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THESIS

GENETIC ANALYSIS ON GROWTH AND REPRODUCTIVE TRAITS OF ANGLO-NUBIAN, SAANEN, THAI NATIVE AND THEIR CROSSBREDS

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A Thesis Submitted in Partial Fulfillment of
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Data on growth and reproductive traits of Anglo-Nubian, Saanen, Native and crossbred goats at Yala Livestock Research and Breeding Center were analyzed to estimate breed effects, genetic parameters, breeding values and economic values. The investigated growth traits were birth weight (BW) and weaning weight (WW). These were recorded from 2,857 kids born during the period 1995 to 2005. The reproductive measures were type of birth (TB) and kidding interval (KI) that pertained to 1,487 parturitions from the years 1995 to 2005.

Additive breed and heterosis breed effects for growth and reproductive traits were estimated by using fixed effect models. Maternal additive breed effects for Anglo-Nubian and Saanen as deviation from Native were significant ($P<0.01$) for BW (0.96 and -1.54 kilograms, respectively) and WW (3.34 and 5.26 kilograms, respectively). The significant heterosis breed effects observed from Anglo-Nubian x Saanen, Anglo-Nubian x Native and Saanen x Native crossing types ranging from -5.03 to 0.63 kilograms for BW and WW. There was no significant difference in direct additive breed effects for Anglo-Nubian and Saanen for reproductive traits. Heterosis breed effect in the cross of Anglo-Nubian and Native was significant ($P<0.05$) with increasing number of kids born (0.12 heads). Estimation of variance components and parameters were carried out with single-trait and multiple-trait analyses using a derivative-free restricted maximum likelihood procedure. Estimates of direct heritability, maternal heritability and ratio of variance due to maternal permanent environmental effects from single-trait analyses were 0.68, 0.28 and 0.09, respectively for BW. Corresponding estimates were 0.28, 0.10 and 0.04 for WW. Estimates of heritability and permanent environmental variance as a proportion of phenotypic variance of TB and KI were low. The genetic and environmental correlations among BW, WW, TB and KI from multiple-trait analyses ranged from -0.97 to 0.76. Across-breed estimated breeding values for total maternal genetic ranged from -0.37 to 1.03 kilograms for BW and -0.62 to 6.03 kilograms for WW. Across-breed estimated breeding values for direct genetic were from -0.15 to 0.13 heads for TB and -17.34 to 29.84 days for KI. Production and economical data were used to develop profit function for breeding objective. The economic values of breeding objective traits of WW, TB and KI were 86.58, 479.07 and -4.34 baht per unit, respectively.

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Chittima Kantanamalakul
March 2010

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LIST OF ABBREVIATIONS

A = Anglo-Nubian
BW = Birth weight
c^2 = Permanent environmental effect
$D\hat{B}V$ = Estimated direct breeding value
h^2 = Direct heritability
KI = Kidding interval
$M\hat{B}V$ = Estimated maternal breeding value
m^2 = Maternal heritability
N = Native
REML = Restricted maximum likelihood
r_a = Direct genetic correlation
r_c = Maternal permanent environmental correlation
r_e = Environmental correlation
r_m = Maternal genetic correlation
r_{pe} = Permanent environmental correlation
S = Saanen
TB = Type of birth
$TM\hat{B}V$ = Estimated total maternal breeding value
WW = Weaning weight

GENETIC ANALYSIS ON GROWTH AND REPRODUCTIVE TRAITS OF ANGLO-NUBIAN, SAANEN, THAI NATIVE AND THEIR CROSSBREDS

INTRODUCTION

According to the 2008 Yearly Statistics Report, there were approximately 374,029 goats in Thailand (Department of Livestock Development, 2009). About 37.68% of the total population of goats was found in the southern part of Thailand, while the other parts shared nearly 62.32% of them. Most of goats raised in Thailand are recognized as important meat-producing animals, and are similar to many parts of the tropical and subtropical regions (Devendra and Burns, 1983). Apart from meat, milk is a secondary product and mainly used for home consumption. Skin is its by-product. Goat hair and wool are not of economic important in Thailand since there is no domestic demand for these products. Goats in Thailand play a significant role in the poor rural households and contribute a substantial amount to the farmer's total income. Goats are mostly raised by small farmers since they are easily handled by a single person. They are generally grazed on natural grasses and weeds available under tree crops or along roadsides. Wastes and by-products such as fruit peel and tree leaves are popular supplemental feeds for goats. In general, no mineral supplements or systematic disease prevention or parasites prevention such as vaccination or deworming are provided for goats on small farms (Chantalakhana, 1985). Breeds of goats in the southern part of Thailand are mostly of indigenous type. Some of goats are crossbreds between Native goats and exotic breeds such as Anglo-Nubian, Alpine, Boer and Saanen. However, the number of studies on breeding and genetics has been limited and among those is little evidence to suggest progress in the development of the goat as a meat or milk animal. It is imperative that research on breeding and genetics of goat should be given more attention, if goat development is to be realized in the future.

The innovative breeding technology for meat goat production comes from the application of more recently developed knowledge on quantitative genetics that have achieved success in the cattle, swine, sheep and poultry. These major advances include breed evaluation, crossbreeding, formation of composite population, selection indices based on phenotypic and genetic parameters and economic worth, the use of multiple trait mixed model methodologies to estimate of genetic parameters and the simultaneous estimation of breeding values of parents and offspring for identification of individuals with potential merit for their genetic improvement (Shrestha and Fahmy, 2005). The evaluation of breeds is based on the performance of purebred, crossbred and a combination of them. The results have provided vital information that demonstrates opportunity for the genetic improvement of morphological characteristics and production performance under specific feeding and management conditions. A fraction of 570 recognized goat breed populations in the world listed in the inventory of domestic animal diversity of the Food and Agriculture Organization of the United Nation (Scherf, 2000) has been subjected to evaluation. The more important breeds that appear to be capable of making a special genetic contribution to the improvement of goat production in tropical and subtropical regions mentioned here are Anglo-Nubian, Saanen, and Kambing Katjang. The Anglo-Nubian breed is a cross between the Prick eared goats indigenous to Britain and Nubian-type goats from Africa and India (Zaraibi, Chitral and Jamnapari). It is recognized as a dual-purpose (meat and milk) breed. It has proved to be well suited to tropical climates and used widely for upgrading local goats for meat and milk in various countries. The Saanen breed originated from West Switzerland. This breed has the highest milk yield of any breed and for this reason has been introduced into many countries. In most instances, Saanen has produced well, yet it is commonly believed to be less suited to the tropics than other European breeds (Devendra and Burns, 1983). The Kambing Katjang goats, indigenous to Malaysia and Indonesia, are raised for meat and are common throughout Southeast Asia including the southern part of Thailand (Falvey, 1977). The Kambing Katjang goats are capable of breeding all year round. They possess good natural characteristics of heat and tick tolerance and high fecundity under harsh circumstances but low growth potential (Hirooka *et al.*, 1997).

Crossbreeding is a widely accepted and common practice in livestock and poultry around the world. All crossbreeding systems are based on breed diversity and therefore, heterosis influences performance. Some crossbreeding systems also benefit from complementarity (Leymaster, 2002). The objective of crossbreeding is realized to improve efficiency of growth traits, reproduction traits and survival rate. Several approaches to crossbreeding have been practiced in goat production: two-breed cross derived from exotic breeds and indigenous goats; three-breed cross by mating the crossbred dams with purebred sires; backcross of two-breed cross dams to male parent; and a combination of specific breed cross to form composite populations. In developing countries, two-breed cross derived from exotic breeds that have demonstrated considerable potential for improved productivity in their country of origin and indigenous goats with superior adaptability are perceived to be more productive under conditions and requirements. This belief has led to successive generations of unintentional crossbreeding, often resulting in upgrading to the exotic breeds and thereby contributing to the loss of important characteristics such as adaptability, fecundity and disease resistance and the narrowing of the genetic base to the detriment of performance in crossbred population. Therefore, there is a need to evaluate likely sources of breeding animals for crossbreeding from selected breeds in each country. Furthermore, performance of all possible cross combinations of two or more breeds would be predicted in order to identify the optimum cross that would approach maximum efficiency (Shrestha and Fahmy, 2007).

Selection is a strategy of genetic improvement usually carried out in individual populations in order to increase the average level of genetic merit of those populations. Objective selection involves measuring and selecting on performance for traits considered to be of economic importance for meat goat production. Estimates of genetic parameters for traits such as heritability and correlation between traits indicate individual situation the extent to which the traits of interest can be improved simultaneously. Therefore, the potential of genetic improvement depends on genetic parameters that have been utilized for development selection criteria. Furthermore, the identification of the most promising animal based on estimated breeding values for a specific trait or an index of several traits, followed by dissemination of genetic gain makes it possible to achieve rapid and permanent improvement of the breeding stock (Bourdon, 2000). However, the general goal in animal breeding is aiming a new generation of animals that can produce more efficiently under future in economic and social circumstances than at present generation of animals. In practice the optimal selection strategy should be defined in terms of maximized gain for the aggregate genotype including all relevant traits. In breeding objectives for other livestock species such as dairy cattle or pigs, traits are often weighted by their effect on genetic improvement, and therefore, on the economic efficiency of production (economic values) (Albera *et al.*, 2004).

Most breeders play more attention to growth and reproductive performance of goat. Because biological production in goat system oriented on meat production basically consists of the accumulation of live weight through the growth of individual animals and through an increase in number of animals (Alexandre and Mandonnet, 2005). Growth performance could be measured and expressed as the body weights at various ages. Growth before preweaning age becomes importance in goat production system, especially the system that kids were sold at weaning. Birth weight and weaning weight are strongly correlated with survival, postnatal growth and adult size (Devendra and Burns, 1983). The rapid growth during the preweaning period minimizes cost of rearing and provides more profit to farmers (Malik *et al.*, 1986).

The profitability of production depends primarily on the efficiency of offspring production and the most factor affecting flock efficiency is reproduction. Especially in the tropical conditions where only the most hardy and adapted females are able to give and rear their offspring under heat stress, malnutrition, disease and parasite problem and poor management. Reproduction efficiency in female goats is determined by many different processes. These processes include, for example, the length of breeding season, cyclic activity, ovulation rate, fertilization rate, the post-partum anoestrus period and the growth and viability of the offspring. Reproductive efficiency as such can be measured and expressed as the kidding rate, weaning rate, kidding interval, number of kids born or weaned and length of reproductive cycle (Greyling, 2000). However, there is still limited information on reproductive performance of goats from temperate climate performing in the tropics, particularly in Thailand.

OBJECTIVES

The objectives of this study were:

1. To estimate breed effects for birth weight, weaning weight, type of birth and kidding interval.

2. To estimate genetic parameters for birth weight, weaning weight, type of birth and kidding interval.

3. To estimate breeding values for birth weight, weaning weight, type of birth and kidding interval.

4. To estimate economic values of weaning weight, type of birth and kidding interval.

5. To construct an index selection on dam for genetic improvement and increasing profit from the sale of weaned kids.

LITERATURE REVIEW

1. Growth performance

1.1 Growth performance of purebred goat

It is estimated that there are 570 breeds, types, populations and landraces of goats in the world, of which 187 (33%) are in Europe, 146 (26%) in Asia and Pacific regions and 89 (16%) in Africa (Scherf, 2000). These goats vary conspicuously in body size. Devendra and Burns (1983) classify them into three categories (large, small and dwarf) according to height at withers. The approximate weight of adult females is also indicated, despite its unreliability due to variation with condition. It will be seen that dams of the large breeds weight anything from 20 to 65 kilograms, the small breed females weight 20 to 45 kilograms and dwarf dams weight 18 to 25 kilograms. The temperate breeds such as Alpine, Anglo-Nubian, Saanen and Toggenburg would be classified as large goats, while tropical and some subtropical breeds such as Draa, Emirati, Katjang and West African Dwarf would be small and dwarf goats.

Information on birth weights of various breeds of goat in the tropics and other regions in the world has ranged from 1.28 to 4.47 kilograms. The variation in birth weight is due to both genetic and environmental factors. The differences between breeds are primary genetic that have been considerable selection. The Alpine, Anglo-Nubian, Blended, Boer, Common African, Damascus, Jamunapari, Saanen, Sahel, Sirohi and Toggenburg classified as large goats according to height at withers are heavier at birth with the range of 2.47 to 4.47 kilograms (Epstein and Herz, 1964; Gill and Dev, 1972; Mishra and Chawla, 1976; Mavrogenis *et al.*, 1984; Sharma and Das, 1995; Das *et al.*, 1996; Mohammed and Amin, 1996; Mehta *et al.*, 1997; Schoeman *et al.*, 1997; Els, 1998; Mourad and Anous, 1998; Ahuya *et al.*, 2009). The breeds classified as small and dwarf goats such as Black Bengal, Chanthangi, Creole, Draa, Emirati, Thai Native, Turkish Angora and West African Dwarf are all near the lower end of the range (1.28 to 2.43 kilograms; Malik *et al.*, 1986; Milton *et al.*, 1987; Saithanoo *et al.*, 1993; Gerstmayr and Horst, 1995; Sheikh *et al.*, 1996; Alexandre *et al.*, 1999; Al-Shorepy *et al.*, 2002; Bosso *et al.*, 2007; Boujenane and El Hazzab, 2008). Within breed differences are largely due to variation of environment, especially in nutrition, health and management that can affect the efficiency with which nutrients in the feed are converted by the dam to foetal weight.

In this review, performance of weaning weight from different studies varied from 5.29 to 17.80 kilograms. This trait is known to be affected by many factors such as breed, farm flock condition, level of nutrition, type of birth in the litter, age of dam, sex and season. In comparison of breed different size, weaning weights of large size goats (8.70 to 17.80 kilograms; Mavrogenis *et al.*, 1984; Sharma and Das, 1995; Das *et al.*, 1996; Mohammed and Amin, 1996; Mehta *et al.*, 1997; Schoeman *et al.*, 1997; Els, 1998; Mourad and Anous, 1998; Ahuya *et al.*, 2009) tend to be higher than those of the small breeds (8.82 to 10.90 kilograms; Milton *et al.*, 1987; Saithanoo *et al.*, 1993; Gerstmayr and Horst, 1995; Al-Shorepy *et al.*, 2002; Boujenane and El Hazzab, 2008) and dwarf breeds (5.29 to 8.34 kilograms; Malik *et al.*, 1986; Sheikh *et al.*, 1996; Alexandre *et al.*, 1999; Bosso *et al.*, 2007). The summary of body weights at birth and weaning age of straightbreds are available in Table 1.

1.2 Growth performance of crossbred goat

Ruvuna *et al.* (1988) evaluated body weights of 810 kids of East African and Galla goats and their crossbreds sired by the Toggenburg and Anglo-Nubian breeds in Kenya. Body weights of kids from birth and 4 months of age were lowest for East African and heaviest for Anglo-Nubian x Galla. Kids derived from Toggenburg and Anglo-Nubian-sired East African dams exceed the dam breed in body weight by 10% at birth and 8 to 10% at 4 months of age. In India, Acharya (1988) summarized body weight at birth and older ages of the Beetal, Malabari and Sangamaneri breeds and their crosses derived from sires of the Alpine, Saanen and Angora breeds. In general, the crossbred offspring derived from dairy breeds exceeded the female parent in body weight from birth to 12 months of age. Similarly, Saithanoo *et al.* (1993) reported that 50% and 75% Anglo-Nubian x Native kids had significantly ($P<0.01$) higher growth rates than Native and 25% Anglo-Nubian x Native kids. They also observed that 50% and 75% Anglo-Nubian x Native crossbred dams had higher milk yields from week 1 to 12 after kidding than Native and 25% Anglo-Nubian x Native dams.

Crossbreeding of two-breed cross dams to sires to produce the backcross offspring is common among goat producers in many countries. This procedure not only benefits from heterosis in maternal performance of the crossbred female parent but also in their offspring. However, the proportion of heterozygosity and expected heterosis in the backcross offspring results in a reduction in performance arising from the failure to benefit from the full complement of heterosis and genetic superiority associated with the parental breeds may not be optimal (Shrestha and Fahmy, 2007). Gebrelul *et al.* (1994) compared kids of the Alpine and Nubian breeds and their single and backcrosses (including reciprocal crosses) in USA. The body weight of kids of the single cross exceeded contemporary kids of the purebred dam by 4 to 11% at birth and 8 to 17% at 10 to 12 weeks of age. Correspondingly, body weight of kids of the backcross compared to contemporary kids of the single cross were -3 to 6% at birth and -8 to 16% at 10 to 12 weeks of age. Crossbreeding the Beetal breed with dams of the Sirohi breed to produce the Beetal x Sirohi cross was followed by backcrossing the crossbred dams with sires of the Beetal breed to produce Beetal x (Beetal x Sirohi) cross kids for comparison with contemporary kids of the Sirohi and Beetal x Sirohi. The body weights of the Sirohi, Beetal x Sirohi and Beetal x (Beetal x Sirohi) kids were 2.9, 3.1 and 2.9 kilograms, respectively at birth and 9.6, 10.4 and 8.4 kilograms, respectively at 3 months of age (Taneja, 1982).

2. Reproductive performance

2.1 Reproductive performance of purebred goat

The goat is the most prolific of all domestic ruminants under tropical and subtropical conditions (Greyling, 2000). The female goats can give births from one to four kids per kidding. The variation may range from 1.25 heads for the Alpine breed under a dry tropical forest of Mexico (Dickson-Urdaneta *et al.*, 2000) to 2.90 heads for the Zaraibi breed under a hot arid climate of Egypt (Marai *et al.*, 2002). The Zaraibi goats are the main progenitor of the Anglo-Nubian and are one of the most prolific seasonal breeders (Devendra and Burns, 1983). The higher odds of multiple births of the Nubian breed than those of dairy goats of European origin (Alpine and Saanen) were observed by Amoah *et al.* (1996) and Dickson-Urdaneta *et al.* (2000). These were consistent with Freitas *et al.* (2004) who found that the occurrence of multiple partum was superior in Anglo-Nubian than Saanen in semi-arid of the North-eastern Brazil (62.1% vs 47.4%).

Seasonality of reproduction is a common feature in goat breeds in temperature latitudes and photoperiod seems to be the key factor controlling reproduction (Shelton, 1978). However, under tropical conditions, where the amplitude of the changes of the photoperiod is lower, it is known that local breeds of goats are either nonseasonal breeders or exhibit only a weak seasonality in reproduction. Females of these breeds ovulate and exhibit oestrus almost the whole year round (Chemineau, 1986). The earlier studies of kidding interval have shown the range of 207.80 to 414.30 days. The intervals were shorter in the Creloe, Red Sokoto and Korean native which were indigenous goats of Guadeloupe, Nigeria and Korea, respectively (Alexandre *et al.*, 1999; Awemu *et al.*, 1999; Song *et al.,* 2006). While the temperate goats such as the Alpine, Saanen, Toggenburg and Nubian breeds had the longer kidding interval that were more than 300 days (Silva *et al.*, 1998; Dickson-Urdaneta *et al.*, 2000). In comparison between Anglo-Nubian and Saanen, Freitas *et al.* (2004) observed that Saanen goats showed more efficient milk production but presented a longer post-partum anoestrus when compared to Anglo-Nubian raised under semi-arid of North-eastern Brazil. The greater efficiency in milk production of Saanen breed, comparing to Anglo-Nubian breed, was probably responsible for the negative correlation between body condition at partum and length of post-partum anoestrus detected in this breed. The body weight and condition of a mother at partum was important because mothers below normal weight or with unsatisfactory body condition at partum produce lighter kids, less milk and take longer to recover the ovarian function after partum. As stated by Devendra and Burns (1983), "Kidding interval is the period between two consecutive kidding dates, and is composed of service period (from kidding to conception) and gestation length. Its duration depends on the start of oestrus activity during the post-partum period." The performance of type of birth and kidding interval of various breed are summarized in Table 2.

2.2 Reproductive performance of crossbred goat

In India, reproductive performance of the Beetal and Malabari breeds and their crosses derived from sires of the Alpine and Saanen breeds were evaluated. The study revealed that the crossbred offspring derived from dairy breeds had lower incidence of twin and triplet pregnancies, but longer service period and kidding interval than those of purebred Beetal and Malabari (Acharya, 1988). Montaldo *et al.* (1995) analyzed performance data of 1,424 goats from crossing Alpine, Granadina, Nubian, Saanen and Toggenburg sires with local Mexican dams. They concluded that the low and high grade Alpine, Nubian, Saanen and Toggenburg were more productive than local Mexican goats in little size at birth under stall feeding conditions.

Table 1 Body weights at birth and weaning age of various breeds

Breed	Location	Trait[1]		Reference
		BW (kg)	WW (kg)	
Large breed				
Alpine	Egypt	2.80 ± 0.10[3]	10.40 ± 0.10[3]	Mourad and Anous (1998)
Anglo-Nubian	India	2.90	-	Gill and Dev (1972)[4]
Anglo-Nubian	Israel	3.40	-	Epstein and Herz (1964)[4]
Blended	Tanzania	2.47 ± 0.02[3]	11.14 ± 0.15[3]	Das *et al.* (1996)
Boer	South Africa	4.40 ± 0.73[2]	17.80 ± 4.42[2]	Schoeman *et al.* (1997)
Boer	Republic of Namibia	4.42 ± 0.73[2]	17.80 ± 4.42[2]	Els (1998)
Common African	Egypt	2.70 ± 0.10[3]	8.70 ± 0.10[3]	Mourad and Anous (1998)
Damascus	Cyprus	4.47 ± 0.06[3]	17.69 ± 0.30[3]	Mavrogenis *et al.* (1984)
Jamunapari	India	3.19 ± 0.07[3]	12.27 ± 0.41[3]	Sharma and Das (1995)
Saanen	Israel	3.30	-	Epstein and Herz (1964)[4]
Saanen	India	3.00	-	Mishra and Chawla (1976)[5]
Sahel	Nigeria	2.70 ± 0.50[2]	8.80 ± 0.60[2]	Mohammed and Amin (1996)
Sirohi	India	2.88 ± 0.03[3]	12.58 ± 0.17[3]	Mehta *et al.* (1997)
Toggenburg	Kenya	3.27 ± 0.66[2]	16.17 ± 3.83[2]	Ahuya *et al.* (2009)
Small breed				
Emirati	United Arab Emirates	2.43 ± 0.71[2]	10.90 ± 2.58[2]	Al-Shorepy *et al.* (2002)
Draa	Morocco	2.32 ± 0.42[2]	9.29 ± 1.63[2]	Boujenane and El Hazzab (2008)

Table 1 (Continued)

Breed	Location	Trait[1]		Reference
		BW (kg)	WW (kg)	
Small breed				
Native	Thailand	1.90 ± 0.36[2]	10.90 ± 2.30[2]	Milton *et al.* (1987)[6]
Native	Thailand	1.60 ± 0.28[2]	8.90 ± 1.70[2]	Milton *et al.* (1987)[7]
Native	Thailand	1.28 ± 0.19[3]	8.82 ± 0.69[3]	Saithanoo *et al.* (1993)
Turkish Angora	Turkey	1.87 ± 0.27[2]	10.82 ± 1.89[2]	Gerstmayr and Horst (1995)
Dwarf breed				
Black Bengal	India	1.31 ± 0.04[3]	5.29 ± 0.24[3]	Malik *et al.* (1986)
Chanthangi	India	1.82 ± 0.01[3]	8.34 ± 0.01[3]	Sheikh *et al.* (1996)
Creole	Guadeloupe	1.73 ± 0.34[2]	7.75 ± 1.76[2]	Alexandre *et al.* (1999)
West African Dwarf	Keneba	1.57 ± 0.36[2]	5.75 ± 1.65[2]	Bosso *et al.* (2007)

[1] BW= birth weight, WW = weaning weight

[2] standard deviation

[3] standard error

[4] single male born kids

[5] single female born kids

[6] single born kids

[7] twin born kids

Table 2 Type of birth and kidding interval of various breeds

Breed	Location	Trait[1]		Reference
		TB (head)	KI (day)	
Alpine	Georgia, USA	1.90 ± 0.12^{3}	-	Amoah *et al.* (1996)
Alpine	Mexico	1.69 ± 0.50^{2}	345.00 ± 70.00^{2}	Silva *et al.* (1998)
Alpine	Mexico	1.25 ± 0.04^{3}	390.70 ± 15.20^{3}	Dickson-Urdaneta *et al.* (2000)
Boer	Tennessee, USA	1.51 ± 0.07^{3}	-	Browning *et al.* (2006)
Creloe	Guadeloupe	1.95	255.00 ± 36.00^{2}	Alexandre *et al.* (1999)
Damascus	Cyprus	1.62	-	Güney *et al.* (2006)
Kiko	Tennessee, USA	1.69 ± 0.07^{3}	-	Browning *et al.* (2006)
Korean native	Korea	1.69 ± 0.03^{3}	207.80 ± 1.70^{3}	Song *et al.* (2006)
Alpine, Saanen, Toggenburg, Nubian	Mexico	1.67 ± 0.20^{2}	347.00 ± 56.00^{2}	Galina *et al.* (1995)
Local	Mexico	1.72 ± 0.11^{2}	-	Montaldo *et al.* (1995)
Nubian	Georgia, USA	2.00 ± 0.07^{3}	-	Amoah *et al.* (1996)
Nubian	Mexico	1.38 ± 0.05^{3}	414.30 ± 21.50^{2}	Dickson-Urdaneta *et al.* (2000)
Pygmy	Georgia, USA	1.90 ± 0.13^{3}	-	Amoah *et al.* (1996)
Red Sokoto	Nigeria	1.80 ± 0.02^{3}	215.00 ± 3.20^{3}	Awemu *et al.* (1999)
Saanen	Georgia, USA	1.70 ± 0.11^{3}	-	Amoah *et al.* (1996)
Spanish	Tennessee, USA	1.79 ± 0.07^{3}	-	Browning *et al.* (2006)
Toggenburg	Georgia, USA	1.60 ± 0.20^{3}	-	Amoah *et al.* (1996)
West African Dwarf	Nigeria	1.79 ± 0.05^{3}	275.68 ± 6.08^{3}	Odubote (1996)
Zaraibi	Egypt	2.90 ± 0.30^{3}	350.00 ± 13.00^{3}	Marai *et al.* (2002)

[1] TB = type of birth, KI = kidding interval

[2] standard deviation

[3] standard error

3. Breed effects for growth and reproductive traits

Diversity among breeds within each livestock species offers the opportunity to increase production efficiency by crossbreeding. Understanding of the genetic basis of crossbreeding effects was enhanced by Dickerson (1969) who developed a comprehensive model to predict the relative merit of crossbreeding systems in terms of a few parameters, for examples, direct average genetic effects, maternal average genetic effects, heterosis effects in the crossbred progeny and dam and recombination losses in the offspring and dam. Knowledge of these parameters for breeds and breed crosses would allow comparison of various crossing schemes.

