantage as a meat breed compared to the Blue Vienna and Chinchilla breeds of rabbits. The percent heterosis in the weight of the litter at birth was encouraging (6.0-14.6%). With the exception of the BV X NZ cross in the reciprocal cross which witnessed the highest percent heterosis of 14.6% for the trait (litter weight at birth, LWB), the crossbreds from the main cross (CH X NZ and BV X CH) recorded higher percent heterosis (7.0 and 7.5%) than their respective reciprocal crosses (6.1 and 6.0%) Nonetheless, the reverse crosses averagely performed better than the main crosses (8.9% vs 7.8%). Considering the relationship between LSB and the LWB, the comparatively higher percent positive heterosis in the LWB, if there are no pre-weaning mortalities and there are better management decisions to account for the limited resource of the doe at the pre-weaning

stage. Besides, a case can only be made for heavier litter weight at birth and not necessarily heavier bunnies. It thus makes it prudent to select the best cross combination on the basis of the BWB.

### **Bunny Weight at Weaning (BWW)**

In spite of the positive heterotic effect that was recorded in the weight of the bunnies at birth for all the cross combinations, it was only the NZ X CH cross that recorded positive heterotic effect in the BWW. The other crosses recorded varying levels of negative heterosis (-9.1 - -4.3%). Obviously, such a result is undesirable for the BWW, just like for any growth traits of economic importance (El-Bayomi et al., 2012). Of all the cross combinations in the present study, it was only the NZ X CH crossbred which recorded a 4.3% heterosis. That made the NZ X CH cross the ideal cross combination for better BWW or to guarantee better pre-weaning growth performance within the agro-ecological zone. The observed numerous percent negative heterosis in the BWW from the present study is certainly a great challenge due to the potential rippling effect it can have on the post-weaning performance. This could probably be attributed to the poor nutritional status of the does, particularly during the pre-weaning stage (Pascual et al., 2012). Although such an observation made (negative heterosis) is not peculiar to this study, other authors such as Abdel-Azeem (2007), Abdel-Hamid (2015), and Nwakpu et al. (2015) have recorded positive heterosis in all the cross combination for BWW. Such results would require comparatively minimal resources (ration) to reach market weight and such would potentially enhance the profit margin of the farmer (Adedeji et al., 2013; Ansah et al., 2014; Karikari et al., 2011; Mensah et al., 2014; Osei et al., 2012; Safwat et al., 2014)



Poor nutritional status of the doe particularly during the critical periods of gestation and before weaning have actually been identified as the major challenges with almost all livestock species in developing economies in the tropics (Assan, 2013; Maass et al., 2012; Mailafia et al., 2010; Oseni, 2012). As it has been admonished with other livestock species, particularly in developing economies, it would be appropriate to put the suckling does on either a higher plane of nutrition or provide the bunnies with supplements to make up for the limited resource (low milk yield) of the does. This could be an ideal means to reduce if not reverse the effects of negative heterosis on the various cross combinations. Such a provision would most likely not only contribute to the desired improvement in the weaning weight, especially for enterprises that would not fatten the rabbits to market weight, but also ensure an enhanced post-weaning performance for enterprises that would dispose of the rabbits at market weight. This would not only attract a good market value but such weaners would do better than those that recorded negative heterosis.

### **Post-Weaning Growth Performance**

In spite of the negative heterosis that was recorded for the BWW for almost all the crosses, there were remarkable improvements or progress during the post-weaning period. A number of the cross combinations from the study made consistent progress in body weights taken fortnightly from the 8th to 12th week. This was however not without some setbacks or inconsistencies some of the crosses demonstrated, just as some other works have revealed (Abdel-Hamid, 2015; El-Bayomi et al., 2012). For instance, the CH X NZ cross recorded a 9.7% heterosis at BW8wks but declined (-8.6%) at BW10wks, unlike the other cross combinations which made progress from the

BW8wks to the BW10wks. Similar observations were made in some of the cross combination from the BW10wks to market weight (BW12wks), just as Abdel-Hamid observed.

Of all the cross combinations that were considered in the present study, it was only the NZ X BV and CH X BV crosses that maintained consistency in growth performance right from weaning to market weight. Similarly, the BV X CH, NZ X CH and BV X NZ crosses for instance maintained positive heterotic effects in their post-weaning growth performance. That was in contrast to the CH X BV cross that maintained a negative percent heterosis; this was in spite of the consistency it maintained in its progress during the period. Abdel-Hamid (2015) who made similar observation during the period in New Zealand White-Rex and California-Rex crosses explained that this could be due to non-additive inter-breed genetic effects. In contrast, others have also estimated percent negative heterosis for the post-weaning growth performance. Contrary to the observation made by Abdel-Hamid (which was in agreement with the present study), Abdel-Azeem et al. (2007) estimated negative percent heterosis for body weight at all stages of post-weaning growth performance that was studied.

The inconsistencies in the post-weaning growth performance in most of the cross combinations is not peculiar to the present study or animal species (Amin 2014; Abdel-Hamid, 2015; El-Bayomi et al., 2012; Fayeye, 2013) but livestock species in general (Amin, 2015, Blasco, 2013, Dige et al., 2012). The observed inconsistencies in the growth performance, according to Strychalski et al. (2014), could be attributed to variations in the nutritional demands for the various physiological processes with time. The entire cross combinations,

with the exception of the CH X BV cross however, recorded a positive heterotic effect at market weight (BW12wks). Although El-Bayomi et al. also recorded negative percent heterosis for BW12wks in some of the cross combinations, (-2.3 - 7.6%), the result from the present study was quite comparable (-2.4 - 12.2%). Hakima et al. (2013) however, had better heterotic effect (12.7%) on the weight at slaughter of the domestic breed (Algeria-California crossbred). Nevertheless, the NZ X BV cross from the present study offered a better option for the selection as the best cross combination for improvement in the post-weaning growth performance within the coastal savannah agro-ecological zone. This is based on the comparatively better heterotic effect or superiority it exhibited primarily in the market weight (BW12wks), to some extent, the consistent progress it made during the period (weaning to market weight) and the potential effect it has on the market weight (Adedeji et al., 2015; Appiah et al., 2011; Baruwa, 2014; El-Bayomi et al., 2012; Osei et al., 2012; Ouyed et al., 2011).

### **Post-Weaning Growth Rate (PGR)**

Fast growth rate has been one of the major added benefits of heterosis in livestock species in general. It actually ensures early maturity and high productivity by cutting down on the cost of feed required by an animal to reach market weight significantly (Cottle & Pitchford, 2014; Iraqi et al., 2008; Iraqi, Khalil, & El-Attrouny, 2013; Rege et al., 2011; Weaver, 2015). Although there were characteristic inconsistencies in the percent heterosis for body weights that were taken fortnightly after weaning, there was a cumulative improvement in the growth rate for all the crosses at the end of the study. There was a positive and considerably higher heterotic effect on the

PGR and this varied from 5.3-26.5%. The remarkable performance of the cross combinations from the present study involving the Chinchilla, Blue Vienna and New Zealand White in the post weaning daily growth rate is quite comparable to what El-Bayomi et al. (2012) recognised from their crosses (5.3 - 26.5% vs -10.6 - 9.85%). This could be due to the breed difference and how efficient the crossbreds are compared to the pure breed in their ability to utilise the feed consumed.

Even though the CH X BV cross had recorded percent negative heterosis in the entire post-weaning performance, it recorded percent positive heterosis of 5.3 for the daily weight gain, only that this was low compared to all the other crosses, with the exception of the BV X CH cross. The comparatively low percent heterosis in the daily body weight gain could have probably contributed to the percent negative heterosis that was maintained. The observed percent positive heterosis is proof of the fact that the daily weight gain could be improved via crossbreeding. The NZ X BV crossbred which recorded the highest percent positive heterosis of 26.5, should be considered for improving on the daily weight gain of the three rabbit breeds.