3.1 Breed effects for growth traits

Dillard *et al.* (1980) estimated additive genetic effects of Angus and Charolais as deviation from the Hereford additive genetic for birth weight by using regression approach. They observed that Angus additive genetic effect significantly negative (-4.30 kilograms, $P<0.01$), while Charolais additive genetic effect was positive and significant (3.40 kilograms, $P<0.05$). They discussed that a reason might be due to the large mature size potential differential among these three breeds. Charolais was a larger-framed breed as compared with that of Hereford and Hereford was a larger-framed breed as compared with that of Angus. Boujenane *et al.* (1991) estimated direct genetic effect for growth to 1 year from 882 lambs of a diallel cross of Sardi, D’man and D’man x Sardi male and female parents in Morocco. Relative to Sardi breed, D’man had a low breed contribution to birth weight (-0.58 kilograms). They explained that Sardi breed had a higher genetic potential for growth traits than did D’man breed. The mature weights of D’man and Sardi females raised in this flock were from 30 to 35 and 45 to 48 kilograms, respectively.

Ferrell (1991) demonstrated the importance of maternal uterine environment on fetal growth in cow. Data from his study showed that perfusion and function of uteroplacental tissues have central roles in influencing fetal growth. Broadly, function of those tissues involves transmission of water, gases and nutrients to the fetus, excretion of waste products of fetal metabolism to the maternal system and production of hormones and hormone precursors to modify maternal metabolism to ensure that the needs of the fetus are met. Heat stress during gestation would reduce progesterone concentration, uterine blood flow, ovine placental lactogen and birth weight of calves (Collier *et al.*, 1982). In addition to this factor, Mukundan *et al.* (1981) observed that birth weight of Malabari kids was lower than that of Saanen halfbreds. This could result from inadequate uterine space available in Malabari dams, which control foetal size. Boujenane *et al.* (1991) also reported a significantly higher maternal effect of Sarbi as deviation from D'man for birth weight of lambs (0.22 kilograms).

Generating heterosis is one of the most important reasons for crossbreeding, so any worthwhile crossbreeding system should valid any adequate amount of heterosis. An adequate amount of heterosis is depended on genetic difference of original breeds, but has complementary attributes (Bourdon, 2000). The causes of heterosis effect may be due to genetic mechanisms (dominance and epistasis). When dominance is the cause of heterosis and there is no interaction between loci, heterosis is directly proportional to amount of heterozygosity at the loci (Hill, 1981). Heterosis effect is maximized in the F_1 or first cross of unrelated (though not necessarily purebred) populations and should expected to decline in later generations with the loss of heterozygosity. Mugambi *et al.* (2007) estimated heterosis effect from 6,800 progeny of straightbreds, two-bred crosses, four-breed crosses and composite populations of Toggenburg, Anglo-Nubian, Small East African and Galla breeds in Kenya. They observed the positive effect (0.05 kilograms) for birth weight. Tumwasorn *et al.* (1993) estimated heterosis effects for individual components from straightbred and crossbred populations of Native, Brahman and Charolais at Kamphaeng Sean Livestock Research Station, Thailand. They reported that heterosis effects obtained from three crossing types (Natvie x Brahman, Native x Charolais and Brahman x Charolais) significantly positive for birth weight of calves (4.28, 3.68 and 6.13 kilograms, respectively; $P<0.01$). The favorable effects on the same trait were reported by Dillard *et al.* (1980) with small amount of 0.50, 1.10 and 0.70 kilograms, for Angus x Hereford, Angus x Charolais and Charolais x Hereford, respectively.

While the unfavorable effect of heterosis for birth weight of calves were obtained by Kahi *et al.* (1995) for Angus x Sahiwal and Angus x Brown Swiss crosses (-0.70 and -1.01 kilograms, respectively) and Olson *et al.* (1985) for Angus x Brown Swiss cross (-0.10 kilograms).

Mugambi *et al.* (2007) estimated additive breed effects for Anglo-Nubian, Toggenburg and Galla expressed as deviation from the Small East African goat for weaning weight. Among these breeds, Anglo-Nubian had the highest breed contribution to weaning weight, followed by Toggenburg and Galla (1.57, 1.23 and 0.25 kilograms, respectively). Gerstmayr *et al.* (1995), in contrast, reported negative influence of American Angoras additive genetic on upgrading the Turkish Angora goats in the Çifteler government farm, Middle Anatolia, Turkey for body weight at 105 days of kids (-0.79 kilograms).

Maternal effects on postnatal growth mostly refer to differences in weaning weight of offspring caused by differences in maternal environment provided during nursing. The important difference in maternal ability during nursing has been measured in milk production. MacNeil *et al.* (1982) reported a much lower maternal additive breed effects for the Angus dams as compared with that of the Simmental dams. Similar results were observed by Spelbring *et al.* (1977), when comparing the Angus and Milking Shorthorn breeds.

The positive heterosis effects were obtained by Boujenane *et al.* (1991) for D'man x Sardi cross for 90-day weight (0.29 kilograms) and Alenda *et al.* (1980) for 205-day weight ranged from 11.00 kilograms for Charolais x Hereford cross to 20.00 kilograms for Angus x Charolais cross. Mugambi *et al.* (2007) reported of -0.21 kilograms for the overall heterosis effect from Kenya Dual Purpose Goat composite population. They concluded that the unfavorable effect might be due to environmental condition where the animals were reared. Cunningham (1981) suggested that production in poor environment was influenced heavily by heterosis, while production in good environment was determined by breed additive effect.

3.2 Breed effects for reproductive traits

By exploiting both additive and nonadditive effects of gene simultaneously crossbreeding among breeds of sheep provides a means of improving efficiency of lamb production (Dickerson, 1969). In a study by van Haandel and Visscher (1995), crossbreeding parameters for the number of lambs born were estimated from 13 crossbreeding groups between Finnish Landrace and Ile de France sheep by regression analyses. The results showed a significant effect of additive breed for Finnish Landrace as deviation from Ile de France breed with the amount of 0.79 heads and a significant heterosis effect of 0.35 heads from a cross of Ile de France x Finnish Landrace. Boujenane and Bradford (1991) also reported that D'man additive effect as deviation from Sardi sheep was positive and significant for number of lambs born (0.94 heads), while heterosis effect between D'man x Sardi cross was not significant (0.35 heads).

4. Variance components and parameters for growth traits

4.1 Variance components and parameters for birth weight

The reported estimates of heritability for birth weight in goat varied from 0.15 to 0.68. The large variation may be due to main causes of different among populations in particular periods of time under specific environmental circumstance, the different methods employed in computing and the large sampling error. In this review, the estimates of heritability will be categorized into two groups according to methods of computing. From 13 values examined, 6 were calculated by the method of paternal half-sib correlation and 7 were calculated by fitting animal model using a restricted maximum likelihood (REML) procedure.

Heritability estimates which were calculated by the method of paternal half-sib correlation ranged from 0.15 to 0.68 (see Table 3). Mavrogenis *et al.* (1984) studied with 1,542 Damascus kids from Goat Breeding Unit, Akhelia, India. They reported the heritability estimate of 0.31. Das *et al.* (1996) calculated the heritability estimate from 4,799 Blended kids at Malya Research Centre, Tanzania. The value was 0.15. During the years 1993 to 1994, Thongchumroon (1996) collected the data of 411 Anglo-Nubian x Native and Saanen x Native crossbred kids, the progeny of 5 sires and 245 dams at Yala Livestock Research and Breeding Center. He estimated heritability to be 0.20. Heritability estimate obtained from 576 Sirohi kids at Western Regional Research Centre, India was 0.40 (Mehta *et al.*, 1997). The value of 0.68 was obtained from 1,526 Common African and Alpine crossbreds at Masaka, Kigali, Rwanda (Mourad and Anous, 1998). Portolano *et al.* (2002) reported the value of 0.49 from 276 Girgentana kids in experimental farm in Sicily, Italy.

Table 3 Paternal half-sib heritability estimates for birth weight of kids

Breed	Heritability	Reference
Damascus	0.31 ± 0.08	Mavrogenis *et al.* (1984)
Blended	0.15 ± 0.04	Das *et al.* (1996)
Crossbreds	0.20 ± 0.17	Thongchumroon (1996)
Sirohi	0.40 ± 0.25	Mehta *et al.* (1997)
Crossbreds	0.68 ± 0.14	Mourad and Anous (1998)
Girgentana	0.49 ± 0.07	Portolano *et al.* (2002)

The estimates of variance components and parameters for birth weight in goat by fitting animal model using REML procedure are presented in Table 4. Els (1998) estimated phenotypic variance and heritability from 1,517 kids in the Omatjenne Boer goats stud between 1977 and 1986 by fitting animal effect in the model. He observed them to be 0.34 kilogram^2 and 0.36, respectively. Bosso *et al.* (2007) reported the estimates of phenotypic variance and heritability with the same model to be 0.10 kilogram^2 and 0.50, respectively based on 2,080 West African Dwarf goats at the International Trypanotolerance Centre in Keneba.

The growth traits at an early age in farm animals are known to be influenced by direct and maternal effects (Meyer, 1992). Direct effect refers to the effect that an individual's own genes have on its performance. Maternal effect refers to the dam's own genotype for milking and mothering ability and the permanent effect of the environment on her maternal ability. Maternal effects are the phenotypic expressions arising from those influences which the mother may have on the expression of a trait in her offspring. This effect apart from the direct influence of the gene she transmits (Legates and Warwick, 1990). The estimates of direct and maternal components of variance are important to make information genetic evaluations that are required for a successful livestock genetic improvement program. Ferreira *et al.* (1999) and de Mattos *et al.* (2000) found that the effects of maternal genetic and permanent environment can be reduce the biased of direct heritability estimates.

There are few estimates of variance components and heritability for birth weight of kids by fitting maternal effects in the models. Schoeman *et al.* (1997) studied with 3,040 kids in Boer goat herd at the Adelaide Experimental farm in the Eastern Cape Province of South Africa. Estimates of direct and maternal heritability obtained from a comprehensive model which included animal and maternal effects were 0.16 and 0.14, respectively. Zhang *et al.* (2008) reported the values of 0.19 and 0.17 for direct and maternal heritability estimates from the same model. In the earlier studies, direct heritability estimates were larger than their corresponding maternal values. Similar results were obtained in beef cattle (Meyer, 1992; Ferreira *et al.*, 1999; Demeke *et al.*, 2003) and sheep (Al-Shorepy and Notter, 1996; Hassen *et al.*, 2003). Hirooka *et al.* (1997), in contrast, estimated direct and maternal heritabilities from Malaysian local goats and crosses with German Fawn breed to be 0.16 and 0.24. Boujenane and El Hazzab (2008) studied with 1,498 Draa kids belonging to one station at Ouarzazate region (South-East of Morocco). They used animal model including maternal effect in estimating the value of 0.17 and 0.21 for direct and maternal heritabilities, respectively.

Table 4 Estimates of parameters[1] from animal model for birth weight of kids

Breed	σ_P^2	h^2	m^2	r_{am}	c^2	Reference
Crossbreds	-	0.16	0.24	0.19	-	Hirooka *et al.* (1997)
Boer	0.29	0.16	0.14	-0.31	0.06	Schoeman *et al.* (1997)
Boer	0.34	0.36	-	-	-	Els (1998)
Emirati	0.51	0.18	0.18	-	0.00	Al-Shorepy *et al.* (2002)
West African Drawf	0.10	0.50	-	-	-	Bosso *et al.* (2007)
Draa	0.14	0.17	0.21	-0.07	0.00	Boujenane and El Hazzab (2008)
Boer	0.57	0.19	0.17	-0.71	0.11	Zhang *et al.* (2008)

[1] σ_P^2 = phenotypic variance, h^2 = direct heritability, m^2 = maternal heritability, r_{am} = direct-maternal genetic correlation, c^2 = maternal permanent environmental variance as a proportion of phenotypic variance

The estimates of heritability for birth weight considered maternal effects in sheep indicate values to expect in goat. Maternal heritability estimates of most studies (such as Tosh and Kemp, 1994; Bromley *et al.*, 2000; Neser *et al.*, 2001; Rashidi *et al.*, 2008) were low to moderate in magnitude. In the review, Safari *et al.* (2005) reported estimates of weight mean maternal heritability for birth weight of 0.18 to 0.24 in dual-purpose, wool and meat sheep breeds. The estimates of parameters from animal model including animal and maternal effects for birth weight in sheep shows in Table 5.

In general, the estimates of genetic correlation between direct and maternal effects varies considerably indirection from negative to positive and are low to moderate in magnitude. The negative correlations for birth weight of kids and lambs have been reported in the literature ranged from -0.05 (Hanford *et al.*, 2002) to -0.99 (María *et al.*, 1993) (see Tables 4 and 5). The negative values indicate antagonism between the genes for prenatal growth and the genes conditioning the intrauterine environment for heavier weights at birth. Such an antagonism would be a balanced mechanism with the tendency to maintain birth weights in intermediate ranges (Brown and Galvez, 1969). Notter (1998), in addition, observed that allowing of the negative additive-maternal covariance in the model for preweaning weights had the expected effects of inflating direct heritability and maternal heritability estimates but marginally influencing phenotypic variance and a ratio of maternal permanent environmental variance to phenotypic variance. However, the extreme estimates seem far too large to represent true biological relationship (Robinson, 1996). One possible reason for the large negative values of direct-maternal genetic correlations is the small number of progeny per dam and limited information from recorded dams (Gerstmayr, 1992; Maniatis and Pollott, 2003). Heydarpour *et al.* (2008) suggested that complete datasets with more links between dam performance records and offspring records, as well as more progeny per dam were required for reliable estimates of genetic parameters.

Many studies estimated maternal permanent environmental effects for birth weight of kids and lambs to be from 0.00 to 0.17 (such as Mousa *et al.*, 1999; Ligda *et al.*, 2000; Al-Shorepy *et al.*, 2002; Rashidi *et al.*, 2008; Zhang *et al.*, 2008). The higher estimates (0.27 to 0.37) were obtained by a study of Tosh and Kemp (1994) from Hampshire, Pooled Doset and Romanov sheep.

Table 5 Estimates of parameters^1 from animal model for birth weight of lambs

Breed	σ^2_P	h^2	m^2	r_{am}	c^2	Reference
Romanov	0.40	0.04	0.22	-0.99	0.10	María *et al.* (1993)
Hampshire	0.60	0.39	0.22	-0.56	0.37	Tosh and Kemp (1994)
Pooled Doset	0.40	0.12	0.31	-0.35	0.27	Tosh and Kemp (1994)
Romanov	0.30	0.07	0.13	-0.13	0.32	Tosh and Kemp (1994)
Crossbreds	1.02	0.09	0.17	0.01	0.09	Mousa *et al.* (1999)
Columbia	0.74	0.18	0.24	-0.20	0.09	Bromley *et al.* (2000)
Polypay	0.55	0.16	0.21	0.12	0.10	Bromley *et al.* (2000)
Rambouillet	0.54	0.19	0.18	-0.09	0.11	Bromley *et al.* (2000)
Targhee	0.67	0.22	0.19	0.08	0.10	Bromley *et al.* (2000)

Table 5 (Continued)

Breed	σ_P^2	h^2	m^2	r_{am}	c^2	Reference
Chios	0.51	0.18	0.19	-0.44	0.17	Ligda *et al.* (2000)
Dorper	0.53	0.11	0.10	0.35	0.12	Neser *et al.* (2001)
Columbia	0.54	0.27	0.25	-0.05	0.05	Hanford *et al.* (2002)
Targhee	0.48	0.25	0.20	0.09	0.08	Hanford *et al.* (2003)
Polypay	0.42	0.17	0.20	0.19	0.10	Hanford *et al.* (2006)
Kermani	0.18	0.04	0.23	0.13	0.00	Rashidi *et al.* (2008)

[1] σ_P^2 = phenotypic variance, h^2 = direct heritability, m^2 = maternal heritability, r_{am} = direct-maternal genetic correlation, c^2 = maternal permanent environmental variance as a proportion of phenotypic variance

4.2 Variance components and parameters for weaning weight

Estimates of heritability which were derived by the method of paternal half-sib correlation varied from 0.10 to 0.49 (Mavrogenis *et al.*, 1984; Thongchumroon, 1996; Das *et al.*, 1996; Mehta *et al.*, 1997; Mourad and Anous, 1998), while the estimates by using a REML animal model ranged from 0.07 to 0.60 (Els, 1998; Hirooka *et al.*, 1997; Schoeman *et al.*, 1997; Al-Shorepy *et al.*, 2002; Boujenane and El Hazzab, 2008). Safari *et al.* (2005) reviewed several studies and summarized the weight mean heritability of 0.18 ± 0.02 for weaning weight of lambs.

Table 6 Paternal half-sib heritability estimates for weaning weight of kids

Breed	Heritability	Reference
Damascus	0.27 ± 0.07	Mavrogenis *et al.* (1984)
Blended	0.10 ± 0.04	Das *et al.* (1996)
Crossbreds	0.20 ± 0.17	Thongchumroon (1996)
Sirohi	0.26 ± 0.13	Mehta *et al.* (1997)
Crossbreds	0.49 ± 0.16	Mourad and Anous (1998)

Table 7 Estimates of parameters[1] from animal model for weaning weight of kids

Breed	σ_P^2	h^2	m^2	r_{am}	c^2	Reference
Boer	13.74	0.60	-	-	-	Els (1998)
Crosses	-	0.07	0.11	0.47	-	Hirooka *et al.* (1997)
Boer	15.53	0.18	0.05	-0.15	0.07	Schoeman *et al.* (1997)
Emirati	6.68	0.34	0.00	-	0.20	Al-Shorepy *et al.* (2002)
Draa	1.69	0.38	0.24	-0.92	0.00	Boujenane and El Hazzab (2008)

[1] σ_P^2 = phenotypic variance, h^2 = direct heritability, m^2 = maternal heritability, r_{am} = direct-maternal genetic correlation, c^2 = maternal permanent environmental variance as a proportion of phenotypic variance

The estimated maternal heritabilities for weaning weight of kids and lambs ranged from 0.00 (Notter, 1998; Al-Shorepy *et al*., 2002) to 0.24 (Boujenane and El Hazzab, 2008). Several authors (Hirooka *et al*., 1997; Mousa *et al*., 1999; Ligda *et al*., 2000; Miraei-Ashtiani *et al*., 2007; Rashidi *et al*., 2008) observed that maternal heritability estimates for weaning weight were lower than the estimates of birth weight. The higher estimates of maternal heritability for birth weight compared with estimates for weaning weight supported conclusion of Robinson (1981) that maternal genetic effects generally were important for measurements of body weight at younger ages and were expected to diminish as kids grow older.

Table 8 Estimates of parameters[1] from animal model for weaning weight of lambs

Breed	σ_P^2	h^2	m^2	r_{am}	c^2	Reference
Romanov	9.84	0.09	0.01	-0.97	0.07	María *et al.* (1993)
Hampshire	40.60	0.39	0.19	-0.74	0.20	Tosh and Kemp (1994)
Pooled Doset	25.30	0.25	0.08	-0.31	0.19	Tosh and Kemp (1994)
Romanov	16.90	0.14	0.02	0.43	0.12	Tosh and Kemp (1994)
Suffolk	52.70	0.21	0.00	-0.99	0.19	Notter (1998)
Crossbreds	14.64	0.09	0.09	-0.39	0.12	Mousa *et al.* (1999)
Chios	5.61	0.17	0.07	-0.26	0.08	Ligda *et al.* (2000)
Suffolk	50.61	0.13	0.04	0.25	0.17	Rao and Notter (2000)
Polypay	19.45	0.10	0.02	-0.69	0.22	Rao and Notter (2000)
Dorper	19.32	0.20	0.10	-0.58	0.08	Neser *et al.* (2001)
Columbia	27.60	0.16	0.08	0.35	0.03	Hanford *et al.* (2002)
Targhee	25.40	0.22	0.11	-0.04	0.06	Hanford *et al.* (2003)
Polypay	21.40	0.18	0.07	0.06	0.04	Hanford *et al.* (2006)
Sangsari	5.41	0.17	0.08	-0.54	0.09	Miraei-Ashtiani *et al.* (2007)
Kermani	9.56	0.33	0.05	-0.41	0.12	Rashidi *et al.* (2008)

[1] σ_P^2 = phenotypic variance, h^2 = direct heritability, m^2 = maternal heritability, r_{am} = direct-maternal genetic correlation, c^2 = maternal permanent environmental variance as a proportion of phenotypic variance

Estimates of genetic correlation between direct and maternal effects for weaning weight of kids and lambs reported in literature were positive and negative values. The negative correlations were from -0.99 (Notter, 1998) to -0.04 (Hanford *et al.*, 2003). One reason for large negative value of genetic correlation between direct and maternal effects for WW might be due to the data structure (Gerstmayr, 1992; Maniatis and Pollott, 2003). Another possible explanation might be environmentally induced, i.e. result from management and/or husbandry practices (Robison, 1972).

Many studies reported that estimates of maternal permanent environmental effects for weaning weight of kids and lambs were from 0.00 (Boujenane and El Hazzab, 2008) to 0.22 (Rao and Notter, 2000).

5. Variance components and parameters for reproductive traits

5.1 Variance components and parameters for type of birth

There are few studies have estimated the heritability for type of birth of female goats by the method of paternal half-sib correlation. The estimates have ranged from -0.001 to 0.35 (Table 9). Lawar and Rasane (1996) collected the data of 2,559 Angora and its crosses at MPKV, Rahuri, India during 1972 – 1988. They reported the heritability estimates to be between -0.001 and 0.087 on the basis of paternal half-sib correlation. The high heritability estimate of 0.35 was obtained by Odubote (1996) on the same method which data were collected from 987 kidding records of the West African Dwarf goats at the Goat Unit of the Obafemi Awolowo University Teaching and Research Farm, Ile-Ife, Nigeria. The estimate was higher than those reported of 0.28 by Odubote (1992) for the same flock, 0.02 to 0.06 by Mourad (1994) for African Common breed and 0.15 by Hongping (2001) for Boer breed. Bagnicka *et al.* (2007) estimated variance components and heritability for type of birth in first parity and those in second parity from the data of 8,479 and 5,729 dairy goats at the Polish Regional Sheep and Goats Breeder Associations, Poland by the REML procedure. They observed that phenotypic variance in first and second parities were 0.31 and 0.34 head^2, respectively and heritability estimates in first and second parities were 0.11 and 0.09, respectively.