### **General and Specific Combining Abilities for Some Reproductive Traits**

Rabbits have been identified as one of the livestock species with unique reproductive and growth traits. But as with most biological species, breeds or lines, rabbits have been known to be comparable in such outstanding or unique traits. One objective of most crossbreeding programmes aims at merging or combining the unique traits in the parents or pure breeds in the crossbreds (Thorton, 2010; Wakchaure et al., 2015). It is the combined advantages in the crossbred that gives it a comparative advantage over the

parents. However, it has been found that different breeds are able to combine their uniqueness more efficiently for some economic traits than others do. This gives a wide range of cross combinations or options to select from, depending on the objective of the breeder or the market demand (Kabir et al., 2014). The general combining ability (GCA) helps the efficient evaluation of the parent breeds or lines while the specific combining ability (SCA) helps in the identification of the most promising crossbred for the economic trait(s) of interest. Of all the reproductive traits considered in the present study, only the litter size at birth and at weaning had significant differences in their general and specific combining abilities.

According to Kabir et al. (2012), the significant effect ( $P < 0.05$ ) of GCA observed for litter traits (litter size at birth, LSB and at weaning, LSW) is indicative of the relevance of the additive gene action in the expression of those traits (LSB and LSW) and consequently, their expected response to selection for genetic improvement. Obasi and Ibe (2008) on the other hand, have explained that significant SCA for litter traits (LSB and LSW) is an indication of non-additive gene action for the traits concerned and can thus be improved genetically through appropriate crossing, such as the diallel cross. It may also require the utilisation of non-additive gene effects such as dominance and epistasis. To an extent, improving the environment (e.g. nutrition and housing) can contribute to improvement in the trait. (El-Bayomi et al., 2012; Obasi & Ibe; Strychalski et al., 2014).

#### **Litter Size at Birth (LSB)**

The litter size at birth of both the purebreds and crossbreds recorded significant differences in their combining abilities and thus offered the

opportunity to select the appropriate breeds and crossbreds for the trait (LSB). The GCAs of the LSB for the New Zealand, Blue Vienna and Chinchilla were -2.10, 0.01 and 0.53 respectively. Kabir et al. (2014) also recorded significant but comparatively higher differences in the GCA for the LSB between the Chinchilla, New Zealand and California breeds of rabbits; 6.05 and 6.89 were the respective GCA estimated for the CH and NZ breeds. Beside the comparatively higher GCA that Kabir et al. recorded for the rabbit breeds in their study, the GCA of the NZ was superior to the CH, an observation contrary to what was observed from the present study. To an extent, it was not surprising that the GCA for the LSB from the study was favourable for the CH compared to the NW and BV breeds of rabbit. This is due to the fact that the Chinchilla has been known to have better litter traits than the other breeds that were used in the study. The GCA of the LSB for the Blue Vienna unlike the New Zealand White was not that bad but for selection purposes, it would be better to select the CH breed for higher or better LSB.

On the other hand, the SCA for LSB was more favourable for the BV X CH cross than the CH X NZ and NZ X BV cross combinations. The estimated specific combining ability for the CH X NZ, BV X CH and NZ X BV crosses 1.11, 3.21 and -4.21 respectively. Similarly, Kabir et al. (2014), recorded significance in the SCA for the LSB and they were comparable to the findings of the present study. For instance, 6.4 was recorded as the SCA for the CH X NZ crossbred and this was the least of the three crossbreds (8.5 by the NZ X CH and 7.3 by the CA X CH). The comparative advantage of the BV X CH crossbred was quite expected because LSB is a sex-limited trait and the Chinchilla (does) from the study had exhibited superiority in the litter size

at birth compared to other two rabbit breeds. On the basis of the results from the study, the Blue Vienna-Chinchilla cross would offer better value for money with respect to the LSB than the other crossbreds would.

The comparative advantage of the CH from the study was not different from the expected because, the CH breed of rabbits characteristically have large litters and are excellent mothers compared to the other breeds, NZ and BV. Kabir et al. (2012) however recorded a higher GCA for the LSB in the NZ (6.89) than the CH rabbit breeds (6.05). From the study, it was also observed that the SCA was higher than the GCA, which means that the crossbreds had higher gene variation for LSB.

#### **Litter Size at Weaning (LSW)**

The LSB is one of the key economic traits of great consideration in the selection and development of ideal breeds for specific agro-ecological areas due to its significance in the determination of mothering abilities. Similar but comparable to other findings El-Bayomi et al. (2012) and Kabir et al. (2012), the respective GCA and SCA for the LSW recorded for the respective breeds and crossbreds were significantly different. The GCA for the LSW ranged between -1.10 to 3.25, while the SCA by the three crossbreds ranged between -2.10 to 3.33 respectively. In spite of the fact that the Chinchilla rabbit breed was superior in the GCA for the LSB, it did not maintain that superiority over the other pure breeds in its mothering ability during the pre-weaning stage. Although its 0.53 GCA for the LWS was superior to the NZ (-1.10), it was not better than for the Blue Vienna (3.25). The BV rather recorded the highest GCA (3.25) for the LSW; this suggests that within the breeds of rabbits that

were studied, the BV had better mothering ability than the other two rabbit breeds.

The BV, in spite of its low litter size at birth compared to the CH had the advantage of weaning more of its bunnies than the other two breed (NZ and CH). This is significant to meat production and the economic returns because post-weaning mortalities in most rabbitries with good management practices are most often than not highly insignificant even if any. Likewise, when it becomes expedient to get foster does for extra bunnies born to a doe, the BV would be the best option from the three rabbit breeds because it has demonstrated its ability in the provision of care and adequate nutrition for the bunnies (Jaouzi et al., 2004; Abdel-Azeem et al., 2007; Strychalski et al., 2014). Among the breeds however, the cross involving the Blue Vienna buck and Chinchilla doe maintained its superiority in combining effectively for higher litter size at weaning. In spite of this, the optimal SCA of 3.33 estimated for the LSW was not comparable to the 4.67 (least value), not to mention the 7.08 (highest value) recorded by Kabir et al. (2012). That notwithstanding, it could thus be maintained that the BV X CH cross would be a better option for selection for higher LSW, based on the outcome of the present study.

#### **Age at Sexual Maturity (ASM)**

ASM has been identified as one of the essential reproductive traits in livestock species; this is due to the comparative advantage or the positive effects it has on the average performance of particularly the dam, its welfare and the quality of its progeny, not to mention the economic gains (Bolet et al., 2004; Castellini et al., 2010; Matics et al., 2016). In addition to the economic



benefits for the dam in reaching reproductive maturity earlier and the added benefit in the number of comparable healthier offspring it stands to have within its reproductive period, a considerable number of farmers as well as breeders particularly in developing economies in their bid to develop ideal breeds for their agro-ecological zones do not give the ASM much consideration (Kumar et al 2013; Matics et al.). This is because most tropical livestock species have also been identified to be limited in their age at sexual maturity which has often been linked to malnutrition, among other factors (Momoh et al., 2015; Nafeaa et al., 2011; Oliveira et al., 2011). Neither the GCA nor the SCA that was estimated for ASM, which ranged from -3.10- 3.4 and -1.01-4.31 respectively, recorded any significant differences. Nonetheless, it would not be out of place to select the Blue Vienna rabbit and BV X CH cross for early physiological maturity, for the main breed and crossbred respectively.