Table 9 Paternal half-sib heritability estimates for type of birth

Breed	Heritability	Reference
West African Dwarf	0.28	Odubote (1992)
African Common	0.02 to 0.06	Mourad (1994)
Angora and crossbreds	-0.001 to 0.087	Lawar and Rasane (1996)
West African Dwarf	0.35	Odubote (1996)
Boer	0.15	Hongping (2001)

Okut *et al.* (1999) estimated variance components and heritability for number of lambs born in four breeds of sheep (Columbia, Polypay, Rambouillet and Targhee) with REML using animal models. The analyses were classified dams in three groups as young (1 year old), middle aged (2 and 3 years old) and older (more than 3 years old). The most obvious result was that phenotypic variance was considerably larger for the medium and older age groups, as expected, because of the differences in means. The number of lambs born for the young, medium and older age groups averaged 1.12 to 1.43, 1.53 to 1.92 and 1.76 to 2.11 heads, respectively. While heritability estimates had a similar pattern over four breeds and three age groups with the range of 0.01 to 0.17. Fogarty (1995) summarized 53 reported estimates of heritability for number of lambs born and obtained a mean estimate of 0.10 with a standard error among estimates of 0.07. The range of heritability estimates for the same trait by using the REML procedure were from 0.05 to 0.14 (see Table 10, Waldron and Thomas, 1992; Al-Shorepy and Notter, 1996; Rao and Notter, 2000; Hanford *et al.*, 2002 and 2003; Vanimisetti *et al.*, 2007; Vatankhah *et al.*, 2008). The low estimates of heritability by using a REML animal model may be due to categorical expression of the trait (Hill, 1985; Falconer and Mackay, 1996). The analysis of a trait exhibiting a discrete distribution of phenotype with threshold model resulted in greater heritability estimates for number of lambs born in Rambouillet and Finnsheep (0.45 and 0.14, respectively, Matos *et al.*, 1997). In theory, threshold models seem appropriate for discrete data and thus may capture a higher portion of genetic variation than is possible with linear methodology (Dempster and Lerner, 1950).

Rao and Notter (2000) estimated permanent environmental effects on number of lambs born from Targhee, Suffolk and Polyplay sheep to be 0.02, 0.00 and 0.04, respectively. The higher estimate was reported of 0.10 by Al-Shorepy and Notter (1996).

Table 10 Estimates of parameters[1] for number of lambs born from animal model

Breed	σ^2_P	h^2	pe^2	Reference
Rambouillet	0.27	0.14	0.08	Waldron and Thomas (1992)
Crossbreds	0.40	0.05	0.10	Al-Shorepy and Notter (1996)
Targhee	0.33	0.11	0.02	Rao and Notter (2000)
Suffolk	0.46	0.09	0.00	Rao and Notter (2000)
Polypay	0.51	0.09	0.04	Rao and Notter (2000)
Columbia	0.41	0.09	0.03	Hanford *et al.* (2002)
Targhee	0.39	0.10	0.04	Hanford *et al.* (2003)
Katahdin	0.33	0.12	0.004	Vanimisetti *et al.* (2007)
Lori-Bakhtiari	-	0.08	0.06	Vatankhah *et al.* (2008)

[1] σ^2_P = phenotypic variance, h^2 = direct heritability, pe^2 = permanent environmental variance as a proportion of phenotypic variance

5.2 Variance components and parameters for kidding interval

Odubote (1996) reported heritability estimate for kidding interval to be 0.03 from West African Dwarf goat. This confirmed to the study of Bagnicka *et al.* (2007) who observed the value of 0.015. The calving interval in cattle had values of heritability in range of 0.02 to 0.22 (Bourdon and Brinks, 1983; Lopez de Torre and Brinks, 1990; Gutiérrez *et al*., 2002).

Estimates of variance due to permanent environmental effects on lambing interval were 0.02 for Rambouillet sheep (Waldron and Thomas, 1992) and 0.004 for Katahdin sheep (Vanimisetti *et al*., 2007).

6. Correlations between traits

6.1 Correlations between growth traits

Estimates of direct genetic correlations between BW and WW were low to moderate and positive. The low estimate of 0.15 was reported by Mugambi *et al.* (2007) from 6,800 Kenya Dual Purpose goats. Mourad and Anous (1998) obtained the correlation coefficient of 0.35 from 1,526 Common African of Alpine crossbreds. The estimation of Thongchumroon (1996) from the data of 411 Anglo-Nubian x Native and Saanen x Native crossbred kids at Yala Livestock Research and Breeding Center observed that the genetic correlation was 0.47. Safari *et al.* (2005) reported a weighted mean genetic correlation between birth weight and weaning weight from 14 independent estimates in sheep at 0.47.

Hanford *et al.* (2002, 2003 and 2006) reported that the estimates of maternal genetic correlations between birth weight and weaning weight were 0.58, 0.35 and 0.48 from the data of 24,741 Columbia lambs, 33,994 Targhee lambs and 11,896 Polypay lambs, respectively. In earlier studies, correlations between maternal permanent environmental effects for birth weight and weaning weight of lambs were 0.46, 0.44 and 0.70, respectively. Mousa *et al.* (1999) observed the value of 0.57 from 9,055 lambs of a composite population at the U.S. Meat Animal Research Center. Bromley *et al.* (2000) found that maternal permanent environmental correlation between BW and average dairy gain from birth to weaning age ranged from 0.46 to 0.63. Rashidi *et al.* (2008) also reported positive correlation between WW and average dairy gain from birth to weaning age at 0.46. The estimated residual correlation between birth weight and weaning weight was positive (0.33, Hanford *et al.*, 2002).

6.2 Correlations between growth and reproductive traits

In the previous reviews of genetic correlations for body weights at various ages with number of lambs born found that the estimates were low to moderate with negative and positive signs. Maxa *et al.* (2007) estimated genetic correlations between birth weight and number of lambs born from Danish Texel, Shrepshire and Suffolk sheep to be positive and ranged from 0.02 to 0.14, except for Oxford Down (-0.11). Bromley *et al.* (2000) reported similar estimates in the range of -.01 to 0.26 from the data of Columbia, Polypay, Rambouillet and Targhee sheep. Hanford *et al.* (2006) observed that birth weight and weaning weight were positive correlated with number of lambs born (0.10 and 0.24, respectively). Afolayan *et al.* (2008) showed negative correlation between birth weight and number of lambs born (-0.34) and positive correlation between weaning weight and number of lambs born (0.10). Fogarty (1995) reported average of genetic correlation between weaning weight and number of lambs born of 0.27 from 6 estimates. Other studies (Hanford *et al.*, 2003; Van Wyk *et al.*, 2003; Vanimisetti *et al.*, 2007) also showed estimates of genetic correlations between number of lambs born and various weights in sheep were in range of 0.20 to 0.50. The negative correlation between body weights at birth and weaning age with number of lambs born may be due to the feed consumption. Blackburn (1995) suggested that reproductive performance of female goat was simulated by decreasing in level of nutrition. His study found that as forage available and quality decreased from high to low level, number of kids born for Boer and Spanish goats decreased about 54% and 28.3%, respectively. The reasons were that Spanish dams smaller mature size, and therefore lower maintain requirement, they were able to maintain higher levels of reproductive performance with lower forage conditions.

Meyer *et al.* (1991) showed that genetic correlations between days to calving calculated from maiden joining performance and yearling weights for the Angus breed and Zebu crosses were -0.05 and -0.36, respectively. Johnston and

Bunter (1996), by contrast, reported that days to calving were close to zero but generally unfavorable (0.10 and 0.08, respectively) correlated with weaning and yearling weights in Angus cows. Rege and Famula (1993) found a small negative genetic correlation in Herefords between calving date and weaning weight but a much larger correlation with yearling weight (-0.60). Correlation between residual environmental effects for number of lambs born with birth weight and weaning weight ranged from -0.00 to 0.07 (Hanford *et al.*, 2002, 2003 and 2006).

7. Economic values

Economic values are needed for each trait in breeding goal to ensure that selection emphasis is proportional to the economic importance of each of these traits (Amer *et al.*, 2001). Although several methods used to calculate economic values, deriving the economic values from the difference between costs and revenues has the advantage of simplicity (Ponzoni, 1988). Costs are related to feed costs and non feed costs. Feed costs can be divided into feed for the breeding females and feed for the offspring. For Feed costs can further be derived into feed for maintenance and for production. In the case of the breeding females, feed for production consisted of the feed needed to produce offspring (Weller, 1994). Kosgey *et al.* (2003) observed that feed costs accounted for 56.94% of the total costs for meat sheep production in medium to high production potential areas of the tropics. In agreement with Kahi and Nitter (2004) who concluded that feed cost was a major input in production system and significantly influenced profitability. Haghdoost and Shadparvar (2008) also observed negative profit for Arabic sheep in village system. They suggested that flock profit in generally was negative and high feed costs were the most important cause. Whereas Seleka *et al.* (2001) mentioned that high mortality rate influenced cash returns in goat and sheep production of smallholders in Botswana. Non feed costs are related to replacement breeding females, labour, buildings, machinery, health service, marketing activities and interest on investments. Kosgey *et al.* (2003) estimated the fixed costs at a proportion of 4.82% for meat sheep in medium to high production potential areas of the tropics. Revenues originate from the sale of products for example young animals, culled animals and manure.

An analysis conducted by Upton (1985) suggested that small ruminant in the tropics where improvements were most needed was that of reducing mortality. The second most influential factor on overall economic performance was reproduction rate, while variation in growth rate had only a relatively small impact. Greeff *et al.* (1995) reported that high reproductive and survival rates played an important role in increasing efficiency of lamb production. Kosgey *et al.* (2004) estimated economic values for traits considering in traditional management systems of sheep in tropical area. They observed that number of lambs born had the most impact upon profitability. Likewise, Haghdoost and Shadparvar (2008) reported the most important trait of Arabic sheep in village system of Iran was number of lambs born, followed by ewe survival, dressing percentage, wool weight and weaning weight, respectively. The positive economic values for live weight and postweaning average daily gain were reported by Kahi and Nitter (2004) in cattle and Kosgey *et al.* (2004) in sheep. They suggested that an increase in average daily gain would directly affect weight at which animal were sold.

Albera *et al.* (2004) observed negative economic value for calving interval (-2.60 € per cow per day) derived for the Piemontese cattle farm in Italy. They concluded that the cost of dairy net energy intake of cows affected economic value for calving interval in a moderate way. The improvement of this trait (declining calving interval) increased the nutrient requirements for gestation and lactation. In contrast to Kahi and Nitter (2004) who showed positive economic value for calving interval in developing breeding schemes for pasture based dairy production systems in Kenya.

MATERIALS AND METHODS

1. Animals

All animals included in this study were purebred and crossbred in Anglo-Nubian, Saanen and Native from Yala Livestock Research and Breeding Center, Department of Livestock Development, located in the east coast of southern part of Thailand (5 to 7°N, 100 to 102°E). The climate was tropical monsoon with annual means of ambient temperature, relative humidity and rainfall of 28.14°C, 74.89% and 2,386.10 millimeters, respectively in the year 2007 (Yala Meteorological Station, 2008).

2. Management

2.1 Housing

There were four houses for breeding goat and one house for replacement herd. Each house was the stilted housing with slatted-floor and was raised about 1.5 meters above ground level. The houses for breeding group were partitioned into stalls. Each stall was provided with a forage rack, a concentrate bowl and a water trough. Ten to twelve dams were grouped in a stall during mating and gestation. One to three dams were kept in a stall during kidding. The sires were kept in separate stalls from females.

2.2 Feeding

There were two types of feed, concentrate and roughage. Concentrate feed contained approximately 16% crude protein and 2,600 kcal of metabolized energy per kilogram as fed-basis for sires, dams and replacements were provided at 1% of body weight once a day in the morning. Dams and replacements were rotationally grazed from 9.00 am to 3.00 pm and were offered cut-and-carry forage in the evening ad libitum. Roughage was mainly *Brachiaria decumbens*, *Paspalum plicatulum*, *Panicum maximum* and *Pennisetum purpureum*. Clean water was always available ad libitum for all animals.

2.3 Selection

Replacement sires and dams were usually recruited from within the herd (10% of sires and 90% of dams) and some animals were purchased from other livestock research and breeding centers of Department of Livestock Development and were imported from abroad (Australia and the United States of America). The young males and females that were chosen from the kids of primiparous and multiparous dams were performance tested with the age of three to nine months of age using body weight at nine months of age and pedigree information as selection criteria. The selected goats were remained in the center for breeding, while the unselected ones were sold to farmers for further breeding in commercial herds that produce meat goat to Muslim consumers for religious activities and holidays. All breeding sires were culled after three breeding years and breeding dams were culled for old age (approximately six years of age), udder mastitis and failure of reproductive efficiency.

2.4 Mating

After performance test at nine months of age, replacement females were penned in groups of 12 animals. They were observed for estrus in these pens and were mated to males from 3.00 pm until 9.00 am on the next day. Estrous detection was performed at 21 days after mating. If females showed estrus within 21 days after mating, they might be mated later.

2.5 Kidding

Gestation period in goat was approximately 150 days. About one month before kidding, pregnant dams were moved into kidding stalls. The new born kids were ear tagged, weighed and identified by sex, breed combination, sire breed and dam breed within 24 hours of birth.

2.6 Weaning

The new born kids received colostrums for three days, thereafter, were fed with milk of their dams and milk powder. The multiple born kids and orphan kids were driven to supplemental milk powder more than others. The milk allowance was gradually reduced until milk was eliminated from the diet at three months old. The kids started eating solid feed, such as hay, bush leaves, dry fodder and concentrate at four weeks of age. At weaning, the kids were weighed and moved to another house for performance test.

2.7 Health management

Health management included deworming internal parasites and dipping baths against external parasites every three months after weaning age.

3. Traits analyzed

The traits of interest were two main categories namely growth traits and reproductive traits. Growth traits were measured in early life of animals (males and females) and reproductive traits were the subsequent performance in females. About 12% of a total number of females provided growth and reproductive records.

3.1 Growth traits

Growth traits were birth weight and weaning weight of animals that were born and survived from the years 1995 to 2005. Birth weight (BW) was recorded within 24 hours of birth. Data from kids that did not have a valid value of body weight at birth, i.e. kids with ambiguous birth dates, birth weight from incomplete pregnancy and kids were born alive and dead within 24 hours of birth were set as a missing value. Records of BW that were admitted and used for analyses ranged from 1 to 4 kilograms. Weaning weight (WW) was recorded from kids born alive and survived until weaning age at three months. Data from kids that did not have a valid value of body weight at weaning age, i.e. weaning weight taken more than three month after birth and kids were considered to be sick were set as a missing value. Records of WW that were admitted and used for analyses ranged from 5 to 20 kilograms.

Contemporary groups were formed for growth traits based on year and season at birth and all records were checked for sire connectedness across contemporary groups. Contemporary groups that were not connected through at least one common sire and contained only one record of growth performance were discarded. After editing, the final data were composed of 2,857 records from the progeny of 54 sires and 619 dams. The structure of data set used in analyses is shown in Table 11. Table 12 presents mean and standard deviation for performance of growth traits according to 20 different purebred and crossbred groups.

3.2 Reproductive traits

Data on reproductive traits were expressed as type of birth and kidding interval to females kidding during the period 1995 to 2005. Type of birth (TB) was defined as the number of live kids at birth that could be single (1 head), twins (2 heads) and triplets (3 heads). Kidding interval (KI) was computed as the interval, in days, between two consecutive kidding dates, and was composed of service period (from kidding to conception) and gestation period. As some dams had incomplete kidding date information, the periods that were shorter than 180 days or longer than 500 days were set as a missing value. Animals were assigned to contemporary groups of traits based on year and season of kidding. After editing, the final data were composed of 1,487 records from 476 females. The structure of data set used in analyses is shown in Table 11. Table 13 presents mean and standard deviation for performance of reproductive traits according to 13 different purebred and crossbred groups.

Table 11 Data structure for growth and reproductive traits

Item	Trait[1]			
	BW	WW	TB	KI
Number of animals in pedigree file	4,303	4,303	4,303	4,303
Number of records	2,857	2,857	1,487	948
Number of animals with records	2,857	2,857	476	349
Number of sires with progeny records	54	54	120	95
Number of dams with progeny records	619	619	327	258
- 1 kid	230	230	-	-
- > 1 kid	389	389	-	-
Number of dams with own records	186	186	-	-
Number of contemporary groups	33	33	33	32
Mean inbreeding coefficient	0.14	0.14	0.14	0.14

[1] BW = birth weight, WW = weaning weight, TB = type of birth, KI = kidding interval

Table 12 Means and standard deviations for growth traits

Breed group[1]			Trait		
Animal	Sire	Dam	No[2]	BW (kg)[3]	WW (kg)[4]
Pure breed					
A	A	A	285	2.68±0.55	14.45±3.12
S	S	S	26	2.19±0.41	15.04±2.76
N	N	N	791	1.96±0.45	9.07±2.59
Two-breed cross					
$\frac{1}{2}$A$\frac{1}{2}$N	A	N	123	2.02±0.42	10.93±2.99
$\frac{1}{2}$A$\frac{1}{2}$N	$\frac{1}{2}$A$\frac{1}{2}$N	$\frac{1}{2}$A$\frac{1}{2}$N	361	2.55±0.32	11.42±2.76
$\frac{9}{16}$A$\frac{7}{16}$N	$\frac{1}{2}$A$\frac{1}{2}$N	$\frac{5}{8}$A$\frac{3}{8}$N	18	2.72±0.42	11.08±2.90
$\frac{5}{8}$A$\frac{3}{8}$N	$\frac{1}{2}$A$\frac{1}{2}$N	$\frac{3}{4}$A$\frac{1}{4}$N	18	2.75±0.34	10.86±2.02

Table 12 (Continued)

Breed group[1]			Trait		
Animal	Sire	Dam	No[2]	BW (kg)[3]	WW (kg)[4]
$\frac{5}{8}$A$\frac{3}{8}$N	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{1}{2}$A$\frac{1}{2}$N	45	2.55±0.43	11.95±3.57
$\frac{11}{16}$A$\frac{5}{16}$N	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{5}{8}$A$\frac{3}{8}$N	15	2.68±0.39	12.63±2.14
$\frac{3}{4}$A$\frac{1}{4}$N	A	$\frac{1}{2}$A$\frac{1}{2}$N	291	2.59±0.43	9.99±1.94
$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{3}{4}$A$\frac{1}{4}$N	186	2.69±0.37	12.15±3.08
$\frac{13}{16}$A$\frac{3}{16}$N	A	$\frac{5}{8}$A$\frac{3}{8}$N	19	2.53±0.54	10.74±1.41
$\frac{7}{8}$A$\frac{1}{8}$N	A	$\frac{3}{4}$A$\frac{1}{4}$N	73	2.67±0.46	14.41±2.99
$\frac{1}{2}$S$\frac{1}{2}$N	$\frac{1}{2}$S$\frac{1}{2}$N	$\frac{1}{2}$S$\frac{1}{2}$N	209	2.47±0.37	10.49±2.32
$\frac{5}{8}$S$\frac{3}{8}$N	$\frac{1}{2}$S$\frac{1}{2}$N	$\frac{3}{4}$S$\frac{1}{4}$N	18	2.48±0.38	10.62±2.18
$\frac{3}{4}$S$\frac{1}{4}$N	$\frac{3}{4}$S$\frac{1}{4}$N	$\frac{3}{4}$S$\frac{1}{4}$N	277	2.51±0.36	11.13±2.52
$\frac{7}{8}$S$\frac{1}{8}$N	S	$\frac{3}{4}$S$\frac{1}{4}$N	14	2.62±0.32	11.50±2.85
Three-breed cross					
$\frac{1}{8}$A$\frac{1}{4}$S$\frac{5}{8}$N	N	$\frac{1}{4}$A$\frac{1}{2}$S$\frac{1}{4}$N	44	2.31±0.41	10.89±2.17
$\frac{1}{4}$A$\frac{1}{2}$S$\frac{1}{4}$N	$\frac{1}{4}$A$\frac{1}{2}$S$\frac{1}{4}$N	$\frac{1}{4}$A$\frac{1}{2}$S$\frac{1}{4}$N	20	2.16±0.42	9.35±1.97
$\frac{1}{2}$A$\frac{1}{4}$S$\frac{1}{4}$N	$\frac{1}{2}$A$\frac{1}{4}$S$\frac{1}{4}$N	$\frac{1}{2}$A$\frac{1}{4}$S$\frac{1}{4}$N	24	2.28±0.39	9.84±1.99
Total			2,857	2.37±0.51	10.93±3.15

[1] A = Anglo-Nubian, S = Saanen, N = Native

[2] No = number of records

[3] BW = birth weight

[4] WW = weaning weight

Table 13 Means and standard deviations for reproductive traits

Breed group[1]			Trait			
Female	Sire	Dam	No[2]	TB (head)[3]	No[2]	KI (day)[4]
Pure breed						
A	A	A	259	1.31±0.49	160	273.12±71.03
S	S	S	23	1.35±0.57	10	271.40±96.69
N	N	N	754	1.34±0.50	504	258.63±70.02
Two-breed cross						
$\frac{1}{2}$A$\frac{1}{2}$N	A	N	36	1.19±0.40	11	235.36±42.22
$\frac{1}{2}$A$\frac{1}{2}$N	$\frac{1}{2}$A$\frac{1}{2}$N	$\frac{1}{2}$A$\frac{1}{2}$N	146	1.32±0.51	84	284.20±73.35
$\frac{5}{8}$A$\frac{3}{8}$N	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{1}{2}$A$\frac{1}{2}$N	33	1.55±0.56	22	242.27±68.33
$\frac{3}{4}$A$\frac{1}{4}$N	A	$\frac{1}{2}$A$\frac{1}{2}$N	76	1.46±0.58	60	256.88±62.23
$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{3}{4}$A$\frac{1}{4}$N	71	1.30±0.49	41	272.29±69.41
$\frac{1}{2}$S$\frac{1}{2}$N	$\frac{1}{2}$S$\frac{1}{2}$N	$\frac{1}{2}$S$\frac{1}{2}$N	20	1.35±0.49	10	257.50±69.33
$\frac{5}{8}$S$\frac{3}{8}$N	$\frac{3}{4}$S$\frac{1}{4}$N	$\frac{1}{2}$S$\frac{1}{2}$N	9	1.44±0.53	6	220.50±40.43
$\frac{3}{4}$S$\frac{1}{4}$N	$\frac{3}{4}$S$\frac{1}{4}$N	$\frac{3}{4}$S$\frac{1}{4}$N	43	1.39±0.49	27	268.63±67.37
Three-breed cross						
$\frac{3}{8}$A$\frac{3}{8}$S$\frac{1}{4}$N	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{3}{4}$S$\frac{1}{4}$N	9	1.33±0.50	7	266.14±41.02
$\frac{5}{8}$A$\frac{1}{8}$S$\frac{1}{4}$N	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{1}{2}$A$\frac{1}{4}$S$\frac{1}{4}$N	8	1.13±0.35	6	251.00±16.67
Total			1,487	1.34±0.50	948	263.35±69.87

[1] A = Anglo-Nubian, S = Saanen, N = Native

[2] No = number of records

[3] TB = type of birth

[4] KI = kidding interval

Analysis I: Estimation of breed effects for growth and reproductive traits

Estimation of breed effects were carried out using fixed effect models. For data used in this study, the parameter estimates were direct additive breed, maternal additive breed and heterosis breed effects. Direct and maternal additive breed effects for Anglo-Nubian and Saanen breeds were expressed as deviation from Native. The crossing types for which heterosis breed effects fitted were Anglo-Nubian x Saanen, Anglo-Nubian x Native and Saanen x Native. The effects were fitted in the models as linear regression covariates across all breed groups. Coefficients of direct and maternal additive breed effects were related to breed contents in animal and its dam that were proportion of genes contributed by each breed. Heterosis breed effects were based on the assumption that a linear relationship existed between dominance and degree of heterozygosity. Heterozygosity was calculated as $\sum ps_i pd_j$, where ps_i and pd_j were a proportion of breed i in sire and breed j in dam, respectively (Dillard *et al.*, 1980; Kahi *et al.*, 1995). Table 14 presents coefficients of additive and heterosis breed effects in 23 breed groups.

Single-trait models were fitted to the data for estimation of breed effects on growth and reproductive traits through the GLM procedure (SAS, 1996). All models included additive and heterosis breed effects as covariates. Growth trait models added parity number of dam, sex of kid, type of birth and year-season at birth, while reproductive trait models added parity number of female, sex and type of birth combination (only kidding interval) and year-season at kidding (Table 15). Parities were divided into seven classes (1, 2, 3, 4, 5, 6 and ≥ 7). Sex was either male or female. The type of birth was defined as 1, 2 and 3. Sex and type of birth combination could be one of 9 ratios between male and female as 1:0, 0:1, 2:0, 0:2, 1:1, 3:0, 0:3, 2:1 and 1:2. Four-month-birth and four-month-kidding periods were groups into three seasons with low rainfall season (January to April), moderate rainfall season (May to August) and high rainfall season (September to December). Annual means of ambient temperature, relative humidity and rainfall in low rainfall season were 27.70 ± 0.76°C, 74.00 ± 1.78% and 50.32 ± 60.82 millimeters, respectively. Those values in moderate rainfall season were 28.55 ± 0.49°C, 77.37 ± 2.79% and 99.76 ± 53.46 millimeters, respectively, and in high rainfall season were 27.22 ± 0.77°C, 77.98 ± 3.60% and 319.17 ± 207.47 millimeters, respectively.