#### **Kindling Interval (KIN)**

There was neither any significant differences in the GCA nor SCA with respect to the KIN; which varied between 0.11 to 1.61 and 1.12 to 3.68 respectively, for the breeds and crossbreds. Similar to the observation made on the age at which the does have their first litter or bunnies, records from the study gives very limited option as to the respective purebreds or crossbreds that would be ideal for having shorter kindling interval. This notwithstanding, farmers should not compromise on the welfare of the does, especially due to their ability to be rebred shortly (24 hours) after kindling. The significant difference that was not observed in the combining abilities of the KIN could be as a result of the management system the rabbitry had adopted. The

statutory or uniformity in the dry period for all the breeds and crossbreds from the study did not offer the opportunity to record any significant effects. This can be inferred from the non-significant effect of the KIN in all the cross combinations from the study, as recorded in Table 1.

### **Mortality (MT)**

The values recorded for the GCA and SCA with respect to MT ranged from 0.24 to 1.54 and -6.10 to 6.31 respectively. Although on the basis of the numerical values that were recorded for the various cross combinations, the CH (0.24%) and BV X CH (-6.10) recorded the least GCA and SCA respectively, this did not have any significant effect on the mortalities that were recorded. That is, the estimated GCA and SCA did not make any significant contribution in deciding the ideal cross combination that would ensure reduced mortalities, particularly at the pre-weaning stage. This would obviously put much stress on either the breeder or the farmer in the selection of a breed and crossbred that would offer the best results, so far as reduced mortalities from the study is concerned. Nonetheless, a point could be made for the breeds and crossbreds on the basis of the numerical weight the various cross combinations recorded. On that basis, the CH and BV X CH cross could be considered as ideal.

## **The General and Specific Combining Abilities for Some Growth Traits**

### **Bunny Weight at Birth (BWB)**

From Table 6, it was observed that both the GCA and SCA for the BWB were significant; and this was not different from the observations made by Kabir et al. (2012). This would certainly offer an opportunity to select the most appropriate breeds and crossbred for heavier bunny weight at birth. The

growth rate have been known to have significant effect on not only the weight of the rabbit at weaning, but on the market weight as well (Matics et al., 2016; Momoh et al., 2015). The records of the combining abilities from their study was however very comparable to the observation made from the present study. The estimation made by Kabir et al. for the respective GCA and SCA, for the main breeds and crossbreds considered in their study, ranged from 21.3-27.1 and 19.9-26.5. The respective GCA and SCA estimated for the BWB for the present study on the hand varied between -2.5-10.5 and 1.2-4.4.

From this study, it was only the BV that recorded a negative value for the trait, and this makes it not only inferior to the other two breeds but also not ideal for consideration in selecting breeds of rabbits that would give heavier bunnies at birth. On the basis of the GCA and SCA estimated for the three main breeds of rabbits and crossbreds, it would be more appropriate to select the CH breed and BV X CH cross, for heavier bunnies at birth. It could be reasoned that, BV and CH had a better nicking ability in producing heavier bunnies compared to the other crossbreds. Nevertheless, there still exists the opportunity to improve on the combining abilities that were estimated for the bunny weight at birth, in the breed combinations that were considered in the present study. The estimated GCA for BWB for the CH and NZ, according to Kabir et al. (2012) for instance, were 27.1 and 21.3 respectively; while 10.5 and 5.5 were the estimated GCA for BWB in the current study. Similarly, the SCA for the CH X NZ cross was 26.5 while the current study recorded 3.8 from a similar cross.

### **Bunny Weight at Weaning (BWW)**

Unlike the BWB, the estimated GCA and SCA for BWW did not record any significant differences in the various cross combinations that were considered in the present study. This is quite worrying because the weight of the bunnies at weaning, among other things, has serious implication on the post-weaning growth performance, the reproductive performance and the economic returns, particularly for enterprises that dispose of their bunnies at weaning. In addition, it is an indication of the does' ability to provide nourishment for its bunnies to ensure good health and fast growth; and is thus a major determining factor in assessing the mothering abilities of the doe. Besides the non-significant effect observed in the combining abilities for the weaning weight, the estimated GCA and SCA were comparable to the findings of other researchers. For instance, in the estimation of the GCA for body weight at weaning, El-Bayomi et al. (2012) recorded estimated GCAs of 9.5 for the New Zealand White while 18.5 was estimated for the same breed in the current study. The observed variation in the GCA for the BWW in the New Zealand according to Apori et al., (2014) Assan, (2014); Egena et al. (2014), Kabir et al (2014) and Onyiro et al. (2008) could be attributed to a lesser extent genetics of the breed but more importantly, the effects of the environmental factors. Such as their nutrition, management, housing condition and management.

### **Post-Weaning Growth Performance**

In spite of the fact that the estimated combining abilities of the various cross combinations for BWW did not record any significance, there were significance in the estimated GCA and SCA for the post-weaning growth

performance, with the exception of the BW10wks. The observation made (inconsistencies) were not peculiar to the species or this study. Amin (2015) for instance, also recorded similar inconsistencies with respect to the estimated GCA and SCA for the monthly growth records of a local chicken strain (Mandarrah) and two exotic parental commercial meat type strains (Saso and Italian II) chickens. The observed significance in the GCA and SCA estimated for the 8th week body weight were considerably high and positive. The GCA for the BW8wks varied from 8.6 to 42.3 while the SCA varied from 10.5 to 18.5. The estimated combining abilities were comparable to the observation made by El-Bayomi et al. (2012) with the New Zealand White, California and the Flander rabbits breeds. The respective GCA and SCA ranged between -5.5 -3.4 and -58.3 - 17.7. The observed significance in the combining abilities for BW8wks is very laudable. This gave a good impression of the additive genetic effect on the performance of the rabbit breeds after weaning, and the extent of progress in growth that can be made during this period.

In view of the fact that the estimated combining abilities for the BWW did not record any significance, and it would be a prudent management decision to dispose of the weaned rabbits at the eighth week by which time some level of significance would have been attained in their output. This would offer quite a better in opportunity to have value for money from the best performing pure breed and crossbred combinations. In that case, it would not be out of place to select the NZ and CH X NZ crosses from the purebred and crossbred combinations. This is based on the GCA of 42.3 and SCA of 18.5 recorded in the NZ and CH X NZ cross respectively. To an extent, the comparative advantage of the NZ over the CH and BV breeds was expected

because it (NZ) has been identified as a meat breed with comparatively fast growth rate (Bora et al., 2010). The CH X NZ cross, with its SCA of 18.5 for the BW8wks, positioned it as the best option for selection between the breeds. This is in comparison to the estimated SCA of 16.8 and 10.5 in the BV X CH and NZ X BV crosses respectively. Thus, the CH X NZ cross was able to exhibit their ability to nick or channelled their unique advantages together to obtain heavier weight by the 8th week more efficiently than the other crossbreds did. On the contrary, El-Bayomi et al. (2012) did not record significance on the GCA for the BW8wks, although the SCA recorded some significant effect.

In spite of the general decline in the market weight (BW12wks) as revealed in the combining abilities of the cross combinations compared to the SCA and GCA recorded for the BW8wks, the differences in the estimated GCA and SCA for the BW12wks were significant. Unlike the SCA, there was positive effect on the estimated GCA for the market weight of three rabbit breeds. The estimated GCA for the BW12wks ranged between 2.3 - 12.5; and is comparable to the findings of other researchers (Adenaike et al., 2013; Bora et al., 2010; El-Bayomi et al., 2012; Kabir et al., 2014). Unlike Kabir et al. who recorded significance in the GCA for the BW12wks, El-Bayomi et al. on the contrary did not register any significant differences in the GCA and SCA for the BW12wks. El-Bayomi et al for instance, recorded 15.7 as the estimated GCA in the NZ while the current study recorded 5.5 for the same breed. Bora et al. on the other hand, recorded 0.7 with the same breed. In like manner, estimated GCA in the Chinchilla from the study was 12.5 while Kabir et al. on the other hand, recorded 0.6.