Table 14 Coefficients of additive and heterosis breed effects in 23 breed groups[1]

Breed group			Additive breed						Heterosis breed		
Animal	Sire	Dam	Direct			Maternal					
			A	S	N	A	S	N	AxN	SxN	AxS
A	A	A	1	0	0	1	0	0	0	0	0
S	S	S	0	1	0	0	1	0	0	0	0
N	N	N	0	0	1	0	0	1	0	0	0
$\frac{1}{2}$A$\frac{1}{2}$N	A	N	$\frac{1}{2}$	0	$\frac{1}{2}$	0	0	1	1	0	0
$\frac{1}{2}$A$\frac{1}{2}$N	$\frac{1}{2}$A$\frac{1}{2}$N	$\frac{1}{2}$A$\frac{1}{2}$N	$\frac{1}{2}$	0	$\frac{1}{2}$	$\frac{1}{2}$	0	$\frac{1}{2}$	$\frac{1}{2}$	0	0
$\frac{9}{16}$A$\frac{7}{16}$N	$\frac{1}{2}$A$\frac{1}{2}$N	$\frac{5}{8}$A$\frac{3}{8}$N	$\frac{9}{16}$	0	$\frac{7}{16}$	$\frac{5}{8}$	0	$\frac{3}{8}$	$\frac{1}{2}$	0	0
$\frac{5}{8}$A$\frac{3}{8}$N	$\frac{1}{2}$A$\frac{1}{2}$N	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{5}{8}$	0	$\frac{3}{8}$	$\frac{3}{4}$	0	$\frac{1}{4}$	$\frac{1}{2}$	0	0
$\frac{5}{8}$A$\frac{3}{8}$N	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{1}{2}$A$\frac{1}{2}$N	$\frac{5}{8}$	0	$\frac{3}{8}$	$\frac{1}{2}$	0	$\frac{1}{2}$	$\frac{1}{2}$	0	0
$\frac{11}{16}$A$\frac{5}{16}$N	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{5}{8}$A$\frac{3}{8}$N	$\frac{11}{16}$	0	$\frac{5}{16}$	$\frac{5}{8}$	0	$\frac{3}{8}$	$\frac{7}{16}$	0	0
$\frac{3}{4}$A$\frac{1}{4}$N	A	$\frac{1}{2}$A$\frac{1}{2}$N	$\frac{3}{4}$	0	$\frac{1}{4}$	$\frac{1}{2}$	0	$\frac{1}{2}$	$\frac{1}{2}$	0	0
$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{3}{4}$	0	$\frac{1}{4}$	$\frac{3}{4}$	0	$\frac{1}{4}$	$\frac{3}{8}$	0	0
$\frac{13}{16}$A$\frac{3}{16}$N	A	$\frac{5}{8}$A$\frac{3}{8}$N	$\frac{13}{16}$	0	$\frac{3}{16}$	$\frac{5}{8}$	0	$\frac{3}{8}$	$\frac{3}{8}$	0	0
$\frac{7}{8}$A$\frac{1}{8}$N	A	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{7}{8}$	0	$\frac{1}{8}$	$\frac{3}{4}$	0	$\frac{1}{4}$	$\frac{1}{4}$	0	0
$\frac{1}{2}$S$\frac{1}{2}$N	$\frac{1}{2}$S$\frac{1}{2}$N	$\frac{1}{2}$S$\frac{1}{2}$N	0	$\frac{1}{2}$	$\frac{1}{2}$	0	$\frac{1}{2}$	$\frac{1}{2}$	0	$\frac{1}{2}$	0
$\frac{5}{8}$S$\frac{3}{8}$N	$\frac{1}{2}$S$\frac{1}{2}$N	$\frac{3}{4}$S$\frac{1}{4}$N	0	$\frac{5}{8}$	$\frac{3}{8}$	0	$\frac{3}{4}$	$\frac{1}{4}$	0	$\frac{1}{2}$	0

Table 14 (Continued)

Breed group			Additive breed						Heterosis breed		
Animal	Sire	Dam	Direct			Maternal					
			A	S	N	A	S	N	AxN	SxN	AxS
$\frac{5}{8}S\frac{3}{8}N$	$\frac{3}{4}S\frac{1}{4}N$	$\frac{1}{2}S\frac{1}{2}N$	0	$\frac{5}{8}$	$\frac{3}{8}$	0	$\frac{1}{2}$	$\frac{1}{2}$	0	$\frac{1}{2}$	0
$\frac{3}{4}S\frac{1}{4}N$	$\frac{3}{4}S\frac{1}{4}N$	$\frac{3}{4}S\frac{1}{4}N$	0	$\frac{3}{4}$	$\frac{1}{4}$	0	$\frac{3}{4}$	$\frac{1}{4}$	0	$\frac{3}{8}$	0
$\frac{7}{8}S\frac{1}{8}N$	S	$\frac{3}{4}S\frac{1}{4}N$	0	$\frac{7}{8}$	$\frac{1}{8}$	0	$\frac{3}{4}$	$\frac{1}{4}$	0	$\frac{1}{4}$	0
$\frac{1}{8}A\frac{1}{4}S\frac{5}{8}N$	N	$\frac{1}{4}A\frac{1}{2}S\frac{1}{4}N$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{5}{8}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{2}$	0
$\frac{1}{4}A\frac{1}{2}S\frac{1}{4}N$	$\frac{1}{4}A\frac{1}{2}S\frac{1}{4}N$	$\frac{1}{4}A\frac{1}{2}S\frac{1}{4}N$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{4}$
$\frac{3}{8}A\frac{3}{8}S\frac{1}{4}N$	$\frac{3}{4}A\frac{1}{4}N$	$\frac{3}{4}S\frac{1}{4}N$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{1}{4}$	0	$\frac{3}{4}$	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{9}{16}$
$\frac{1}{2}A\frac{1}{4}S\frac{1}{4}N$	$\frac{1}{2}A\frac{1}{4}S\frac{1}{4}N$	$\frac{1}{2}A\frac{1}{4}S\frac{1}{4}N$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{4}$
$\frac{5}{8}A\frac{1}{8}S\frac{1}{4}N$	$\frac{3}{4}A\frac{1}{4}N$	$\frac{1}{2}A\frac{1}{4}S\frac{1}{4}N$	$\frac{5}{8}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{1}{16}$	$\frac{3}{16}$

[1] A = Anglo-Nubian, S = Saanen, N = Native

Table 15 Fixed factors and covariates included in the models

Factor	Trait[1]			
	BW	WW	TB	KI
Fixed effect				
Parity number of dam	X	X	-	-
Sex	X	X	-	-
Type of birth	X	X	-	-
Year-season at birth	X	X	-	-
Parity number of female	-	-	X	X
Sex and type of birth combination	-	-	-	X
Year-season at kidding	-	-	X	X

Table 15 (Continued)

Factor	Trait[1]			
	BW	WW	TB	KI
Covariate				
Direct additive breed effect	X	X	X	X
Maternal additive breed effect	X	X	-	-
Heterosis breed effect	X	X	X	X

[1] BW = birth weight, WW = weaning weight, TB = type of birth, KI = kidding interval

The statistical models in matrix notation were described below,

a) birth weight and weaning weight

$$y = X_1 b + X_2 g + X_3 d + X_4 h + e$$

b) type of birth and kidding interval

$$y = X_1 b + X_2 g + X_4 h + e$$

where

y = vector of observations for each trait

b = vector of fixed effects

g = vector of direct additive breed effects for Anglo-Nubian and Saanen animals as deviation from Native

d = vector of maternal additive breed effects for Anglo-Nubian and Saanen dams as deviation from Native

h = vector of heterosis breed effects for Anglo-Nubian x Saanen, Anglo-Nubian x Native and Saanen x Native

e = vector of random residual effects

X_1 was an incidence matrix relating records to fixed effects. X_2, X_3 and X_4 were the matrices of coefficients relating records to direct additive breed effects, maternal additive breed effects and heterosis breed effects, respectively.

Single-trait models as described above were used to predict performance of various breed combinations which were included in the original data. Predicted least-squares means for growth traits of twenty breed groups and for reproductive traits of thirteen breed groups were computed as a function of coefficients contributed by each breed in Table 14 and breed effects (referred to as direct additive breed, maternal additive breed and heterosis breed effects for each particular breed group).

a) birth weight and weaning weight

Predicted least-squares mean = Native least-squares mean + (Anglo-Nubian direct additive breed effect) (Anglo-Nubian direct additive breed coefficient) + (Saanen direct additive breed effect) (Saanen direct additive breed coefficient) + (Anglo-Nubian maternal additive breed effect) (Anglo-Nubian maternal additive breed coefficient) + (Saanen maternal additive breed effect) (Saanen maternal additive breed coefficient) + (Anglo-Nubian x Saanen heterosis breed effect) (Anglo-Nubian x Saanen heterosis breed coefficient) + (Anglo-Nubian x Native heterosis breed effect) (Anglo-Nubian x Native heterosis breed coefficient) + (Saanen x Native heterosis breed effect) (Saanen x Native heterosis breed coefficient)

b) type of birth and kidding interval

Predicted least-squares mean = Native least-squares mean + (Anglo-Nubian direct additive breed effect) (Anglo-Nubian direct additive breed coefficient) + (Saanen direct additive breed effect) (Saanen direct additive breed coefficient) + (Anglo-Nubian x Saanen heterosis breed effect) (Anglo-Nubian x Saanen heterosis breed coefficient) + (Anglo-Nubian x Native heterosis breed effect) (Anglo-Nubian x Native heterosis breed coefficient) + (Saanen x Native heterosis breed effect) (Saanen x Native heterosis breed coefficient)

Analysis II: Estimation of variance components, parameters and breeding values

Estimation of variance components were obtained for each trait separately and for all traits jointly, using a derivative-free restricted maximum likelihood algorithm (Graser *et al.*, 1987). The maximum likelihood value was found by the Simplex method. The convergence criterion was considered to be reached when the variance of the function values used in the Simplex method was less than 10^{-8}. Analyses were restarted from the converged values to check that a global rather than a local maximum had been reached. When estimates did not change, convergence was assumed.

1. Variance components and parameters from single-trait analyses for growth traits

Single-trait analyses for growth traits were carried out considering four models to establish which model fitted best. Model 1 was a simple animal model with direct genetic effect. Model 2 allowed for maternal permanent environmental effect in addition. Model 3 included maternal genetic effect and assumed that direct and maternal genetic effects were correlated. Model 4 fitted both maternal genetic and maternal permanent environmental effects and accounting for genetic correlation due to direct and maternal effects.

All models contained the same fixed effects that were parity number of dam, sex of kid, type of birth and year-season at birth. Additive breed and heterosis breed effects for all traits were fitted as covariates because several studies showed that it was important to account for additive breed and nonadditive effects in the models for estimation of variance components and genetic parameters in crossbred populations (Demeke *et al.*, 2003). Animal models in matrix notation could be expressed as follows,

Model 1: $y = X_1b + X_2g + X_3d + X_4h + Za + e$

Model 2: $y = X_1b + X_2g + X_3d + X_4h + Za + Wc + e$

Model 3: $y = X_1b + X_2g + X_3d + X_4h + Za + Mm + e$ with $\mathrm{cov}(a,m) \neq 0$

Model 4: $y = X_1b + X_2g + X_3d + X_4h + Za + Mm + Wc + e$ with $\mathrm{cov}(a,m) \neq 0$

where

y = vector of observations for each trait
b = vector of fixed effects
g = vector of direct additive breed effects
d = vector of maternal additive breed effects
h = vector of heterosis breed effects
a = vector of direct genetic effects
m = vector of maternal genetic effects
c = vector of maternal permanent environmental effects
e = vector of random residual effects

X_1 was an incidence matrix relating records to fixed effects. X_2, X_3 and X_4 were the matrices of coefficients relating records to direct additive breed effects, maternal additive breed effects and heterosis breed effects, respectively. Z, M and W were incidence matrices relating records to direct genetic effects, maternal genetic effects and maternal permanent environmental effects, respectively.

First moment for all models of growth traits was

$$E[y] = X_1b + X_2g + X_3d + X_4h$$

The variance-covariance structure of random effects for the most complex model was

$$V\begin{bmatrix} a \\ m \\ c \\ e \end{bmatrix} = \begin{bmatrix} A\sigma_a^2 & A\sigma_{am} & 0 & 0 \\ A\sigma_{am} & A\sigma_m^2 & 0 & 0 \\ 0 & 0 & I_c\sigma_c^2 & 0 \\ 0 & 0 & 0 & I_n\sigma_e^2 \end{bmatrix}$$

where A was a numerator relationship matrix, σ_a^2, σ_m^2, σ_c^2 and σ_e^2 were direct genetic variance, maternal genetic variance and maternal permanent environmental variance and residual variance, respectively. σ_{am} was direct-maternal genetic covariance. I_c and I_n were identity matrices of order equal to number of dams and number of records, respectively.

Comparisons of the different models for seeking the best fit for BW and WW were made by using likelihood ratio test (Meyer, 1992). The likelihood ratio statistic could be written as $-2\ln(\hat{L}_1/\hat{L}_2)$ or $-2\ln\hat{L}_1 - (-2\ln\hat{L}_2)$, where $\hat{L}_1$ was the maximized likelihood value for the less complex model and $\hat{L}_2$ was the maximized likelihood value for the more complex model. The differences between functional values for pairs of models were tested against the chi-square distribution with degrees of freedom being the difference in number of variance or covariance components in the models (Kleinbaum *et al.*, 1998). If the values were not significantly different (P>0.05), the model with the fewest number of variance components was chosen. For Model 1 versus Model 2 and Model 3 versus Model 4, the value of degrees of freedom was computed to be 1. Model 1 versus Model 3 and Model 2 versus Model

4, the value of degrees of freedom was computed to be 2. Model 1 was used to compare with Model 4, using 3 degrees of freedom.

2. Variance components and parameters from single-trait analyses for reproductive traits

Single-trait analyses for reproductive traits (TB and KI) were conducted with the models that included fixed and random effects. Fixed factors were parity number of female, sex and type of birth combination (only KI), year-season at kidding and covariates of additive breed and heterosis breed effects. For random effects that were direct genetic, permanent environmental effect and random residual. Animal model in matrix notation could be expressed as follows,

$$y = X_1b + X_2g + X_4h + Za + Spe + e$$

where

y = vector of observations for each trait
b = vector of fixed effects
g = vector of direct additive breed effects
h = vector of heterosis breed effects
a = vector of direct genetic effects
pe = vector of permanent environmental effects
e = vector of random residual effects

X_1 was an incidence matrix relating records to fixed effects. X_2 and X_4 were the matrices of coefficients relating records to direct additive breed effects and heterosis breed effects, respectively. Z and S were incidence matrices relating records to direct genetic effects and permanent environmental effects, respectively.

First moment for reproductive traits was

$$E[y] = X_1 b + X_2 g + X_4 h$$

The variance structure of random effects for reproductive traits was

$$V\begin{bmatrix} a \\ pe \\ e \end{bmatrix} = \begin{bmatrix} A\sigma_a^2 & 0 & 0 \\ 0 & I_{pe}\sigma_{pe}^2 & 0 \\ 0 & 0 & I_n\sigma_e^2 \end{bmatrix}$$

where A was a numerator relationship matrix, σ_a^2, σ_{pe}^2 and σ_e^2 were direct genetic variance, permanent environmental variance and residual variance, respectively. I_{pe} and I_n were identity matrices of order equal to number of females and number of records, respectively.

3. Variance components and parameters from Multiple-trait analyses for growth and reproductive traits

Following completion of single-trait analyses, multiple-trait analyses were performed for all traits. The best fit models based on likelihood ratio test for BW and WW in single-trait analyses were used in multiple-trait analyses. Animal models for TB and KI in single-trait analyses were also used in multiple-trait analyses except that sex and type of birth combination was dropped from KI model. Direct genetic and residual covariances were estimated for all pairs of traits. Maternal genetic covariances were estimated for BW and WW with other traits. Maternal permanent environmental covariances were estimated between BW and WW. Covariances between permanent environmental effects on reproductive traits were estimated. Other covariances between different traits were initially assumed to be zero.

Table 16 Fixed and random factors in the models associated with traits

Trait[1]	Fixed factor and covariate[2]	Random factor
BW and WW	Parity number of dam	Direct genetic
	Sex of kid	Maternal genetic
	Type of birth	Maternal permanent environmental
	Year-season at birth	
	Direct additive breed	
	Maternal additive breed	
	Heterosis breed	
TB	Parity number of female	Direct genetic
	Year-season at kidding	Permanent environmental
	Direct additive breed	
	Heterosis breed	
KI	Parity number of female	Direct genetic
	Sex and type of birth combination	Permanent environmental
	Year-season at kidding	
	Direct additive breed	
	Heterosis breed	

[1] BW = birth weight, WW = weaning weight, TB = type of birth, KI = kidding interval

[2] For multiple-trait analyses, sex and type of birth combination was dropped from the model for kidding interval

The statistical model in matrix notation could be expressed as below,

$$
\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix} = \begin{bmatrix} X_{11} & 0 & 0 & 0 \\ 0 & X_{12} & 0 & 0 \\ 0 & 0 & X_{13} & 0 \\ 0 & 0 & 0 & X_{14} \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} + \begin{bmatrix} X_{21} & 0 & 0 & 0 \\ 0 & X_{22} & 0 & 0 \\ 0 & 0 & X_{23} & 0 \\ 0 & 0 & 0 & X_{24} \end{bmatrix} \begin{bmatrix} g_1 \\ g_2 \\ g_3 \\ g_4 \end{bmatrix} + \begin{bmatrix} X_{31} & 0 & 0 & 0 \\ 0 & X_{32} & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} d_1 \\ d_2 \\ d_3 \\ d_4 \end{bmatrix} +
$$

$$
\begin{bmatrix} X_{41} & 0 & 0 & 0 \\ 0 & X_{42} & 0 & 0 \\ 0 & 0 & X_{43} & 0 \\ 0 & 0 & 0 & X_{44} \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \\ h_3 \\ h_4 \end{bmatrix} + \begin{bmatrix} Z_1 & 0 & 0 & 0 \\ 0 & Z_2 & 0 & 0 \\ 0 & 0 & Z_3 & 0 \\ 0 & 0 & 0 & Z_4 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix} + \begin{bmatrix} M_1 & 0 & 0 & 0 \\ 0 & M_2 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} m_1 \\ m_2 \\ m_3 \\ m_4 \end{bmatrix} +
$$

$$
\begin{bmatrix} W_1 & 0 & 0 & 0 \\ 0 & W_2 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & S_3 & 0 \\ 0 & 0 & 0 & S_4 \end{bmatrix} \begin{bmatrix} pe_1 \\ pe_2 \\ pe_3 \\ pe_4 \end{bmatrix} + \begin{bmatrix} e_1 \\ e_2 \\ e_3 \\ e_4 \end{bmatrix}
$$

where

y_1, y_2, y_3 and y_4 = vector of observations for birth weight, weaning weight, type of birth and kidding interval

b_1, b_2, b_3 and b_4 = vector of fixed effects for birth weight, weaning weight, type of birth and kidding interval

g_1, g_2, g_3 and g_4 = vector of direct additive breed effects for birth weight, weaning weight, type of birth and kidding interval

d_1, d_2, d_3 and d_4 = vector of maternal additive breed effects for birth weight, weaning weight, type of birth and kidding interval

h_1, h_2, h_3 and h_4 = vector of heterosis breed effects for birth weight, weaning weight, type of birth and kidding interval

a_1, a_2, a_3 and a_4 = vector of direct genetic effects for birth weight, weaning weight, type of birth and kidding interval

m_1, m_2, m_3 and m_4 = vector of maternal genetic effects for birth weight, weaning weight, type of birth and kidding interval

c_1, c_2, c_3 and c_4 = vector of maternal permanent environmental effects for birth weight, weaning weight, type of birth and kidding interval

pe_1, pe_2, pe_3 and pe_4 = vector of permanent environmental effects for birth weight, weaning weight, type of birth and kidding interval

e_1, e_2, e_3 and e_4 = vector of random residual effects for birth weight, weaning weight, type of birth and kidding interval

X_{11}, X_{12}, X_{13} and X_{14} were incidence matrices relating records to fixed effects of birth weight, weaning weight, type of birth and kidding interval, respectively. X_{21}, X_{22}, X_{23} and X_{24} were the matrices of coefficients relating records to direct additive breed effects of birth weight, weaning weight, type of birth and kidding interval, respectively. X_{31} and X_{32} were the matrices of coefficients relating records to maternal additive breed effects of birth weight and weaning weight, respectively. X_{41}, X_{42}, X_{43} and X_{44} were the matrices of coefficients relating records to heterosis breed effects of birth weight, weaning weight, type of birth and kidding interval, respectively. Z_1, Z_2, Z_3 and Z_4 were incidence matrices relating records to direct genetic effects of birth weight, weaning weight, type of birth and kidding interval, respectively. M_1 and M_2 were incidence matrices relating records to maternal genetic effects of birth weight and weaning weight, respectively. W_1 and W_2 were incidence matrices relating records to maternal permanent environmental effects of birth weight and weaning weight, respectively. S_3 and S_4 were incidence matrices relating records to permanent environmental effects of type of birth and kidding interval, respectively.

The variance-covariance structure of random effects for all traits was

$$
V\begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ m_1 \\ m_2 \\ m_3 \\ m_4 \\ c_1 \\ c_2 \\ c_3 \\ c_4 \\ pe_1 \\ pe_2 \\ pe_3 \\ pe_4 \\ e_1 \\ e_2 \\ e_3 \\ e_4 \end{bmatrix} =
\begin{bmatrix}
A\sigma^2_{a1} & A\sigma_{a1a2} & A\sigma_{a1a3} & A\sigma_{a1a4} & A\sigma_{a1m1} & A\sigma_{a1m2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
A\sigma_{a1a2} & A\sigma^2_{a2} & A\sigma_{a2a3} & A\sigma_{a2a4} & A\sigma_{a2m1} & A\sigma_{a2m2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
A\sigma_{a1a3} & A\sigma_{a2a3} & A\sigma^2_{a3} & A\sigma_{a3a4} & A\sigma_{a3m1} & A\sigma_{a3m2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
A\sigma_{a1a4} & A\sigma_{a2a4} & A\sigma_{a3a4} & A\sigma^2_{a4} & A\sigma_{a4m1} & A\sigma_{a4m2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
A\sigma_{a1m1} & A\sigma_{a2m1} & A\sigma_{a3m1} & A\sigma_{a4m1} & A\sigma^2_{m1} & A\sigma_{m1m2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
A\sigma_{a1m2} & A\sigma_{a2m2} & A\sigma_{a3m2} & A\sigma_{a4m2} & A\sigma_{m1m2} & A\sigma^2_{m2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & I\sigma^2_{c1} & I\sigma_{c1c2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & I\sigma_{c1c2} & I\sigma^2_{c2} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & I\sigma^2_{pe3} & I\sigma_{pe3pe4} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & I\sigma_{pe3pe4} & I\sigma^2_{pe4} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & I\sigma^2_{e1} & I\sigma_{e1e2} & I\sigma_{e1e3} & I\sigma_{e1e4} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & I\sigma_{e1e2} & I\sigma^2_{e2} & I\sigma_{e2e3} & I\sigma_{e2e4} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & I\sigma_{e1e3} & I\sigma_{e2e3} & I\sigma^2_{e3} & I\sigma_{e3e4} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & I\sigma_{e1e4} & I\sigma_{e2e4} & I\sigma_{e3e4} & I\sigma^2_{e4}
\end{bmatrix}
$$

where

A = numerator relationship matrix

I = identity matrix

$\sigma^2_{a1}, \sigma^2_{a2}, \sigma^2_{a3}$ and σ^2_{a4} = direct genetic variance for birth weight, weaning weight, type of birth and kidding interval

σ_{a1a2} = direct genetic covariance between birth weight and weaning weight

σ_{a3a4} = direct genetic covariance between type of birth and kidding interval

σ^2_{m1} and σ^2_{m2} = maternal genetic variance for birth weight and weaning weight

σ_{a1m1} and σ_{a2m2} = direct-maternal genetic covariance for birth weight and weaning weight

σ_{a1m2} = covariance between direct genetic for birth weight and maternal genetic for weaning weight

σ_{a2m1} = covariance between direct genetic for weaning weight and maternal genetic for birth weight

σ^2_{c1} and σ^2_{c2} = maternal permanent environmental variance for birth weight and weaning weight

σ_{c1c2} = maternal permanent environmental covariance between birth weight and weaning weight

σ^2_{pe3} and σ^2_{pe4} = permanent environmental variance for type of birth and kidding interval

σ_{pe3pe4} = permanent environmental covariance between type of birth and kidding interval

$\sigma^2_{e1}, \sigma^2_{e2}, \sigma^2_{e3}$ and σ^2_{e4} = residual variance for birth weight, weaning weight, type of birth and kidding interval