The estimated GCA for the market weight from the study is quite evident in that the performance of the breeds considered in the study were superior to what other studies have revealed. Similarly, the estimated SCA of -10.1 for the BW12wks in the CH X NZ cross is comparable to the -0.7 Kabir et al. (2014) recorded in the same breed combination. Bora et al. (2010) also recorded -1.0 in similar cross combination. According to Mohammed (2012), the negative values suggest that the breeds in the hybrid combination were inferior in their combining abilities for the trait. The estimated GCA in the CH for the BW12wks placed it ahead of the BV and NZ for selection for heavier market, weight while the BV X CH cross would be the best of the three rabbit crossbreds from the study.

#### **Post-Weaning Growth Rate (PGR)**

In spite of the inconsistencies in the post-weaning growth performance within and between the three breeds of rabbits that were used in the study, the GCA and SCA values that were recorded for the PGR were significant. The respective GCA and SCA for the PGR varied from 0.1 - 0.9 and -2.3 - 1.8. The SCA, unlike the GCA, varied quite widely. The CH x NZ and BV x CH however, crosses recorded -1.1 and -2.3 respectively. That obviously made the NZ X BV cross well placed in the selection of an ideal breed for fast growth rate. The estimated SCA for the PGR in the NZ X BV cross was 1.8. That meant that with the exception of the NZ X BV cross, the other two crosses did not respond favourably to the expected effects of crossbreeding. This high performance of the NZ X BV cross can be linked to the comparative growth advantage of the NZ doe which is known for its growth performance. For faster or higher growth rate, it would not be out of place to select the BV breed

of rabbit because its estimated GCA for PGR was the best or highest (0.9) of the three rabbit breeds.



## CHAPTER SIX

### SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

#### Summary

Almost all the crosses respond favourably to the expected effects of heterosis particularly in the reproductive traits compared to the growth traits considered in the present study. Such a positive heterotic effect encourages the application of crossbreeding schemes in commercial rabbit production within the coastal savannah agro-ecological zone. Nonetheless, the highest heterosis was recorded in growth traits. In spite of the disturbing negative heterosis that most of the crosses recorded at weaning, the NZ X BV cross for instance recorded the highest percent heterosis of 26.5; this makes it the ideal cross for improved growth rate post-weaning. Although some of the crosses did not exhibit the expected or desired heterotic effect on all the economic traits (ASM, KIN, MT, BWW, PGR and bi-weekly growth rates) considered in the present study, it was quite evident that a number of the crosses responded favourably; this offers an opportunity for selection. Notable among them was the MT which recorded substantial reduction in most of the crosses. Thus, with the exception of the BV X CH crossbred, all the other crosses would make significant contribution to rabbit production within the agro-ecological zone. The NZ X BV crossbred for instance recorded -24.8% heterosis (i.e. approximately 25% reduction in pre-weaning mortality) and that is very encouraging for farmers within the agro-ecological zone.

The observed reduction in mortalities would also contribute to food security by ensuring that a greater fraction of the litter size reach market

weight (Assan, 2014; McNitt et al., 2013). Likewise, the sale of the rabbits either at weaning or slaughter would positively contribute to the economic status of particularly resource-poor rural-based and backyard farms within the agro-ecological zone. The biweekly body weights after the rabbits had been weaned also recorded both positive and negative heterosis. The inconsistencies in the biweekly growth performance was characteristic of periodic growth measurements and thus inevitable. It was thus not surprising that this did not have any detrimental effect on the post-weaning growth rate of the rabbit crossbreds. The focus or major consideration for selection should thus be on the target market weight. It is however quite obvious that any calculated attempt aimed at improving on the reproductive and growth performance of existing breeds of rabbits via crossbreeding rabbit, just like in any livestock specie within would most likely exhibit any or all of the following outcomes.

- a desired positive heterotic effect in which case the crossbred performance is superior to the performance of the performance of the mid-parents.
- an undesired negative heterotic effect in which case the output of the crossbred is inferior to that of the mid-parents.
- a zero percent heterosis in which the performance of the crossbred is not different from the mid-parent performance but has the added benefit of nicking effect.