σ_{e1e2} = residual covariance between birth weight and weaning weight

σ_{e1e3} = residual covariance between birth weight and type of birth

σ_{e1e4} = residual covariance between birth weight and kidding interval

σ_{e2e3} = residual covariance between weaning weight and type of birth

σ_{e2e4} = residual covariance between weaning weight and kidding interval

σ_{e3e4} = residual covariance between type of birth and kidding interval

4. Parameters estimates

The genetic parameters were derived from estimates of variance-covariance components in single-trait analyses and multiple-trait analyses. According to Willham (1972) and Falconer and Mackay (1996), the parameters were estimated as equations below,

- Direct heritability (h^2)

$$h^2 = \frac{\sigma_a^2}{\sigma_p^2}$$

- Maternal heritability (m^2)

$$m^2 = \frac{\sigma_m^2}{\sigma_p^2}$$

- Maternal permanent environmental variance as a proportion of total variance (c^2)

$$c^2 = \frac{\sigma_c^2}{\sigma_p^2}$$

- Permanent environmental variance as a proportion of total variance (pe^2)

$$pe^2 = \frac{\sigma_{pe}^2}{\sigma_p^2}$$

- Residual variance as a proportion of total variance (e^2)

$$e^2 = \frac{\sigma_e^2}{\sigma_p^2}$$

- Direct-maternal genetic correlation (r_{am})

$$r_{am} = \frac{\sigma_{am}}{\sigma_a \cdot \sigma_m}$$

- Direct genetic correlation (r_a)

$$r_a = \frac{\sigma_{a1a2}}{\sigma_{a1} \cdot \sigma_{a2}}$$

- Maternal genetic correlation (r_m)

$$r_m = \frac{\sigma_{m1m2}}{\sigma_{m1} \cdot \sigma_{m2}}$$

- Maternal permanent environmental correlation (r_c)

$$r_c = \frac{\sigma_{c1c2}}{\sigma_{c1} \cdot \sigma_{c2}}$$

- Permanent environmental correlation (r_{pe})

$$r_{pe} = \frac{\sigma_{pe1pe2}}{\sigma_{pe1} \cdot \sigma_{pe2}}$$

- Environmental correlation (r_e)

$$r_e = \frac{\sigma_{e1e2}}{\sigma_{e1} \cdot \sigma_{e2}}$$

5. Estimated breeding values

Across-breed estimated breeding values for direct genetic $(D\hat{B}V)$, maternal genetic $(M\hat{B}V)$ and total maternal genetic $(TM\hat{B}V)$ of individual animals were estimated through the use of animal models in multiple-trait analyses. The models were assumed that had a common additive variance for all breed groups and the differences between breed groups were expected to be accounted for by additive breed effects. According to Quaas and Pollak (1981), estimated direct breeding value of an individual was a function of a fixed of direct additive breed effect and the solution for its direct genetic effect as a deviation from the breed contributions for the animal. Estimated maternal breeding value of an individual was a function of maternal additive breed effect and the solution for its maternal genetic effect. Estimated total maternal breeding value of an individual was composed of a half of estimated direct breeding value and estimated maternal breeding value. Equations for these parameters were,

$$D\hat{B}V = X_2\hat{g} + \hat{a}$$

$$M\hat{B}V = X_3\hat{d} + \hat{m}$$

$$TM\hat{B}V = \frac{1}{2}D\hat{B}V + M\hat{B}V$$

where

$D\hat{B}V$, $M\hat{B}V$, $TM\hat{B}V$	=	vectors of estimated direct breeding values, estimated maternal breeding values and estimated total maternal breeding values
X_2	=	a matrix of breed contents in animals relating the vector of direct additive breed effects ($\hat{g}$)
X_3	=	a matrix of breed contents in animals relating the vector of maternal additive breed effects ($\hat{d}$)
$\hat{a}$	=	vector of direct genetic effects
$\hat{m}$	=	vector of maternal genetic effects

Estimated breeding values for direct genetic, maternal genetic and total maternal genetic of individual animals were estimated for BW and WW. For TB and KI, only direct breeding values were estimated.

Analysis III: Estimation of economic values and construction of index for selection

1. Economic values

Performance records of 1,301 parturitions obtained from Yala Livestock Research and Breeding Center, Department of Livestock Development were used to estimate economic values for weaned kid production by Empirical method (Weller, 1994). There were three steps need to be considered when economic values were derived.

First step was description production system. Production system in this herd was described according to final goal (weaned kids sold for commercial herds). It was assumed that a few adult males were necessary for breeding and that female kids were kept for replacements. All breeding males were culled after three breeding years and females were culled at six years of age (approximately 6 parities). A proportion of male mated to females was 1:12 and kidding frequency was 1.3. Kid survival rate from birth to three months old varied with type of birth. Single, twin and triplet born kids had mean survival approximately 90%, 81% and 67%, respectively. About 20% of a total number of weaned kids were remained in the center for replacements and 59.33% of them were sold for being the parents of offspring in production herds that produce meat goat to Muslim consumers for religious activities and holidays. The production herds in Yala province and other provinces in the south could be classified based on scale of production as small-, medium- and large-scale. About 95% of the total production is smallholders and the rest is medium and large size farms. The prices of the animals depend on breed and body weight at weaning age (Figure 1).

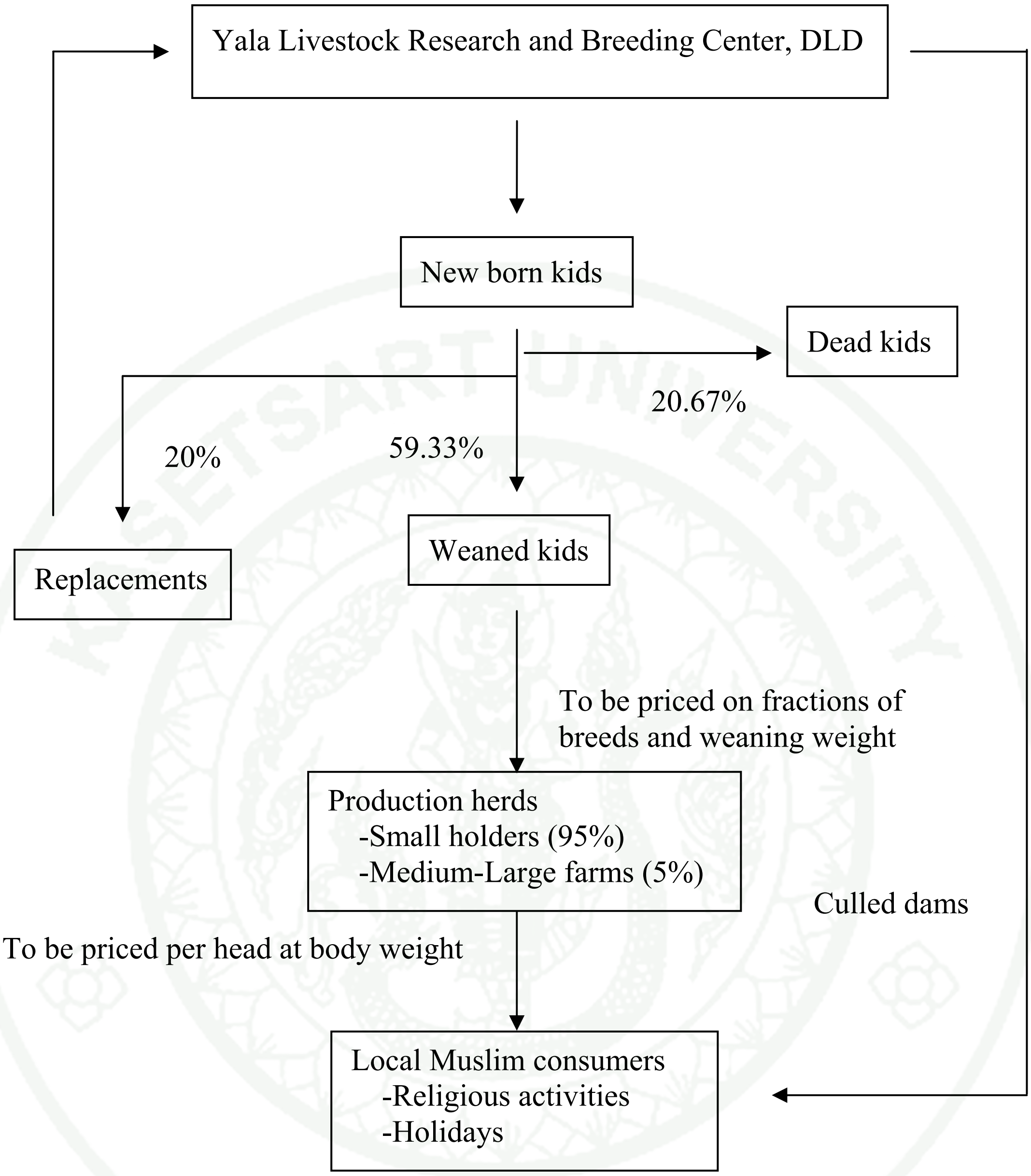

Figure 1 Production model of goat at Yala Livestock Research and Breeding Center

Second step was modeling the profit function. Herd profit was expressed as the difference between revenues and costs. Throughout this study, prices for 2009 were used in analysis and all costs and prices were expressed in Thai baht. The production unit was the dam and the time unit was one parity. Revenue per dam per parity (R) came from the sale of weaned kid that depended on number of kids born, survival rate, replacement rate, weaning weight and sale price. Sale price was based on 80 baht per kilogram of body weight, additional 500 to 1,000 baht per head due to breed combination of the animal that was more than 50% of Anglo-Nubian and/or Saanen. Revenue per dam per parity was then calculated as

$$R = ((Sr - Re) \times TB \times WW \times 80) + (EPr_k \times (Sr - Re) \times TB)$$

where Sr and Re were survival rate and replacement rate, respectively. TB and WW were type of birth and weaning weight. EPr_k were extra price per head due to breed combination of the kid.

Costs per dam per parity were divided into two categories, variable and fixed costs. Sources of variable costs were feed and veterinary costs. Feed costs for the kid from birth to weaning age (C_{fk}) and for the dam during two consequent kidding dates (C_{fd}) were considered from price of feed, the amount of feed and length of rearing. Veterinary costs were endo- and ecto-parasite controls taken for sires and dams.

$$C_{fk} = ((Pr_{mk} \times FI_{mk}) + (Pr_{ck} \times FI_{ck}) + (Pr_{fk} \times FI_{fk})) \times TB \times 90$$
$$C_{fd} = (Pr_{cd} \times FI_{cd} \times KI) + (Pr_{fd} \times FI_{fd} \times KI)$$

where Pr_{mk}, Pr_{ck}, and Pr_{fk} were price per kilogram of milk powder, concentrate and forage for the kid. FI_{mk}, FI_{ck} and FI_{fk} were the amount of milk powder, concentrate and forage were given in kilogram per day for the kid. Pr_{cd} and Pr_{fd} were price per kilogram of concentrate and forage for the dam. FI_{cd} and FI_{fd} were the amount of concentrate and forage were given in kilogram per day for the dam. TB and KI were type of birth and kidding interval, respectively.

Depreciation for purchased replacements and labor were considered as fixed costs for the herd. Depreciation for purchased sire (De_s) was calculated from initial value of animal, longevity of animal, mating ratio and kidding frequency, while depreciation for purchased dam (De_d) was considered from initial value and longevity of animal. The initial value of the sire and dam was calculated from yearling weight multiplied by sale price at 80 baht per kilogram and would be added 500 to 1,000 baht per head due to breed combination of animal with more than 50% of Anglo-Nubian and/or Saanen. Equations for depreciation for the sire and dam could be expressed as

$$De_s = Pr_s / (L_s \times MR \times KF)$$
$$De_d = Pr_d / L_d$$
$$Pr_s = (YW \times 80) + EPr_s$$
$$Pr_d = (YW \times 80) + EPr_d$$

where Pr_s and Pr_d were sale price of the sire and the dam, respectively. L_s and L_d were longevity in year of the sire and in parity of the dam, respectively. MR and KF were mating ratio and kidding frequency. EPr_s and EPr_d were extra price per head due to breed combination of the sire and the dam, respectively.

Labor was taken as part of management. The current study assumed that one stockman taking care of 5 sires, 60 dams and 101 kids and working for 8 hours per day earned about 5,400 baht per month (approximately 30 days). Labor costs per head (C_l) were calculated as

$$C_l = (5{,}400 \times AKI) / (5 + 60 + 101)$$

where AKI was average kidding interval in day.

Performance data and economic parameters used in analysis are summarized in Table 17.

Third step was calculation of economic values of traits. The economic values of traits affecting the profitability of goat production system in this herd were determined from linear regression model through REG procedure (SAS, 1996). Traits considered in the model as independent variables were weaning weight, type of birth and kidding interval, while profit per dam per parity was dependent variable. Linear regression coefficients of these traits were economic values for herd profit that predicted changes in profit associated with changes in a given trait while holding other traits constant.

$$y_i = b_0 + b_1 x_{i1} + b_2 x_{i2} + b_3 x_{i3} + e_i$$

where y_i was profit per dam per parity of the i^{th} observation. b_0 was the intercept. b_1, b_2 and b_3 were regression of profit per dam per parity on weaning weight (x_{i1}), type of birth (x_{i2}) and kidding interval (x_{i3}), respectively. e_i was random residual ~ NID (0, σ_e^2).

Table 17 Performance data and economic parameters

Parameter	Value
Replacement rate (%)	20
Longevity of the dam (parities)	6
Longevity of the sire (years)	3
Sire : dam ratio	1:12
Kidding frequency	1.30
Survival rate (%)	
- type of birth = 1	90
- type of birth = 2	81
- type of birth = 3	67
Average body weight of the sire at yearling age (kg)	30
Average body weight of the dam at yearling age (kg)	20
Average kidding interval (day)	264
Feed intake (kg/animal/day)	
- milk powder	0.03
- concentrate for the kid	0.10
- forage for the kid	1.00
- concentrate for the dam	0.30
- forage for the dam	4.00

Table 17 (Continued)

Parameter	Value
Feed price (baht/kg)	
- milk powder	35.00
- concentrate for the kid	14.00
- concentrate for the dam	10.00
- forage	0.50
Veterinary costs (baht/parity)	45.00
Labor costs (baht/head)	286.27
Sale price of the kid and replacements (baht/kg)	80.00
Extra price due to breed of the kid and replacements (baht/head)	
- ≥ 93.75 to 100% Anglo-Nubian or Saanen	1,000.00
- ≥ 87.5 to < 93% Anglo-Nubian or Saanen	850.00
- ≥ 75 to < 87.5% Anglo-Nubian or Saanen	750.00
- ≥ 50 to < 75% Anglo-Nubian or Saanen	500.00

2. Index for selection

An index for selection in female line was described as a linear function of estimated breeding values for three traits, each multiplied by their economic values (Dekkers and Gibson, 1998).

$$I = b_1 TM\hat{B}V_1 + b_2 D\hat{B}V_2 + b_3 D\hat{B}V_3$$

where

I = index for selection for female line

b_1 = economic value for weaning weight

b_2 = economic value for type of birth

b_3 = economic value for kidding interval

$TM\hat{B}V_1$ = estimated breeding values for total maternal genetic of weaning weight

$D\hat{B}V_2$ = estimated breeding values for direct genetic of type of birth

$D\hat{B}V_3$ = estimated breeding values for direct genetic of kidding interval

RESULTS

Analysis I: Estimation of breed effects for growth and reproductive traits

1. Breed effects for growth traits

Estimates of direct and maternal additive breed effects expressed as deviation from Native and heterosis breed effects for BW and WW are presented in Table 18. Table 19 shows predicted least-squares means of growth performance for twenty breed groups due to breed effects.

Table 18 Estimates of breed effects for growth traits and standard errors

Effect	Trait[1]			
	BW (kg)	P-value	WW (kg)	P-value
Direct additive breed				
Anglo-Nubian	-0.16 ± 0.09	0.0879	1.82 ± 0.58	0.0015
Saanen	1.84 ± 0.24	0.0001	-0.43 ± 1.51	0.7750
Maternal additive breed				
Anglo-Nubian	0.96 ± 0.09	0.0001	3.34 ± 0.55	0.0001
Saanen	-1.54 ± 0.26	0.0001	5.26 ± 1.62	0.0012
Heterosis breed				
Anglo-Nubian x Saanen	-1.49 ± 0.26	0.0001	-5.03 ± 1.61	0.0018
Anglo-Nubian x Native	0.38 ± 0.04	0.0001	-0.60 ± 0.27	0.0258
Saanen x Native	0.63 ± 0.09	0.0001	-1.77 ± 0.59	0.0028

[1] BW = birth weight, WW = weaning weight

1.1 Breed effects for birth weight

Direct additive breed effect for Saanen was significant difference from zero for BW with the amount of 1.84 kilograms ($P<0.01$). The same effect for Anglo-Nubian breed was small and not significant for BW (-0.16 kilograms, $P>0.05$). Estimates of maternal additive breed effects of Anglo-Nubian and Saanen were significant for BW (0.96 and -1.54 kilograms, $P<0.01$). Heterosis breed effects associated with crossing Anglo-Nubian, Saanen and Native were important ($P<0.01$) for BW. The negative effect was observed from Anglo-Nubian x Saanen cross (-1.49 kilograms), while other crossing types had positive values (0.38 and 0.63 kilograms for Anglo-Nubian x Native and Saanen x Native crosses, respectively).

Table 19 Predicted least-squares means of growth performance for 20 breed groups

	Breed group[1]		Trait[2]	
Animal	Sire	Dam	BW (kg)	WW (kg)
Pure breed				
A	A	A	2.71	14.03
S	S	S	2.21	13.71
N	N	N	1.91	8.87
Two-breed cross				
$\frac{1}{2}$A$\frac{1}{2}$N	A	N	2.21	9.18
$\frac{1}{2}$A$\frac{1}{2}$N	$\frac{1}{2}$A$\frac{1}{2}$N	$\frac{1}{2}$A$\frac{1}{2}$N	2.50	11.15
$\frac{9}{16}$A$\frac{7}{16}$N	$\frac{1}{2}$A$\frac{1}{2}$N	$\frac{5}{8}$A$\frac{3}{8}$N	2.56	11.76
$\frac{5}{8}$A$\frac{3}{8}$N	$\frac{1}{2}$A$\frac{1}{2}$N	$\frac{3}{4}$A$\frac{1}{4}$N	2.48	11.38
$\frac{5}{8}$A$\frac{3}{8}$N	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{1}{2}$A$\frac{1}{2}$N	2.72	12.21
$\frac{11}{16}$A$\frac{5}{16}$N	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{5}{8}$A$\frac{3}{8}$N	2.57	11.95
$\frac{3}{4}$A$\frac{1}{4}$N	A	$\frac{1}{2}$A$\frac{1}{2}$N	2.46	11.61
$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{3}{4}$A$\frac{1}{4}$N	2.65	12.52
$\frac{13}{16}$A$\frac{3}{16}$N	A	$\frac{5}{8}$A$\frac{3}{8}$N	2.52	12.21

Table 19 (Continued)

Breed group[1]			Trait[2]	
Animal	Sire	Dam	BW (kg)	WW (kg)
$\frac{7}{8}A\frac{1}{8}N$	A	$\frac{3}{4}A\frac{1}{4}N$	2.52	12.00
$\frac{1}{2}S\frac{1}{2}N$	$\frac{1}{2}S\frac{1}{2}N$	$\frac{1}{2}S\frac{1}{2}N$	2.37	10.40
$\frac{5}{8}S\frac{3}{8}N$	$\frac{1}{2}S\frac{1}{2}N$	$\frac{3}{4}S\frac{1}{4}N$	2.22	11.68
$\frac{3}{4}S\frac{1}{4}N$	$\frac{3}{4}S\frac{1}{4}N$	$\frac{3}{4}S\frac{1}{4}N$	2.37	11.84
$\frac{7}{8}S\frac{1}{8}N$	S	$\frac{3}{4}S\frac{1}{4}N$	2.52	12.00
Three-breed cross				
$\frac{1}{8}A\frac{1}{4}S\frac{5}{8}N$	N	$\frac{1}{4}A\frac{1}{2}S\frac{1}{4}N$	2.23	11.43
$\frac{1}{4}A\frac{1}{2}S\frac{1}{4}N$	$\frac{1}{4}A\frac{1}{2}S\frac{1}{4}N$	$\frac{1}{4}A\frac{1}{2}S\frac{1}{4}N$	2.09	10.80
$\frac{1}{2}A\frac{1}{4}S\frac{1}{4}N$	$\frac{1}{2}A\frac{1}{4}S\frac{1}{4}N$	$\frac{1}{2}A\frac{1}{4}S\frac{1}{4}N$	2.19	11.03

[1] A = Anglo-Nubian, S = Saanen, N = Native

[2] BW = birth weight, WW = weaning weight

On the basis of prediction of growth performance found that Native had a lower BW than those of Anglo-Nubian and Saanen (1.91, 2.71 and 2.21 kilograms, respectively). Predicted BW of two-breed crosses with the range of 2.21 to 2.72 kilograms mostly tended to exceed than those of Native and three-breed crosses (2.09 to 2.23 kilograms). Among Anglo-Nubian-Native two-breed crosses, the 5/8Anglo-Nubian3/8Native from 3/4Anglo-Nubian1/4Native sires mated with 1/2Anglo-Nubian1/2Native dams had heaviest weight at birth (2.72 kilograms), while the 1/2Anglo-Nubian1/2Native from Native dams had lowest weight at birth (2.21 kilograms). The 3/4Anglo-Nubian1/4Native from *inter se* mating was predicted to be heavier than the 3/4Anglo-Nubian1/4Native from backcross (2.65 vs 2.46 kilograms). Similar result was found from the 1/2Anglo-Nubian1/2Native from *inter se* mating, as compared to the first cross between Anglo-Nubian and Native (2.50 vs 2.21 kilograms).

1.2 Breed effects for weaning weight

Anglo-Nubian had significantly direct additive breed effect on WW (1.82 kilograms, P<0.01). On the other hand, direct additive breed effect for Saanen was small and not significant (-0.43 kilograms, P>0.05). The significant maternal additive breed effects on WW were noted for Anglo-Nubian and Saanen with the amount of 3.34 and 5.26 kilograms, respectively (P<0.01). Estimates of heterosis breed effects for WW were significantly at -5.03, -0.60 and -1.77 kilograms for Anglo-Nubian x Saanen, Anglo-Nubian x Native and Saanen x Native crosses, respectively (P<0.05).

Predicted WW of Anglo-Nubian and Saanen were higher than Native (14.03, 13.71 and 8.87 kilograms, respectively). Weaning weight of two-breed crosses with the range of 9.18 to 12.52 kilograms mostly tended to exceed than those of Native and three-breed crosses (10.80 to 11.43 kilograms). Among Anglo-Nubian-Native two-breed crosses, the 3/4Anglo-Nubian1/4Native from *inter se* mating had highest weaning weight (12.52 kilograms), while the 1/2Anglo-Nubian1/2Native from Native dams had lowest weaning weight (9.18 kilograms). The 3/4Anglo-Nubian1/4Native from *inter se* mating was predicted to be heavier than the 3/4Anglo-Nubian1/4Native from backcross (12.52 vs 11.61 kilograms). Similar result was found from the 1/2Anglo-Nubian1/2Native from *inter se* mating, as compared to the first cross between Anglo-Nubian and Native (11.15 vs 9.18 kilograms).

2. Breed effects for reproductive traits

Table 20 shows direct additive breed effects as deviation from Native and heterosis breed effects for TB and KI. The predicted reproductive performances from thirteen breed groups of females due to breed effects are shown in Table 21.

Table 20 Estimates of breed effects for reproductive traits and standard errors

Effect	Trait[1]			
	TB (head)	P-value	KI (day)	P-value
Direct additive breed				
Anglo-Nubian	0.02 ± 0.03	0.5569	8.98 ± 6.12	0.1423
Saanen	-0.09 ± 0.10	0.3747	18.62 ± 20.98	0.3618
Heterosis breed				
Anglo-Nubian x Saanen	-0.17 ± 0.28	0.5306	-31.59 ± 45.09	0.4836
Anglo-Nubian x Native	0.12 ± 0.06	0.0349	-6.23 ± 11.30	0.5818
Saanen x Native	0.34 ± 0.21	0.0960	-9.32 ± 41.21	0.8212

[1] TB = type of birth, KI = kidding interval

2.1 Breed effects for type of birth

Estimates of direct additive breed effects for Anglo-Nubian and Saanen for TB were small and not significant (0.02 and -0.09 heads, respectively, P>0.05). Heterosis breed effect between Anglo-Nubian and Native was positive and significant for TB (0.12 heads, P<0.05), while the others (Anglo-Nubian x Saanen and Saanen x Native) were not significant (-0.17 and 0.34 heads, P>0.05).