In spite of the remarkable output for the economic traits that were considered in the study from the cross combinations, some of the crosses were to an extent outstanding and that makes them well placed for selection and improvement for those economic traits. Notable among them are

- the CH X NZ that recorded heavier bunnies at birth (BWB) and better heterotic effect for ASM, KIN, MT. and BWB
- the NZ X CH which was superior in the mean performance for the LSB, LSW and market weight (BW12wks) and the highest estimated heterosis for the LSB and at weaning.
- the NZ X BV cross which recorded the best mean performance for both the LSB and BW12wks, the best heterotic effect for the BW12wks and PGR and better combining ability for the PGR.
- the CH X NZ exhibited better heterotic effect for ASM, KIN, MT, BWB while the reciprocal cross recorded the highest LSB
- the BV X CH cross which had better combining ability for the LSB, LSW and better GCA for the BWB and BW12wks
- with the exception of the GCA for LSW for which the Blue Vienna performed better within the agro-ecological zone, the Chinchilla was the best of the pure breeds in both the reproductive and growth traits that recorded significant differences.

### **Conclusions**

It was quite obvious that the general performance of all the cross combinations (the purebred, main and reciprocal crosses) for almost all the economic traits that were assessed under the agro-ecological zone was quite appreciable compared to what other studies within the tropics (particularly the West African sub region) have reported for the same breeds. Some of the cross combinations however exhibited some significant level(s) of superiority for at least an economic traits considered in the study and are thus worth mentioning taking into consideration their relevance and contribution towards enhanced

productivity and food security among the less privileged. There is the possibility of recording greater success with improved nutrition particularly during the sensitive periods of the does' reproductive life and an intensive identification and selection of best performing breeds and breed combinations for specific economic traits within the coastal savannah agro-ecological zone of Ghana

For the economic traits (litter size at birth; LSB, bunny weight at birth; BWB, market weight; BW12wks, and the post-weaning growth rate; PGR) that recorded significant differences in the mean performances of the cross combinations as well as the estimated heterosis and combining abilities (GCAs and SCAs), the output of the crossbred combinations (main cross and reciprocal cross) were superior to the purebred cross combinations only that there was no particular trend was observed. It could thus be concluded that,

- The mean reproductive and growth performance of the various cross combinations (purebred, main and reciprocal crosses) for the economic traits considered in the study were desirable. Notable among them were the market weight (BW12wks) which was attained by all the cross combinations, the low mortalities (< 10%) and the litter size at weaning (LSW) which were within the upper quartile of the performance records of commercial meat rabbit breeds under tropical conditions. However, the crossbred combinations (main and reciprocal cross) were generally superior to the purebred combinations.
- The estimated heterosis for a significant number of the economic traits (reproductive and growth) from both the main and reciprocal crosses demonstrated a positive effect. This is good encouragement for the

application of crossbreeding schemes with the existing rabbit breeds within the agro-ecological zone for improved productivity, economic gains and a contribution to food security.

- The effects of the estimated general and specific combining abilities of the pure breed and crossbred combinations were very minimal on both the reproductive (LSB and LSW) and growth (BWB, BW12wks and PGR) traits.

### **Recommendations**

The following recommendations are made towards achieving the ultimate goal of meeting the ever-increasing demand for protein from animal sources, particularly in developing economies like Ghana.

- For improved reproductive and productive performances, it is prudent for the farmers within the coastal savannah agro-ecological zone to adopt crossbreeding practices like the diallel cross because it would offer them the opportunity to capitalise on the positive effects of heterosis and the complementarity of the various rabbit breeds on a number of economic traits.
- For the attainment of higher or improved crossbreeding effects on the reproductive and productive performance of the existing rabbit breeds, it is advised that the breeds are crossed with improved tropical breeds like the Baladi.
- Other available meat rabbit breeds, especially the California White which have been used extensively in other crossbreeding programmes in other agro-ecological zones with outstanding results should be included in subsequent studies.

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