From the predicted least-squares means of TB, Anglo-Nubian and Native females were higher than that of Saanen females (1.41, 1.40 and 1.31 heads, respectively). Two-breed crosses produced kids between 1.46 and 1.53 heads that tended to be more than those of purebreds and three-breed crosses. Among Anglo-Nubian-Native two-breed crosses, the first cross females between Anglo-Nubian and Native had more number of kids born than others (1.53 heads), including the 1/2Anglo-Nubian1/2Native from *inter se* mating (1.47 heads). The 3/4Anglo-Nubian1/4Native in backcross tended to be superior to the 3/4Anglo-Nubian1/4Native from *inter se* mating (1.47 vs 1.46 heads).

Table 21 Predicted least-squares means of reproductive performance for 13 breed groups

Breed group[1]			Trait[2]	
Female	Sire	Dam	TB (head)	KI (day)
Pure breed				
A	A	A	1.41	283.47
S	S	S	1.31	293.09
N	N	N	1.40	274.47
Two-breed cross				
$\frac{1}{2}$A$\frac{1}{2}$N	A	N	1.53	271.06
$\frac{1}{2}$A$\frac{1}{2}$N	$\frac{1}{2}$A$\frac{1}{2}$N	$\frac{1}{2}$A$\frac{1}{2}$N	1.47	275.02
$\frac{5}{8}$A$\frac{3}{8}$N	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{1}{2}$A$\frac{1}{2}$N	1.47	276.14
$\frac{3}{4}$A$\frac{1}{4}$N	A	$\frac{1}{2}$A$\frac{1}{2}$N	1.47	277.26
$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{3}{4}$A$\frac{1}{4}$N	1.46	278.25
$\frac{1}{2}$S$\frac{1}{2}$N	$\frac{1}{2}$S$\frac{1}{2}$N	$\frac{1}{2}$S$\frac{1}{2}$N	1.52	280.75
$\frac{5}{8}$S$\frac{3}{8}$N	$\frac{3}{4}$S$\frac{1}{4}$N	$\frac{1}{2}$S$\frac{1}{2}$N	1.51	283.08
$\frac{3}{4}$S$\frac{1}{4}$N	$\frac{3}{4}$S$\frac{1}{4}$N	$\frac{3}{4}$S$\frac{1}{4}$N	1.46	286.16
Three-breed cross				
$\frac{3}{8}$A$\frac{3}{8}$S$\frac{1}{4}$N	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{3}{4}$S$\frac{1}{4}$N	1.36	262.66
$\frac{5}{8}$A$\frac{1}{8}$S$\frac{1}{4}$N	$\frac{3}{4}$A$\frac{1}{4}$N	$\frac{1}{2}$A$\frac{1}{4}$S$\frac{1}{4}$N	1.43	273.05

[1] A = Anglo-Nubian, S = Saanen, N = Native

[2] TB = type of birth, KI = kidding interval

2.2 Breed effects for kidding interval

Estimates of direct additive breed effects for Anglo-Nubian and Saanen for KI were positive and not significant (8.98 and 18.62 days, respectively, P>0.05). The negative heterosis breed effects were found from all crossing types for

KI (-31.59, -6.23 and -9.32 days for Anglo-Nubian x Native, Anglo-Nubian x Saanen and Saanen x Native, respectively).

Predicted KI of Anglo-Nubian and Saanen females were 283.47 and 293.09 days, respectively while that of Native was only 274.47 days. The number of days in KI of all crosses was from 262.66 to 286.16 days. Corresponding values of the Anglo-Nubian-Native two-breed cross females (271.06 to 278.25 days) tended to be less than those of Saanen-Native two-breed cross females (280.75 to 286.16 days). The shortest KI for two-breed crosses was found from 1/2Anglo-Nubian1/2Native (271.06 days).

Analysis II: Estimation of variance components, parameters and breeding values

1. Likelihood ratio test

Table 22 shows the differences in log likelihood between models associated with fitting each additional random term. The addition of maternal permanent environmental effect resulted in significant ($P<0.05$) increase in log likelihood over Model 1. Fitting maternal genetic effect in Model 3 and both genetic and environmental components of dam effects in Model 4 also increased value of log likelihood markedly over that of Model 1 ($P<0.05$). Model 4 provided more parameters than Model 2 and 3 and the log likelihood of Model 4 was lower than these models ($P<0.05$). Based on likelihood ratio test, Model 4 consisted of direct genetic, maternal genetic and maternal permanent environmental effects with allowing covariance between direct and maternal was significantly better fit than other models for both traits of growth ($P<0.05$).

Table 22 Differences in log likelihood values between models

Model comparison	Difference in number of Variance component	Difference in log likelihood value[1]	
		BW	WW
1 vs 2	1	14.11*	32.33*
1 vs 3	2	22.47*	98.79*
1 vs 4	3	26.41*	107.09*
2 vs 4	2	12.31*	74.73*
3 vs 4	1	5.06*	8.30*

[1] Critical values were $\chi^2_{.05,1} = 3.84$, $\chi^2_{.05,2} = 5.99$, $\chi^2_{.05,3} = 7.81$

* P<0.05

2. Variance components and parameters from single-trait analyses for growth traits

Estimation of variance components and parameters from single-trait analyses with the best fit models for growth traits (BW and WW) by using derivative-free REML algorithm are summarized in Table 23. Estimate of phenotypic variance for BW was 0.17 kilogram^2. Direct and maternal heritability estimates for BW were 0.64 and 0.28, respectively. The estimated correlation between direct and maternal effects was highly negative (-0.82). The relative variance due to maternal permanent environmental effect was 0.09. The variance due to residual effect as a proportion of total variance was 0.34 for BW.

Phenotypic variance was estimated to be 6.66 kilogram^2 for WW. Weaning weight had moderate estimate of direct heritability (0.36) and low estimate of maternal heritability (0.10). Correlation between direct and maternal effects was estimated to be -0.68. Maternal permanent environmental variance and residual variance as a proportion of total variance were 0.04 and 0.62, respectively for WW.

3. Variance components and parameters from single-trait analyses for reproductive traits

From Table 23, estimate of phenotypic variance for TB was 0.23 head^2. Direct heritability estimate obtained for TB was 0.04. Permanent environmental variance as a proportion of phenotypic variance was very small (0.02), while residual variance as a proportion of phenotypic variance was large (0.94) for TB. Estimate of phenotypic variance was 4459.67 day^2 for KI. The estimated direct heritability of KI was close to zero (0.02). Estimate of variance due to permanent environmental effect was 0.05, while residual variance as a proportion of phenotypic variance was large (0.93) for KI

4. Variance components and parameters from multiple-trait analyses for growth and reproductive traits

Estimates of variance components and parameters from multiple-trait analyses by using derivative-free REML algorithm are summarized in Table 24. The results of multiple-trait analyses for all traits showed that estimates of variance and parameters for BW, WW and TB were similar to those obtained from single-trait analyses, but in some cases the differences were considerable. The values of direct variance, permanent environmental variance and phenotypic variance were a bit higher than those from single-trait analyses for KI.

From Table 25, the estimates of direct genetic correlations were negative between BW and WW (-0.07), BW and TB (-0.26) and WW and TB (-0.30). Weaning weight was moderate and negatively genetic correlated with KI (-0.65). A highly positive correlation (0.76) was found between TB and KI. Environmental correlations for WW with BW and KI were 0.35 and 0.16, respectively. There were a highly negative correlation between WW and TB (-0.97), smaller in magnitude between BW and TB (-0.21) and slightly correlation for KI with BW (-0.06) and TB (-0.03).

Table 23 Estimates of variance components and parameters from single-trait analyses

Parameter[1]	Trait[2]			
	BW	WW	TB	KI
σ_a^2	0.11	2.43	0.01	96.03
σ_m^2	0.05	0.65	-	-
σ_{am}	-0.06	-0.85	-	-
σ_c^2	0.02	0.28	-	-
σ_{pe}^2	-	-	0.01	210.48
σ_e^2	0.06	4.16	0.21	4153.17
σ_p^2	0.17	6.66	0.23	4459.67
h^2	0.64 (0.12)	0.36 (0.11)	0.04 (0.03)	0.02 (0.04)
m^2	0.28 (0.07)	0.10 (0.05)	-	-
r_{am}	-0.82 (0.37)	-0.68 (0.57)	-	-
c^2	0.09 (0.03)	0.04 (0.02)	-	-
pe^2	-	-	0.02 (0.03)	0.05 (0.05)
e^2	0.34 (0.08)	0.62 (0.08)	0.94 (0.02)	0.93 (0.04)

[1] σ_a^2 = direct genetic variance, σ_m^2 = maternal genetic variance, σ_{am} = direct-maternal covariance, σ_c^2 = maternal permanent environmental variance, σ_{pe}^2 = permanent environmental variance, σ_e^2 = residual variance, σ_p^2 = phenotypic variance, h^2 = direct heritability, m^2 = maternal heritability, r_{am} = direct-maternal genetic correlation, c^2 = maternal permanent environmental variance as a proportion of phenotypic variance, pe^2 = permanent environmental variance as a proportion of phenotypic variance, e^2 = residual variance as a proportion of phenotypic variance

[2] BW = birth weight, WW = weaning weight, TB = type of birth, KI = kidding interval

Figures in parentheses are standard errors of estimate

Table 24 Estimates of variance components and parameters from multiple-trait analyses

Parameter[1]	Trait[2]			
	BW	WW	TB	KI
σ_a^2	0.10	2.41	0.01	144.97
σ_m^2	0.05	0.68	-	-
σ_{am}	-0.06	-0.90	-	-
σ_c^2	0.02	0.32	-	-
σ_{pe}^2	-	-	0.01	214.26
σ_e^2	0.06	4.16	0.21	4141.72
σ_p^2	0.17	6.67	0.23	4500.96
h^2	0.61	0.36	0.04	0.03
m^2	0.28	0.10	-	-
r_{am}	-0.81	-0.70	-	-
c^2	0.09	0.05	-	-
pe^2	-	-	0.02	0.05
e^2	0.36	0.62	0.94	0.92

[1] σ_a^2 = direct genetic variance, σ_m^2 = maternal genetic variance, σ_{am} = direct-maternal covariance, σ_c^2 = maternal permanent environmental variance, σ_{pe}^2 = permanent environmental variance, σ_e^2 = residual variance, σ_p^2 = phenotypic variance, h^2 = direct heritability, m^2 = maternal heritability, r_{am} = direct-maternal genetic correlation, c^2 = maternal permanent environmental variance as a proportion of phenotypic variance, pe^2 = permanent environmental variance as a proportion of phenotypic variance, e^2 = residual variance as a proportion of phenotypic variance

[2] BW = birth weight, WW = weaning weight, TB = type of birth, KI = kidding interval

Maternal genetic correlation between BW and WW was close to zero (0.01, data not shown). The correlations between maternal permanent environmental effects on BW and WW was low (0.09) and between permanent environmental effects on TB and KI was relatively high negative (-0.72).

Estimates of correlations between maternal genetic effects for growth traits and direct genetic effects for reproductive traits were mostly low (0.04 to 0.76, data not shown).

Table 25 Estimates of direct genetic (above diagonal) and environmental (below diagonal) correlations between traits

Trait[1]	BW	WW	TB	KI
BW		-0.07	-0.26	-0.10
WW	0.35		-0.30	-0.65
TB	-0.21	-0.97		0.76
KI	-0.06	0.16	-0.03	

[1] BW = birth weight, WW = weaning weight, TB = type of birth, KI = kidding interval

5. Estimated breeding values for growth and reproductive traits

Solutions for breed effects for growth and reproductive traits from multiple-trait analyses are shown in Appendix Table 1. The solutions for direct and maternal additive breed effects were relative to Native effect. Heterosis effects were upon Anglo-Nubian x Saanen, Anglo-Nubian x Native and Saanen x Native crosses. These effects were estimated by generalized least squares (GLS) simultaneously with other fixed and random effects in the model. While the estimates from fixed analyses were the ordinary least square estimators (see Tables 18 and 20). Therefore, the estimates from multiple-trait analyses were different from those reported from fixed analyses of the same data. However, the important point was that for most of four traits, differences in breed effects were large. The breed effects would be expected to have a major impact on ranking of animals for estimated breeding values across breeds for these traits.

Table 26 Minimum and maximum of estimated breeding values for traits

Trait[1]	Sex	No[2]	$D\hat{B}V$[3]		$M\hat{B}V$[4]		$TM\hat{B}V$[5]	
			Min[6]	Max[7]	Min[6]	Max[7]	Min[6]	Max[7]
BW (kg)	Total	3,123	-0.72	1.77	-1.24	1.09	-0.37	1.03
	Male	1,530	-0.72	1.77	-1.24	1.09	-0.35	1.03
	Female	1,593	-0.69	1.34	-1.00	1.04	-0.37	1.00
WW (kg)	Total	3,123	-2.24	4.20	-1.17	5.83	-0.62	6.03
	Male	1,530	-2.24	4.20	-1.14	5.62	-0.60	5.84
	Female	1,593	-2.08	3.32	-1.17	5.83	-0.62	6.03
TB (head)	Female	1,593	-0.15	0.13	-	-	-	-
KI (day)	Female	1,593	-17.34	29.84	-	-	-	-

[1] BW = birth weight, WW = weaning weight, TB = type of birth, KI = kidding interval

[2] No = number of records

[3] $D\hat{B}V$ = estimated direct breeding value

[4] $M\hat{B}V$ = estimated maternal breeding value

[5] $TM\hat{B}V$ = estimated total maternal breeding value

[6] Min = minimum

[7] Max = maximum

Across-breed estimated breeding values ($D\hat{B}V$, $M\hat{B}V$ and $TM\hat{B}V$) for all traits (BW, WW, TB and KI) obtained by adding the corresponding additive breed effects to within-breed estimated breeding values from multiple-trait analyses are shown in Table 26. The minimum values of $D\hat{B}V$, $M\hat{B}V$ and $TM\hat{B}V$ for BW were -0.72, -1.24 and -0.37 kilograms, respectively and the maximum values of $D\hat{B}V$,

$\mathrm{M\hat{B}V}$ and $\mathrm{TM\hat{B}V}$ for the same trait were 1.77, 1.09 and 1.03 kilograms, respectively. For weaning weight, $\mathrm{D\hat{B}V}$, $\mathrm{M\hat{B}V}$ and $\mathrm{TM\hat{B}V}$ ranged from -2.24 to 4.20, from -1.17 to 5.83 and from -0.62 to 6.03 kilograms, respectively. Estimates of $\mathrm{D\hat{B}V}$ for reproductive traits were summarized from animal models that included direct genetic and permanent environmental effects. The ranges in $\mathrm{D\hat{B}V}$ were from -0.15 to 0.13 heads for TB and from -17.34 to 29.84 days for KI.

Table 27 shows minimum and maximum values of across-breed estimated breeding values for different breeds. Minimum and maximum values in $\mathrm{D\hat{B}V}$ of Saanen were higher than those of other breeds for BW, while Anglo-Nubian had positive $\mathrm{M\hat{B}V}$ and $\mathrm{TM\hat{B}V}$ for the same trait. Maximum values in $\mathrm{D\hat{B}V}$, $\mathrm{M\hat{B}V}$ and $\mathrm{TM\hat{B}V}$ of Anglo-Nubian were higher than those of other breeds for WW. Negative values of $\mathrm{D\hat{B}V}$ were observed from Saanen for TB, while Anglo-Nubian, Native and crossbreds had similar ranges. Native had the lowest (desirable) $\mathrm{D\hat{B}V}$ for KI, while Saanen had the highest (least desirable) $\mathrm{D\hat{B}V}$ for the same trait.

Table 28 shows minimum and maximum values of $\mathrm{TM\hat{B}V}$ for growth traits of top 20% in male and female goats. Estimated total maternal breeding values for BW of top 20% ranged from 0.52 to 1.03 kilograms in males and from 0.56 to 0.10 kilograms in females. Breed groups of them were mostly Anglo-Nubian and Anglo-Nubian-Native two-breed crosses. When considering the top twenty males and females in Appendix Tables 2 found that they were mostly Anglo-Nubian breed with the range of $\mathrm{TM\hat{B}V}$ from 0.89 to 1.03 kilograms for males and from 0.91 to 1.00 kilograms for females. Ranges of $\mathrm{TM\hat{B}V}$ of top 20% in males and females were from 3.58 to 5.84 and 3.67 to 6.03 kilograms for WW. About 50% of a total number of top 20% were Anglo-Nubian, 30% were Anglo-Nubian-Native two-breed crosses and 20% were Saanen and Anglo-Nubian-Saanen-Native three-breed crosses. When considering the top twenty males and females in Appendix Tables 3 found that they were Anglo-Nubian breed with the range of $\mathrm{TM\hat{B}V}$ from 5.28 to 5.84 kilograms for males and from 5.38 to 6.03 kilograms for females.

Table 27 Minimum and maximum of estimated breeding values for different breeds

Trait[1]	Breed	No[2]	$D\hat{B}V$[3]		$M\hat{B}V$[4]		$TM\hat{B}V$[5]	
			Min[6]	Max[7]	Min[6]	Max[7]	Min[6]	Max[7]
BW (kg)	Anglo-Nubian	336	-0.56	0.64	0.18	1.09	0.02	1.00
	Saanen	56	0.62	1.77	-1.24	-0.55	-0.37	-0.21
	Native	964	-0.72	0.80	-0.41	0.50	-0.13	0.21
	Crossbreds	1,767	-0.56	1.34	-0.90	0.89	-0.37	1.03
WW (kg)	Anglo-Nubian	336	-2.08	4.20	0.07	5.83	-0.22	6.03
	Saanen	56	0.39	3.64	2.83	4.23	4.05	4.71
	Native	964	-1.86	2.54	-1.17	1.21	-0.62	1.43
	Crossbreds	1,767	-2.24	2.49	-1.07	4.83	-0.60	4.99
TB (head)	Anglo-Nubian	187	-0.10	0.12	-	-	-	-
	Saanen	29	-0.14	-0.03	-	-	-	-
	Native	502	-0.15	0.11	-	-	-	-
	Crossbreds	875	-0.12	0.13	-	-	-	-
KI (day)	Anglo-Nubian	187	-2.52	27.20	-	-	-	-
	Saanen	29	13.97	29.04	-	-	-	-
	Native	502	-17.34	16.45	-	-	-	-
	Crossbreds	875	-9.48	29.84	-	-	-	-

[1] BW = birth weight, WW = weaning weight, TB = type of birth, KI = kidding interval

[2] No = number of records

[3] $D\hat{B}V$ = estimated direct breeding value

[4] $M\hat{B}V$ = estimated maternal breeding value

[5] $TM\hat{B}V$ = estimated total maternal breeding value

[6] Min = minimum

[7] Max = maximum

From Table 28, minimum and maximum values of $D\hat{B}V$ for TB of top 20% of female goats were 0.03 and 0.13 heads, respectively. From 318 females, 164 were Anglo-Nubian-Native two-breed crosses, 97 were Native and 57 were Anglo-Nubian. When considering the top twenty females in Appendix Tables 4 found that they were mostly Native, following by Anglo-Nubian and Anglo-Nubian x Native crossbreds with the range of 0.09 to 0.13 heads. Estimated direct breeding values for KI of bottom 20% in females ranged from -17.34 to 0.59 days. From 318 females, 277 were Native, 27 were the 1/2Anglo-Nubian1/2Native and 14 were Anglo-Nubian. The bottom twenty $D\hat{B}V$ for KI ranged from -17.34 to -7.54 days. Almost females in the bottom twenty according to $D\hat{B}V$ for KI were Native and only one female was the 1/2Anglo-Nubian1/2Native.

Table 28 Minimum and maximum of estimated breeding values for best 20%

Trait[1]	Sex	No[2]	$D\hat{B}V$[3]		$TM\hat{B}V$[4]	
			Min[5]	Max[6]	Min[5]	Max[6]
BW (kg)	Male	306	-	-	0.52	1.03
	Female	318	-	-	0.56	0.10
WW (kg)	Male	306	-	-	3.58	5.84
	Female	318	-	-	3.67	6.03
TB (head)	Female	318	0.03	0.13	-	-
KI (day)	Female	318	-17.34	0.59	-	-

[1] BW = birth weight, WW = weaning weight, TB = type of birth, KI = kidding interval

[2] No = number of records

[3] $D\hat{B}V$ = estimated direct breeding value

[4] $TM\hat{B}V$ = estimated total maternal breeding value

[5] Min = minimum

[6] Max = maximum

Analysis III: Estimation of economic values and construction of index for selection

1. Economic values

Table 29 presents revenues and costs for production system in Yala Livestock Research and Breeding Center. In this study, revenues of the herd from the sale of weaned kids varied from 280.00 to 3,196.40 baht per dam per parity. Revenues from the sale of Anglo-Nubian, Saanen, crossbred and Native kids averaged 1,877.38, 1,862.32, 1,529.08 and 724.31 baht per dam per parity, respectively. The total cost was in range of 1,667.72 to 3,434.24 baht per dam per parity. Feed and veterinary costs as variable costs represented approximately 67.04 and 2.02% of the total cost, respectively. When considering only fixed costs, the most important cost was due to depreciation of purchased replacements, following by labor costs. Herd profit showed negative and positive values, ranging from -2,772.72 to 920.65 baht per dam per parity. Average profit from the sale of weaned kids was -897.70 baht per dam per parity. The less negative value of average profit was observed from the sale of Anglo-Nubian kids, while the sale of Native kids had high negative value.

Results from regression model in predicting profit are reported in Table 30. The regression coefficients from the ordinary multiple regression model for WW, TB and KI were 86.58, 479.07 and -4.34 baht, respectively. Standardized regression coefficients for these traits were 0.47, 0.46 and -0.54, respectively.

Table 29 Revenues, costs and profit

Variable	Average (baht)	Range (baht)
Revenues	1,307.63	280.00 to 3,196.40
Anglo-Nubian	1,877.38	980.00 to 3,196.40
Saanen	1,862.32	1,288.00 to 2,830.40
Native	724.31	280.00 to 1,747.04
Crossbreds	1,529.08	392.00 to 3,161.22
Costs	2,232.97	1,667.72 to 3,434.24
Variable costs		
- Feed costs	1,496.88	1,018.50 to 2,691.00
- Veterinary costs	45.00	-
Fixed costs		
- Depreciation of purchased sires	63.28	51.28 to 72.65
- Depreciation of purchased dams	341.54	266.67 to 433.33
- Labor costs	286.27	-
Profit	-897.70	-2772.72 to 920.65
Anglo-Nubian	-463.34	-2,046.25 to 920.65
Saanen	-467.28	-1,362.75 to 813.45
Native	-1,370.20	-2,772.72 to -266.52
Crossbreds	-718.31	-2,394.74 to 400.50

Table 30 Regression coefficients for traits

Trait	Ordinary coefficient (baht)	Standardized coefficient (baht)
Intercept	-1469.83	-
Weaning weight	86.58 ± 2.84[1]	0.47
Type of birth	479.07 ± 16.13[1]	0.46
Kidding interval	-4.34 ± 0.13[1]	-0.54

[1] standard error

2. Index for selection

An index for selecting female line was developed in order to economically maximize genetic improvement. An index equation was derived by multiplying of each individual's breeding value for the traits under consideration by economic values.

$$I = 86.58TM\hat{B}V_1 + 479.07D\hat{B}V_2 - 4.34D\hat{B}V_3$$

where I was an index for selecting female line. $TM\hat{B}V_1$, $D\hat{B}V_2$ and $D\hat{B}V_3$ were total maternal breeding value for weaning weight, direct breeding value for type of birth and direct breeding value for kidding interval, respectively.

The minimum and maximum values due to index equation as described above were -67.81 and 455.45 baht, respectively. The index values of top 20% of high potential breeding females ranged from 260.10 to 455.45 baht. From 318 females, 186 were Anglo-Nubian, 115 were Anglo-Nubian-Native two-breed crosses, 9 were Anglo-Nubian-Saanen-Native three-breed crosses and 8 were Saanen. The top twenty of high potential breeding females according to index equation are shown in Appendix Table 7. Breed of top twenty females was Anglo-Nubian with the range of 418.42 to 455.45 baht. However, most of index values from top twenty of high potential breeding females were different from index values of top twenty females according to $TM\hat{B}V$ for WW, top twenty females according to $D\hat{B}V$ for TB and bottom twenty females according to $D\hat{B}V$ for KI (Appendix Tables 8 – 10).

DISCUSSION

Analysis I: Estimation of breed effects for growth and reproductive traits

1. Breed effects for growth traits

The analyses were conducted to determine the contributions of direct additive breed, maternal additive breed and heterosis breed effects to differences among various purebred and crossbred groups for BW and WW. Direct and maternal additive breed effects were expressed as deviation from Native. Heterosis breed effects observed upon crossing Anglo-Nubian x Saanen, Anglo-Nubian x Native and Saanen x Native.

1.1 Breed effects for birth weight

Direct additive breed effect was found to be significant for Saanen for BW ($P<0.01$). The result confirmed the breed difference between Saanen and Native in body size. According to Devendra and Burns (1983), Saanen would be classified as a large breed. While Native, similarly to the Malaysian Katjang, would be classified as a small one. The result concurred with that of Dillard *et al.* (1980) who found the Angus additive genetic effect to be negative while the Charolais additive effect to be positive compared to Hereford breed. Boujenane *et al.* (1991), in addition, concluded a low breed contribution to birth weight of D'man when comparing to Sardi sheep.

Maternal additive breed effects were positive for Anglo-Nubian and negative for Saanen relative to Native. The results were in agreement with Boujenane *et al.* (1991) who pointed out an importance of breed maternal effects on weight at birth of lambs. The favorable effect of Anglo-Nubian indicated that the kids from Anglo-Nubian dams were heavier at birth than the kids from Native dams. The reason might be due to uterine space of Native dams controlling foetal size during pregnant period as mentioned by Mukundan *et al.* (1991). A negative maternal breed effect of Saanen for BW of kids reported here was similar to the study of Boujenane *et al.* (1991). The unfavorable effect of Saanen might be that Saanen dams did not provide maternal ability to maximize the growth of a developing fetus under harsh environmental condition of tropics. According to Devendra and Burns (1983), Saanen is commonly believed to be less suited to the tropics than other European breeds. Heat stress during gestation form tropical climate might reduce progesterone concentration, uterine blood flow, ovine placental lactogen and birth weight of kids as observed by Collier *et al.* (1982) in calves.

Heterosis breed effects resulted in this study were found to be significant ($P<0.01$) for all crossing types for BW. The positive estimates obtained from Anglo-Nubian x Native and Saanen x Native crosses were larger than that reported of 0.05 kilograms by Mugambi *et al.* (2007) who estimated from 6,800 progeny of straightbreds, two-breed crosses, four-breed crosses and composite populations of Toggenburg, Anglo-Nubian, Small East African and Galla breeds in Kenya. The positive effects were also reported by Dillard *et al.* (1980) and Tumwasorn *et al.* (1993) for BW of calves. The favorable effects of heterosis breed on BW in current study indicated possible compatibility between genetic diversity of Native with Anglo-Nubian and Saanen. The crossing breeds that are genetically different from each other, but have complementary attributes should provide an adequate amount of heterosis (Bourdon, 2000). However, a negative effect observed from a cross between Anglo-Nubian and Saanen in this study was consistent to Kahi *et al.* (1995) who reported -0.70 and -1.01 kilograms for Angus x Sahiwal and Angus x Brown Swiss crosses, respectively. Olson *et al.* (1985) also reported heterosis effect of -0.10 kilograms on BW for Angus x Brown Swiss cross. The unfavorable effect from a cross between Anglo-Nubian and Saanen for BW observed here might be caused by a lack of compatibility between genetic diversity of Anglo-Nubian and Saanen.

Predicted BW of Anglo-Nubian and Saanen kids found in this study were lower than those reported by Gill and Dev (1972) and Mishra and Chawla (1976) at 2.90 and 3.00 kilograms, respectively in India. While predicted BW of

Native kids was similar to mean weight at birth of 1.90 kilograms for single born kids of Native raised at the Faculty of Natural Resources, the Prince of Songkla University, Thailand (Milton *et al*., 1987). In comparison the predicted BW among purebreds, Anglo-Nubian and Saanen kids were superior to Native kids. These supported the conclusion that BW of Native, classified as a small breed, was near the lower end of the range in birth weights of various breeds of goat, while Anglo-Nubian and Saanen breeds, classified as large, were heavier at birth (Devendra and Burns, 1983). Predicted BW of Native kids also tended to be lower than did two-breed crosses. This could be explained by heterosis effect as reported by Acharya (1988) and Ruvuna *et al.* (1988). The difference for predicted BW of the 3/4Anglo-Nubian1/4Native from *inter se* mating, compared with that of the 3/4Anglo-Nubian1/4Native from backcross was in agreement with the findings of Gebrelul *et al.* (1994) and Taneja (1982). This decrease was due to reduce heterozygosity of progeny from backcross relative to *inter se* kids. Furthermore, the differences for predicted BW of the 1/2Anglo-Nubian1/2Native from *inter se* mating, compared with that of the first cross between Anglo-Nubian and Native showed an advantage of *inter se* mating.

1.2 Breed effects for weaning weight

Estimate of direct additive breed effect for Anglo-Nubian for WW was in similar to Mugambi *et al.* (2007) who reported additive effect of Anglo-Nubian as deviation from Small East African goat about 1.57 kilograms. In contrast to Gerstmayr *et al.* (1995) who obtained negative influence of American Angoras additive genetic on upgrading the Turkish Angora goats for body weight at 105 days of kids (-0.79 kilograms). The maternal additive breed effects were significant in the same direction (positive) for WW for Anglo-Nubian and Saanen ($P<0.01$). This report was in agreement with MacNeil *et al.* (1982) and Spelbring *et al.* (1977) when comparing maternal ability of the Angus dams with those of the Simmental and Milking Shorthorn dams. The reasons of positive effects in this study might be due to milk production potential of Anglo-Nubian and Saanen breeds as compared with Native. Anglo-Nubian is a dual-purpose breed (meat and milk), Saanen is a milk breed and Native is a meat breed (Devendra and Burns, 1983; Falvey, 1977). The milking ability of Anglo-Nubian and Saanen breeds should be better than Native.

Heterosis breed effects were negatively significant for all crossing types for WW ($P<0.05$). This report was similar to the finding of Mugambi *et al.* (2007) who reported of -0.21 kilograms for the overall heterosis effect from Kenya Dual Purpose Goat composite population. On the other hand, Boujenane *et al.* (1991) showed the positive estimate of 0.29 kilograms in D'man x Sardi cross for 90-day weight and Alenda *et al.* (1980) reported positive heterosis effects on 205-day weight ranged from 11.0 kilograms for Charolais x Hereford cross to 20.0 kilograms for Angus x Charolais cross. The unfavorable effects of heterosis breed for WW in current study might be caused by a lack of compatibility between genetic diversity of Anglo-Nubian and Saanen for this trait. Another possible explanation might be due to environmental condition where the animals were reared. The kids after birth in this study were fed on milk of their dams and milk powder during suckling period. As suggestion by Cunningham (1981), production in poor environment was influenced heavily by heterosis, while production in good environment was determined by breed additive effect.

From the prediction of growth performance, purebred Anglo-Nubian and Saanen kids were heavier at weaning age than Native kids. The results supported the conclusion that growth potential of Native was relatively poor (Hirooka *et al.*, 1997). The low predicted WW of Native kids and the 1/2Anglo-Nubian1/2Native kids born to Native dams indicated the superiority of crossbred dams to Native dams. These might be due to positive correlation between birth and weaning weight of kids. Furthermore, maternal ability of crossbred dams for milk yield production during nursing (Saithanoo *et al.*, 1993). The difference for predicted WW of the 3/4Anglo-Nubian1/4Native from *inter se* mating, compared with that of the 3/4Anglo-Nubian1/4Native from backcross was in agreement with the findings of Gebrelul *et al.* (1994) and Taneja (1982) due to heterosis loss (Shrestha and Fahmy, 2007). Furthermore, the difference for predicted BW of the 1/2Anglo-Nubian1/2Native from *inter se* mating, compared with that of the first cross between Anglo-Nubian and Native showed an advantage of *inter se* mating.

2. Breed effects for reproductive traits

The analyses were conducted to determine direct additive breed and heterosis breed effects on TB and KI from thirteen breed groups of Anglo-Nubian, Saanen, Native and crosses. Direct additive breed effects were expressed as deviation from Native. Heterosis breed effects observed upon crossing Anglo-Nubian x Saanen, Anglo-Nubian x Native and Saanen x Native.

2.1 Breed effects for type of birth

Absence of direct additive breed effects for TB indicated that there was a relatively small effect of Anglo-Nubian and Saanen versus Native female goats on this trait. A Lack of significant effect was in contrast to van Haandel and Visscher (1995) who found significant effect of additive breed for Finnish Landrace as deviation from Ile de France sheep with the amount of 0.79 lambs.

Heterosis breed effect obtained from a cross between Anglo-Nubian and Native was important ($P<0.05$) for TB. This was in agreement with van Haandel and Visscher (1995) who reported significant heterosis effect at 0.35 from a cross of Ile de France x Finnish Landrace sheep. The significantly positive for heterosis breed effect for TB in current study indicated possible compatibility between genetic diversity of Anglo-Nubian and Native for this trait. However, estimates of heterosis breed effects for others (Anglo-Nubian x Saanen and Saanen x Native) were not significant with high standard error. These may be due to small number of observations for each breed group.

The predicted performance for TB of Anglo-Nubian, Saanen and Native showed that Anglo-Nubian and Native females were similar in number of kids born (1.41 and 1.40 kids, respectively), while Saanen females tended to produce less number of kids born (1.31 kids) than did two breeds. These were consistent with Freitas *et al.* (2004) who found that the occurrence of multiple partum was superior in Anglo-Nubian than Saanen in semi-arid of the North-eastern Brazil (62.1% vs 47.4%). Amoah *et al.* (1996) and Dickson-Urdaneta *et al.* (2000) also confirmed that Nubian goats presented higher odds of multiple births than dairy goats of European origin. The superiority of Anglo-Nubian and Native over Saanen for TB in present study could be explained that Anglo-Nubian breed is of mixed origin between the Prick eared goats indigenous to Britain and Nubian-type goats from Africa and India (Zaraibi, Chitral and Jamnapari). The higher prolificacy of the Anglo-Nubian was associated with its Zaraibi ancestry, one of the most prolific seasonal breeders (Devendra and Burn, 1983). Marai *et al.* (2000) reported that number of kids born of Zaraibi dams under Egyptian environmental conditions averaged 2.9 heads. Native goats are similar to the Malaysian Kambing Katjang (Falvey, 1977). These goats are capable of breeding all year round and possess high fecundity under harsh circumstances (Hirooka *et al.*, 1997).

From the prediction of reproductive performance, the Anglo-Nubian-Native two-breed crosses tended to produce more number of kids born than Native. This was in agreement with the finding of Montaldo *et al.* (1995). Among Anglo-Nubian-Native two-breed crosses, the first cross females between Anglo-Nubian and Native had significantly larger number of kids born than others ($P<0.05$). This might be explained that heterosis is directly proportional to the amount of heterozygosity at the loci (Hill, 1981). This effect is maximized in the F_1 or first cross of unrelated (though not necessarily purebred) populations and should decline in later generations with the loss of heterozygosity. In this study, degreed of heterozygosity in the first cross females between Anglo-Nubian and Native, the 1/2Anglo-Nubian1/2Native from *inter se* mating, the 5/8Anglo-Nubian3/8Native, the 3/4Anglo-Nubian1/4Native from backcross and the 3/4Anglo-Nubian1/4Native from *inter se* mating were 1.00, 0.50, 0.05, 0.05 and 0.25, respectively. Therefore, predicted TB performance was highest in first cross females between Anglo-Nubian and Native and declined with decreasing heterozygosity.

2.2 Breed effects for kidding interval

Direct additive breed effects obtained from this study were nonsignificant for KI (P>0.05). Furthermore, heterosis breed effects detected from all crosses (Anglo-Nubian x Saanen, Anglo-Nubian x Native and Saanen x Native) were nonsignificant for the same trait. These might be due to a high variation in this trait. Nevertheless, the negative sings of all heterosis breed effects showed an advantage of crossing breeds that resulted in a shorter period of KI.

Predicted KI of Anglo-Nubian, Saanen and Native showed that Saanen females tended to have a longer period than did Anglo-Nubian females, while Native had the shortest period. As stated by Devendra and Burns (1983), "Kidding interval is the period between two consecutive kidding dates, and is composed of service period (from kidding to conception) and gestation length. Its duration depends on the start of oestrus activity during the post-partum period." Freitas *et al.* (2004) observed that Saanen goats showed more efficient milk production but presented a longer post-partum anoestrus when compared to Anglo-Nubian raised under semi-arid of North-eastern Brazil. The greater efficiency in milk production of Saanen breed, comparing to Anglo-Nubian breed, was probably responsible for the negative correlation between body condition at partum and length of post-partum anoestrus detected in this breed. The body weight and condition of a mother at partum was important because mothers below normal weight or with unsatisfactory body condition at partum produce lighter kids, less milk and take longer to recover the ovarian function after partum. The longer predicted KI found from two-breed crosses when comparing to Native in this study were similar to the finding of Acharya *et al.* (1988).

Analysis II: Estimation of variance components, parameters and breeding values

1. Variance components and parameters from single-trait analyses for birth weight

Based on likelihood ratio test, the best fit models including direct genetic, maternal genetic and maternal permanent environmental effects with allowing covariance between direct and maternal for growth traits were discussed.

Thongchumroon (1996) reported that heritability estimate for BW of crossbred kids at Yala Livestock Research and Breeding Center, Thailand was 0.20. Estimate of direct heritability in this study were higher (0.64) than that of previous report. These differences could be partly explained through selected data set and procedure of analyses. The data set complied by Thongchumroon (1996) was collected from 411 Anglo-Nubian x Native and Saanen x Native crossbred kids, progeny of 5 sires and 245 dams, during 1993 and 1994. Genetic analyses were carried out using paternal half-sib correlation, not the restricted maximum likelihood procedure as occurred in current study.

Estimates of heritability for BW of kids varied substantially in other studies from 0.15 (Das *et al.*, 1996) to 0.68 (Mourad and Anous, 1998) by the method of paternal half-sib correlation and from 0.16 (Hirooka *et al.*, 1997; Schoeman *et al.*, 1997) to 0.50 (Bosso *et al.*, 2008) by fitting animal model using the restricted maximum likelihood procedure. The direct heritability estimate for BW reported here was at the high end of those from earlier studies. The high estimate of direct heritability indicated a much higher proportion of genetic variation on this trait. However, Notter (1998) suggested that the inclusion of negative additive-maternal covariance in animal model for analyses resulted to increase magnitude of direct heritability.

Maternal heritability estimates for BW of kids reported in the literature ranged from 0.14 to 0.24 (Hirooka *et al*., 1997; Schoeman *et al*., 1997; Al-Shorepy *et al*., 2002; Boujenane and El Hazzab, 2008; Zhang *et al*., 2008). In a review of Safari *et al.* (2005) reported weight mean of maternal heritability estimates for BW of 0.18 to 0.24 in dual-purpose, wool and meat sheep breeds. The estimated maternal heritability for BW in the current study was slightly higher than those reports. One reason might be due to effect of highly negative additive-maternal covariance (Notter, 1998). Estimate of direct heritability for BW tended to be higher than the corresponding maternal value for the same trait. This report confirmed to several authors reported in goat (Schoeman *et al*., 1997; Zhang *et al*., 2008), beef cattle (Meyer, 1992; Ferreira *et al*., 1999; Demeke *et al*., 2003) and sheep (Al-Shorepy and Notter, 1996; Hassen *et al*., 2003). The lower maternal heritability than direct heritability implied that BW was determined more by genetic characteristics of the kids than those of the dams.

Negative association between direct and maternal components for BW reported here were in agreement with the findings of María *et al.* (1993) from Romanov sheep (-0.99) and Zhang *et al.* (2007) from Boer goat (-0.71). The negative values indicate antagonism between the genes for prenatal growth and the genes conditioning the intrauterine environment for heavier weights at birth. Such as an antagonism would be a balanced mechanism with the tendency to maintain birth weights in intermediate ranges (Brown and Galvez, 1969). However, the extreme estimates seem far too large to represent true biological relationship as discussed by Robinson (1996). One possible reason for the large negative values of direct-maternal genetic correlations is the small number of progeny per dam and limited information from recorded dams (Gerstmayr, 1992; Maniatis and Pollott, 2003). In this study, the data structure for growth traits consisted of the number of dams which had more than one progeny was approximately 62.84%. The number of dams with own records were approximately 12%. Therefore, the completely datasets with more links between dam performance records and offspring records, as well as more progeny per dam were required for reliable estimates of genetic parameters (Heydarpour *et al*., 2008)

Proportion of phenotypic variance due to maternal permanent environmental effects for BW in current study was in range of 0.00 to 0.17 reported by many studies (such as Mousa *et al.*, 1999; Ligda *et al.*, 2000; Al-Shorepy *et al.*, 2002; Rashidi *et al.*, 2008; Zhang *et al.*, 2008). The low estimate in this study indicated that there was a little influence of uterine environment on BW of kids.

2. Variance components and parameters from single-trait analyses for weaning weight

Direct heritability estimate for WW was lower than that of Thongchumroon (1996) who obtained heritability estimate to be 0.52 of goats raised in Yala Livestock Research and Breeding Center. The differences could be partly explained through selected data set and procedure of analyses as discussed above. Estimates of direct heritability for WW of goat found from other studies ranged from 0.07 (Hirooka *et al.,* 1997) to 0.60 (Els, 1998). The estimated direct heritability of WW reported here was in the middle range of previous studies. The moderate estimate might be due to selection criteria in this population aimed to increase body weight of goat.

The estimated maternal heritability for WW reported here was in range of 0.00 (Notter, 1998; Al-Shorepy *et al.*, 2002) to 0.24 (Boujenane and El Hazzab, 2008). Maternal heritability estimate for WW was lower than estimate of BW, in agreement with several authors (Hirooka *et al.*, 1997; Mousa *et al.*, 1999; Ligda *et al.*, 2000; Miraei-Ashtiani *et al.*, 2007; Rashidi *et al.*, 2008). The higher estimate of maternal heritability for BW compared with estimate for WW supported conclusion of Robinson (1981) that maternal genetic effects generally were important for measurements of body weight at younger ages and were expected to diminish as kids grow older.

Large negative value of genetic correlation between direct and maternal effects for WW reported here was in agreement with several reports (Tosh and Kemp, 1994; Notter, 1998; Rao and Notter, 2000). One reason might be due to the data structure as discussed above. Another possible explanation might be environmentally induced, i.e. result from management and/or husbandry practices (Robison, 1972). The new born kids were received dam milk and milk powder until weaning age. The multiple born kids and orphan kids were driven to supplemental milk powder more than others. The kids with excess supplemental milk powder consumed more than compensating for the lower dam milk intake.

Many studies reported that estimates of maternal permanent environmental effects for weaning weight of kids and lambs were from 0.00 (Boujenane and El Hazzab, 2008) to 0.22 (Rao and Notter, 2000). The permanent environmental effect due to the dam observed here was near the low end of those reports. In addition, the permanent environmental effect due to the dam consistently decreased in importance as kids became increasingly independent of the dam.

3. Variance components and parameters from single-trait analyses for type of birth

Estimate of heritability for TB was at the lower end of the range reported in the literature (-0.001 to 0.35, Lawar and Rasane, 1996; Odubote, 1992 and 1996; Mourad, 1994; Hongping, 2001; Bagnicka *et al.*, 2007). Fogarty (1995) summarized 53 reported estimates of heritability for TB and obtained a mean estimate of 0.10 with a standard error among estimates of 0.07. The range of heritability estimates for the same trait by using the REML procedure were from 0.05 (Al-Shorepy and Notter, 1996) to 0.14 (Waldron and Thomas, 1992). The low estimates of heritability for TB in current study may be due to categorical expression of this trait (Hill, 1985; Falconer and Mackay, 1996) and the REML procedure in analyses. The analysis of a trait exhibiting a discrete distribution of phenotype with threshold model resulted in greater heritability estimates for number of lambs born in Rambouillet and Finnsheep (0.45 and 0.14, respectively, Matos *et al.*, 1997). In theory, threshold models seem appropriate for discrete data and thus may capture a higher portion of genetic variation than is possible with linear methodology (Dempster and Lerner, 1950). It was noticed that a fraction of residual variance of this trait was high (0.94), indicating that the major source of variation in TB appeared to be due to temporary environmental effect. For example, ovulation rate, fertilization rate, uterine capacity, embryo survival, climate, age and body weight of the dam.

Estimate of permanent environmental variance as a proportion of phenotypic variance for TB was in agreement with the finding of Rao and Notter (2000) in Targhee sheep. The low estimate indicating that a dam with large litter in one kidding year tends to produce small litter the next year.

4. Variance components and parameters from single-trait analyses for kidding interval

Estimate of heritability for KI was at the lower end of previous estimates from 0.02 to 0.22 for kidding interval of West African Dwarf goat (Odubote, 1996) and dairy goats (Bagnicka *et al.*, 2007) and calving interval in cattle (Bourdon and Brinks, 1983; Lopez de Torre and Brinks, 1990; Gutiérrez *et al.*, 2002). The low heritability estimate indicated that direct genetic effect for this trait was relatively less important.

The fraction of variance for permanent environmental effect for KI was likewise consistent with previous reported values. Waldron and Thomas (1992) estimated variance due to permanent environmental effects on lambing interval from Rambouillet sheep to be 0.02. More recently, Vanimisetti *et al.* (2007) reported of 0.004 for Katahdin sheep. It was noticed that a fraction of variance for permanent environmental effect on KI was small, while a fraction of residual variance of this trait was high (0.92). This indicated that KI seemed sensitive to temporary environmental effect.

5. Variance components and parameters from multiple-trait analyses for growth and reproductive traits

Estimates of direct genetic correlations between growth and reproductive traits in the current study ranged from -0.65 to 0.76. The estimated genetic correlation between BW and WW was nearly zero (-0.07). This was lower than the range of estimates from 0.15 (Mugambi *et al.*, 2007) to 0.47 (Thongchumroon, 1996) in goat. Safari *et al.* (2005) reported a weighted mean genetic correlation between BW and WW from 14 independent estimates in sheep at 0.47. The weak genetic correlation between BW and WW in present study suggested that selecting for increase BW would not affect WW in this population.

Estimate of maternal genetic correlation between BW and WW was close to zero and lower than that reported of 0.58, 0.35 and 0.48 from Columbia, Targhee and Polypay sheep, respectively by Hanford *et al.* (2002, 2003 and 2006) in sheep. This estimate suggested that no correlation existed between maternal effect on BW and maternal effect on WW.

Estimates of maternal permanent environmental correlation between BW and WW reported by Mousa *et al.* (1999) and Hanford *et al.* (2002, 2003 and 2006) were from 0.44 to 0.70. Bromley *et al.* (2000) found that maternal permanent environmental correlation between BW and average dairy gain from birth to weaning age ranged from 0.46 to 0.63. Rashidi *et al.* (2008) also reported positive correlation between WW and average dairy gain from birth to weaning age at 0.46. The estimated maternal permanent environmental correlation between BW and WW observed here (0.09) was lower than those from previous studies.

Many authors estimated genetic correlations for body weights at various ages with number of lambs born to be in range of -0.34 to 0.50 (Bromley *et al.*, 2000; Hanford *et al.*, 2003; van Wyk *et al.*, 2003; Hanford *et al.* 2006; Maxa *et al.*, 2007; Vanimisetti *et al.*, 2007; Afolayan *et al.*, 2008). In this study, both BW and WW were negatively correlated with TB (-0.26 and -0.30, respectively). The results implied that female goats with lighter body weights at birth and weaning age had more number of kids born than female goats with heavier weights. Perhaps females with heavier weights at birth and weaning might need more feed during growth to maintain better reproductive performance than females with lighter weights. Blackburn (1995) concluded that reproductive performance of female goat was simulated by decreasing in level of nutrition. His study found that as forage available and quality of forage decreased from high to low level, number of kids born for Boer and Spanish goats decreased about 54% and 28.3%, respectively. The reasons were that Spanish dams had smaller mature size, and therefore lower maintain requirement, they were able to maintain higher levels of reproductive performance with lower forage conditions. Negative correlations for BW and WW with TB (unfavorable) in present study suggested that selection on BW or WW would likely decrease number of kids born.

Kidding interval was negative correlated (favorable) with BW and WW (-0.10 and -0.65, respectively). These were in line with the finding of Meyer *et al.* (1991) who showed that genetic correlations between days to calving calculated from maiden joining performance and yearling weights for the Angus breed and Zebu crosses were -0.05 and -0.36, respectively. Johnston and Bunter (1996), by contrast, reported that days to calving were close to zero but generally unfavorable (0.10 and 0.08, respectively) correlated with weaning and yearling weights in Angus cows. Rege and Famula (1993) found a small negative genetic correlation in Herefords between calving date and weaning weight but a much larger correlation with yearling weight (-0.60). The favorable genetic correlations between early growth and female reproduction in this study might occur where animals with higher genetic potential for growth were advantage at mating.

Estimates of environmental correlations between growth and reproductive traits in the current study ranged from -0.97 to 0.35. The estimated environmental correlation between BW and WW was moderately positive (0.35) and higher than corresponding genetic correlation. The estimate was in agreement with Hanford *et al.* (2002) who reported of 0.33. The result suggested that relationship between prenatal environment and postnatal environment was moderately positive. The environmental effects that promote rapid gains from birth to weaning age in this study tended to be positively associated with environmental effects that lead to heavy BW.

Correlation between environmental effects for BW with TB was small and negative. A highly negative was found between WW and TB. These estimates were in opposite to the findings of Hanford *et al.* (2002, 2003 and 2006), ranging from -0.00 to 0.07. Estimate of environmental correlation between BW and TB was similar to genetic correlation between BW and TB. Corresponding parameter for WW with TB was higher in magnitude than genetic correlation between WW and TB. The results showed that environmental effects were more responsible relationship between WW and TB.

Estimates of environmental correlations for KI with BW and TB were close to zero. Corresponding parameter for KI with WW was positive but it was small. Environmental correlations for KI with other traits were small in magnitude as compared with genetic correlations from the same traits. These indicated that non genetic factors were less responsible for relationships between KI, TB and growth traits.

6. Estimated breeding values for growth and reproductive traits

Ranges in estimated breeding values for direct genetic ($\mathrm{D\hat{B}V}$), maternal genetic ($\mathrm{M\hat{B}V}$) and total maternal genetic ($\mathrm{TM\hat{B}V}$) across breeds for BW were lower than those for WW.

According to $\mathrm{TM\hat{B}V}$ for growth traits of top 20% in male and female goats, Anglo-Nubian and Anglo-Nubian-Native two-breed crosses were superior to other breed groups. The top twenty males and females according to $\mathrm{TM\hat{B}V}$ for BW and WW were mostly Anglo-Nubian breed. Some of top twenty males and females according to $\mathrm{TM\hat{B}V}$ for BW were the same animals obtained when considering $\mathrm{TM\hat{B}V}$ for WW.

Breed groups of top 20% and top twenty females according to $D\hat{B}V$ for TB were Native, Anglo-Nubian and Anglo-Nubian-Native two-breed crosses. While bottom 20% and bottom twenty females according to $D\hat{B}V$ for KI were mostly Native. The top twenty females according to $D\hat{B}V$ for TB were different identification numbers from bottom twenty females according to $D\hat{B}V$ for KI.

Analysis III: Estimation of economic values and construction of index for selection

1. Economic values

In production system of Yala Livestock Research and Breeding Center, revenue source originated from the sale of weaned kids. Revenue varied in a large range (280.00 to 3,196.40 baht per dam per parity) due to type of birth, survival rate, breed combination and weaning weight. Costs were related to feeding, veterinary, depreciation of purchased replacements and labor costs. Feed and veterinary costs contributed to the variable costs which included 69.05% of total costs. For variable costs, feed costs were the most important accounting approximately 67.04% of total costs, in agreement with Kosgey *et al.* (2003) who reported feed costs at a proportion of 56.94% for meat sheep production in tropics. Feed costs in current study included the costs of concentrate and forage. Concentrate costs were based on purchased feed prices that were expensive. Forage costs, on other hand, were relatively cheep to produce or purchased. Fixed costs that represented for 30.95% of total costs had a limited role in this system production. Kosgey *et al.* (2003) estimated the fixed costs at a proportion of 4.82%. The difference might be due to different assumption of model used to estimate economic values. The previous study considered feeding, management and marketing costs as variable costs and the rest were fixed costs. This study considered only feed and veterinary costs as variable costs and fixed costs were from depreciation of purchased replacements and labor costs.

Profit of the herd was derived as difference between revenues and costs. Average profit with a value of -897.70 baht per dam per parity reported here implied that revenues were lower than the total costs (average 1,307.63 and 2,232.97 baht per dam per parity, respectively). Haghdoost and Shadparvar (2008) also observed negative profit for Arabic sheep in village system. They suggested that flock profit in generally was negative and high feed costs were the most important cause. Another possible reason might be due to high mortality rate from birth to weaning age of kids as mentioned by Seleka *et al.* (2001). Mortality rate in this study varied with TB. Single, twin and triplet born kids were assumed to have mortality rate of 10%, 19% and 33%, respectively. Overall mortality was close to 20.67%.

Results from the ordinary multiple regression model with profit as a dependent variable showed that regression coefficients for WW and TB were positive. The positive economic values for WW and TB mainly originated from increase in revenues from sale of weaned kids. The positive economic value of WW was in agreement with the findings of Kahi and Nitter (2004) and Kosgey *et al.* (2004). When considering the standardized regression coefficients, WW and TB had similar values. These indicated that WW and TB played important roles in increasing profit. Because an increase of one standard deviation of WW when TB and KI were fixed led to the same increase in expected profit as did an increase of one standard deviation of TB when WW and KI were fixed. In contrast to the reviews of some authors (Upton, 1985; Greeff *et al.*, 1995; Kosgey *et al.*, 2004; Haghdoost and Shadparvar, 2008) who concluded that reproductive performance seemed to be more important economically than growth.

The economic value for KI exhibited a negative sign due to a total cost increased under an additional day in the interval. This was in agreement with Albera *et al.* (2004) who observed negative economic value for calving interval (-2.60 € per year per cow per day) derived for the Piemontese cattle farm in Italy. When considering the standardized regression coefficient, KI led to a much larger decrease in profit than did an increase of one standard deviation of WW and TB.

2. Index for selection

An index for female line developed in this study was based on three traits, each genotype being weighted according to the economic value of that trait. The top twenty females resulted from using index-based selection were Anglo-Nubian breed. About 10 from top twenty females were the same animals of those obtained when considering $\mathrm{TM\hat{B}V}$ for WW. But all of them were different identification numbers to those obtained when considering $\mathrm{D\hat{B}V}$ for TB or $\mathrm{D\hat{B}V}$ for KI. These might be due to positive economic values of WW and high heritable trait of WW, while heritability estimates for TB and KI were low and correlations for WW with TB and KI in genetic and environmental effects were negative. However, the breeding goal in this herd was to increase profit from the sale of weaned kids. Therefore, selecting directly on estimated breeding values of one trait (WW, TB or KI) probably did not balance the loss due to another trait. Furthermore, the potential breeding females from selecting on $\mathrm{TM\hat{B}V}$ for WW or $\mathrm{D\hat{B}V}$ for TB or $\mathrm{D\hat{B}V}$ for KI might be less than those obtained from index-base selection. Because index values of top twenty females according to $\mathrm{TM\hat{B}V}$ for WW, $\mathrm{D\hat{B}V}$ for TB and $\mathrm{D\hat{B}V}$ for KI were mostly lower than those of top twenty females according to index-base selection.

CONCLUSIONS

The investigations of this thesis involved four growth and reproductive traits obtained from Anglo-Nubian, Saanen, Native and crossbred goats raised in Yala province, the southern part of Thailand. The studied traits were BW, WW, TB and KI. The study determined breed effects on variations of traits. Genetic parameters for traits and genetic evaluations of animals were estimated. Economic values of breeding objective traits were calculated in order to develop index for selection on female line. The following conclusions were drawn from the present investigations:

1. Direct additive breed effects were significant difference from zero for Saanen for BW and for Anglo-Nubian for WW. Maternal additive breed effects of Anglo-Nubian and Saanen were important ($P<0.01$) for growth traits. The significant heterosis breed effects in Anglo-Nubian x Saanen, Anglo-Nubian x Native and Saanen x Native crosses were found for growth traits. For reproductive traits, direct additive breed effects were not significant for Anglo-Nubian and Saanen. The significant heterosis breed effect was observed from a cross between Anglo-Nubian and Native for TB.

2. Prediction of growth performance found that Native had lower BW and WW than those of Anglo-Nubian and Saanen breeds. Among Anglo-Nubian-Native two-breed crosses, the 5/8Anglo-Nubian3/8Native from 3/4Anglo-Nubian1/4Native sires mated with 1/2Anglo-Nubian1/2Native dams had heaviest weight at birth and weaning age. From the predicted reproductive performance, Native females had similar number of kids born to that of Anglo-Nubian females. Native females had shorter period of KI than those of Anglo-Nubian and Saanen females. Among Anglo-Nubian-Native two-breed crosses, the first cross females between Anglo-Nubian and Native had more number of kids born than others. The shortest KI for two-breed crosses was found from 1/2Anglo-Nubian1/2Native females.

3. Estimates of direct and maternal heritability for BW and WW were low to high. Heritability estimates for TB and KI were low. The relative variances due to maternal permanent environmental effects and permanent environmental effects were low for growth traits and reproductive traits, respectively.

4. Direct genetic correlations among BW, WW and TB were low and negative. Weaning weight was moderate and negatively genetic correlated with KI. A highly positive correlation was found between TB and KI. Environmental correlations for WW with BW and KI were positive whereas those for TB with BW, WW and KI were negative.

5. Across-breed genetic evaluation by adding the corresponding additive breed effects to within-breed genetic evaluation from multiple-trait analyses were estimated in term of $D\hat{B}V$, $M\hat{B}V$, $TM\hat{B}V$ for growth and reproductive traits. The top 20% in males and females according to $TM\hat{B}V$ for BW and WW were mostly Anglo-Nubian and Anglo-Nubian-Native two-breed crosses. The top 20% of female goats according to $D\hat{B}V$ for TB were Native, Anglo-Nubian and Anglo-Nubian-Native two-breed crosses. The bottom 20% of female goats according to $D\hat{B}V$ for KI were mostly Native.

6. The profit from the sale of weaned kids showed negative and positive values, ranging from -2772.72 to 920.65 baht per dam per parity. The economic values for WW, TB and KI were 86.58, 479.07 and -4.34 baht per unit. The range of index for selecting female line by considering WW, TB and KI were -67.82 to 455.45 baht. The top 20% of high potential breeding females according to index equation were mostly Anglo-Nubian and Anglo-Nubian-Native two-breed crosses.

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APPENDIX

Appendix Table 1 Estimates of breed effects for traits from multiple-trait analyses

Effect	Trait[1]			
	BW (kg)	WW (kg)	TB (head)	KI (day)
Direct additive breed				
Anglo-Nubian	0.07	0.26	0.03	14.48
Saanen	1.13	1.53	-0.09	22.88
Maternal additive breed				
Anglo-Nubian	0.75	4.73	-	-
Saanen	-0.88	3.79	-	-
Heterosis breed				
Anglo-Nubian x Saanen	-1.34	-7.68	-0.16	-34.59
Anglo-Nubian x Native	0.20	0.44	0.13	-14.09
Saanen x Native	0.64	-1.74	0.31	-18.90

[1] BW = birth weight, WW = weaning weight, TB = type of birth, KI = kidding interval

Appendix Table 2 Top twenty males and females according to estimated total maternal breeding values for birth weight

Animal ID	Breed[1]	BW(kg)[2]			WW(kg)[2]			TB(head)[2]	KI(day)[2]
		$D\hat{B}V^3$	$M\hat{B}V^3$	$TM\hat{B}V^3$	$D\hat{B}V^3$	$M\hat{B}V^3$	$TM\hat{B}V^3$	$D\hat{B}V^3$	$D\hat{B}V^3$
Male									
2334	$\frac{1}{2}S\frac{1}{2}N$	0.37	0.84	1.03	0.31	4.83	4.99	-0.02	14.31
1887	A	0.17	0.90	0.98	2.31	4.69	5.84	-0.05	8.36
2683	A	-0.14	1.04	0.97	1.64	4.88	5.70	0.00	14.04
1533	A	0.45	0.74	0.96	1.97	4.83	5.81	-0.06	8.53
2873	A	-0.21	1.06	0.96	2.48	4.36	5.60	0.02	10.34
4275	A	-0.28	1.09	0.95	1.54	4.52	5.29	0.01	10.92
1527	A	0.43	0.73	0.94	1.79	4.79	5.68	-0.06	8.57
816	A	0.33	0.77	0.93	2.38	4.32	5.51	-0.07	3.04
4227	A	0.39	0.74	0.93	1.42	4.65	5.35	-0.06	7.12
1778	A	0.09	0.88	0.92	3.22	3.97	5.58	-0.06	0.64
1095	A	0.25	0.79	0.92	3.57	3.79	5.58	-0.08	-3.11
3366	A	0.21	0.81	0.92	1.39	4.42	5.11	-0.05	5.40
2773	A	0.08	0.87	0.91	0.81	4.82	5.22	-0.02	11.86
2782	A	-0.10	0.96	0.91	1.24	4.75	5.37	0.01	13.24
993	A	0.15	0.83	0.91	2.63	4.19	5.50	-0.04	3.61
4230	A	-0.24	1.03	0.90	1.27	4.20	4.84	0.01	8.39
3014	A	0.13	0.84	0.90	1.15	4.87	5.45	0.02	15.24
2470	A	-0.11	0.95	0.90	1.65	4.38	5.20	0.01	9.43
1282	A	0.13	0.83	0.89	2.07	4.39	5.43	-0.03	6.55
3367	A	-0.07	0.93	0.89	2.16	4.02	5.11	-0.02	3.71
Female									
551	A	0.05	0.97	1.00	1.13	5.47	6.03	-0.01	19.04
2883	A	-0.10	1.02	0.96	1.27	4.89	5.53	-0.01	13.39
2473	A	-0.12	1.02	0.96	2.29	4.06	5.20	0.06	10.85
1281	A	-0.07	0.99	0.95	2.37	4.59	5.77	0.03	13.62
3069	A	-0.12	1.01	0.95	1.62	4.57	5.38	-0.02	8.97
2045	A	0.20	0.85	0.95	1.60	4.54	5.34	-0.07	5.29
1889	A	0.21	0.83	0.94	1.82	4.52	5.43	-0.03	8.02
4276	A	-0.09	0.99	0.94	1.63	4.50	5.31	-0.01	9.48
970	A	0.11	0.89	0.94	0.23	5.59	5.71	0.01	21.30
2071	A	-0.00	0.93	0.93	1.22	4.91	5.52	-0.02	12.56
1535	A	0.42	0.72	0.93	2.40	4.13	5.33	-0.10	-1.25
4178	A	-0.07	0.96	0.93	1.48	4.36	5.11	0.02	10.54
555	A	-0.17	1.01	0.93	0.15	5.35	5.43	0.02	19.74
1513	A	0.29	0.78	0.92	2.12	4.34	5.40	-0.02	6.78
2673	A	-0.01	0.92	0.92	1.31	4.75	5.41	-0.01	11.92
2692	A	0.03	0.90	0.92	1.38	4.79	5.48	0.01	13.73
1534	A	0.38	0.72	0.92	2.59	4.07	5.36	-0.08	-0.17
3159	A	0.08	0.88	0.91	0.78	5.02	5.41	0.02	16.55
540	A	0.09	0.87	0.91	0.99	4.95	5.45	-0.04	11.27
1094	A	0.37	0.73	0.91	2.62	4.21	5.51	-0.08	1.13

[1] A = Anglo-Nubian, S = Saanen, N = Native

[2] BW = birth weight, WW = weaning weight, TB = type of birth, KI = kidding interval

[3] $D\hat{B}V$ = estimated direct breeding value, $M\hat{B}V$ = estimated maternal breeding value, $TM\hat{B}V$ = estimated total maternal breeding value

Appendix Table 3 Top twenty males and females according to estimated total maternal breeding values for weaning weight

Animal ID	Breed[1]	BW(kg)[2]			WW(kg)[2]			TB(head)[2]	KI(day)[2]
		D$\hat{B}$V[3]	M$\hat{B}$V[3]	TM$\hat{B}$V[3]	D$\hat{B}$V[3]	M$\hat{B}$V[3]	TM$\hat{B}$V[3]	D$\hat{B}$V[3]	D$\hat{B}$V[3]
Male									
1887	A	0.17	0.90	0.98	2.31	4.69	5.84	-0.05	8.36
1533	A	0.45	0.74	0.96	1.97	4.83	5.81	-0.06	8.53
2683	A	-0.14	1.04	0.97	1.64	4.88	5.70	0.00	14.04
1527	A	0.43	0.73	0.94	1.79	4.79	5.68	-0.06	8.57
2873	A	-0.21	1.06	0.96	2.48	4.36	5.59	0.02	10.34
1778	A	0.09	0.88	0.92	3.22	3.97	5.58	-0.06	0.64
1095	A	0.25	0.79	0.92	3.57	3.79	5.58	-0.08	-3.11
816	A	0.33	0.77	0.93	2.38	4.32	5.51	-0.07	3.04
993	A	0.15	0.83	0.91	2.63	4.19	5.50	-0.04	3.61
5	A	0.06	0.86	0.89	0.70	5.10	5.45	0.02	16.76
3014	A	0.13	0.84	0.90	1.15	4.87	5.45	-0.07	15.24
702	A	0.24	0.76	0.87	4.20	3.34	5.44	-0.03	-6.62
1282	A	0.13	0.83	0.89	2.07	4.39	5.43	-0.02	6.55
992	A	0.02	0.88	0.89	1.74	4.51	5.38	0.01	8.86
2782	A	-0.10	0.96	0.91	1.24	4.75	5.37	-0.06	13.24
4227	A	0.39	0.74	0.93	1.42	4.65	5.35	-0.04	7.12
1098	A	0.13	0.79	0.85	2.88	3.87	5.31	-0.06	0.98
1512	A	0.43	0.64	0.85	1.87	4.37	5.30	0.01	4.46
4275	A	-0.28	1.09	0.95	1.54	4.52	5.29	-0.03	10.92
1097	A	-0.09	0.89	0.84	3.80	3.38	5.28	-0.06	-3.26
Female									
551	A	0.05	0.97	0.10	1.13	5.47	6.03	-0.01	19.04
1281	A	-0.07	0.99	0.95	2.37	4.59	5.77	0.03	13.61
970	A	0.11	0.89	0.94	0.23	5.59	5.71	0.01	21.30
2132	A	0.10	0.86	0.91	0.97	5.14	5.62	0.02	18.10
2883	A	-0.10	1.02	0.96	1.27	4.89	5.53	-0.01	13.39
2071	A	-0.00	0.93	0.93	1.22	4.91	5.52	-0.02	12.56
1094	A	0.37	0.73	0.91	2.62	4.21	5.51	-0.08	1.13
2133	A	-0.03	0.92	0.91	1.36	4.81	5.50	-0.00	13.02
2692	A	0.03	0.90	0.92	1.38	4.79	5.48	0.01	13.73
3015	A	0.17	0.82	0.91	1.34	4.80	5.47	0.01	14.04
540	A	0.09	0.87	0.91	0.99	4.95	5.45	-0.04	11.27
1798	A	0.19	0.82	0.91	1.53	4.68	5.44	-0.06	7.00
555	A	-0.17	1.01	0.93	0.15	5.35	5.43	0.02	19.74
1889	A	0.21	0.83	0.94	1.82	4.52	5.43	-0.03	8.02
1525	A	0.16	0.82	0.90	1.96	4.43	5.41	-0.04	5.93
3159	A	0.08	0.88	0.91	0.78	5.02	5.41	0.02	16.55
2673	A	-0.01	0.92	0.92	1.31	4.75	5.41	-0.01	11.92
1513	A	0.29	0.78	0.92	2.12	4.34	5.40	-0.02	6.78
994	A	0.16	0.75	0.83	1.73	4.52	5.38	-0.02	8.31
3069	A	-0.12	1.01	0.95	1.62	4.57	5.38	-0.02	8.97

[1] A = Anglo-Nubian

[2] BW = birth weight, WW = weaning weight, TB = type of birth, KI = kidding interval

[3] D$\hat{B}$V = estimated direct breeding value, M$\hat{B}$V = estimated maternal breeding value, TM$\hat{B}$V = estimated total maternal breeding value

Appendix Table 4 Top twenty females according to estimated direct breeding values for type of birth

Female ID	Breed[1]	BW(kg)[2]			WW(kg)[2]			TB(head)[2]	KI(day)[2]
		$D\hat{B}V$[3]	$M\hat{B}V$[3]	$TM\hat{B}V$[3]	$D\hat{B}V$[3]	$M\hat{B}V$[3]	$TM\hat{B}V$[3]	$D\hat{B}V$[3]	$D\hat{B}V$[3]
904	$\frac{5}{8}$A $\frac{3}{8}$N	0.01	0.25	0.25	-1.20	2.58	1.98	0.13	20.10
2274	N	-0.14	0.13	0.07	0.06	0.37	0.40	0.12	13.59
3156	A	-0.22	0.76	0.65	-1.17	4.58	3.99	0.12	19.87
2229	A	0.06	0.59	0.62	-1.72	4.89	4.03	0.12	22.83
3986	A	-0.33	0.18	0.02	-1.01	0.29	-0.22	0.12	23.99
2797	$\frac{1}{2}$A $\frac{1}{2}$N	-0.01	0.44	0.43	-0.97	2.83	2.34	0.11	19.96
543	A	0.02	0.69	0.71	-0.19	4.79	4.69	0.11	21.30
1971	$\frac{9}{16}$A $\frac{7}{16}$N	0.06	0.41	0.44	-1.80	3.79	2.89	0.10	22.97
2370	N	-0.06	0.08	0.06	0.16	0.59	0.67	0.10	13.89
2677	$\frac{1}{2}$A $\frac{1}{2}$N	-0.13	0.55	0.48	-0.79	3.36	2.97	0.10	23.76
3922	N	-0.37	0.21	0.03	-0.58	0.39	0.10	0.10	11.55
4028	N	-0.26	0.11	-0.02	-0.70	0.28	-0.07	0.10	10.47
2366	N	-0.13	0.02	-0.05	0.31	-0.51	-0.35	0.09	2.90
2776	A	-0.13	0.81	0.75	-1.05	5.06	4.54	0.09	22.38
2213	N	0.01	-0.03	-0.03	-0.79	0.03	-0.36	0.09	7.89
2973	$\frac{1}{2}$A $\frac{1}{2}$N	-0.33	0.22	0.05	0.71	-0.40	-0.04	0.09	9.48
2210	N	0.02	-0.01	0.00	-0.58	0.54	0.25	0.09	12.37
4194	N	-0.41	0.25	0.05	0.21	0.10	0.20	0.09	7.72
3284	A	-0.18	0.85	0.76	0.57	4.46	4.74	0.09	16.17
1108	$\frac{3}{4}$A $\frac{1}{4}$N	-0.23	0.48	0.37	-0.59	2.30	2.01	0.09	15.21

[1] A = Anglo-Nubian, N = Native

[2] BW = birth weight, WW = weaning weight, TB = type of birth, KI = kidding interval

[3] $D\hat{B}V$ = estimated direct breeding value, $M\hat{B}V$ = estimated maternal breeding value, $TM\hat{B}V$ = estimated total maternal breeding value

Appendix Table 5 Bottom twenty females according to estimated direct breeding values for kidding interval

Female ID	Breed[1]	BW(kg)[2]			WW(kg)[2]			TB(head)[2]	KI(day)[2]
		$D\hat{B}V$[3]	$M\hat{B}V$[3]	$TM\hat{B}V$[3]	$D\hat{B}V$[3]	$M\hat{B}V$[3]	$TM\hat{B}V$[3]	$D\hat{B}V$[3]	$D\hat{B}V$[3]
2600	N	-0.04	0.08	0.07	1.59	-0.85	-0.05	-0.11	-17.34
3144	N	0.02	0.04	0.04	0.93	-0.55	-0.08	-0.13	-16.04
641	N	-0.23	0.22	0.10	1.92	-1.03	-0.07	-0.07	-15.59
3626	N	-0.53	0.31	0.05	2.24	-1.17	-0.06	-0.03	-14.18
3127	N	-0.41	0.20	-0.00	0.55	-0.78	-0.51	-0.04	-11.15
568	N	0.09	-0.07	-0.03	0.39	-0.40	-0.21	-0.09	-11.14
3627	N	-0.29	0.18	0.04	1.58	-0.76	0.03	-0.04	-10.87
2457	N	0.04	0.01	0.03	0.30	-0.32	-0.16	-0.10	-10.87
3763	N	-0.35	0.20	0.02	1.93	-0.93	0.04	-0.02	-10.83
4209	N	0.29	-0.06	0.09	1.78	-0.30	0.60	-0.10	-10.72
2195	N	-0.35	0.25	0.07	1.30	-1.09	-0.44	-0.00	-10.32
3641	N	-0.19	0.17	0.08	1.73	-1.00	-0.13	-0.01	-10.23
656	N	-0.02	0.00	-0.01	-0.34	-0.02	-0.19	-0.11	-9.56
3919	$\frac{1}{2}$A $\frac{1}{2}$N	-0.00	0.14	0.14	2.10	-0.79	0.26	-0.10	-9.48
2861	N	0.35	-0.10	0.08	1.03	-0.10	0.41	-0.11	-9.28
4293	N	0.26	-0.08	0.05	1.30	-0.28	0.37	-0.08	-9.21
3784	N	0.06	-0.03	-0.00	0.89	-0.53	-0.09	-0.05	-9.04
2918	N	0.66	-0.35	-0.02	0.34	-0.06	0.11	-0.10	-8.24
272	N	-0.12	0.11	0.05	0.96	-0.52	-0.04	-0.04	-7.80
4018	N	0.13	-0.02	0.04	0.24	-0.07	0.05	-0.09	-7.54

[1] A = Anglo-Nubian, N = Native

[2] BW = birth weight, WW = weaning weight, TB = type of birth, KI = kidding interval

[3] $D\hat{B}V$ = estimated direct breeding value, $M\hat{B}V$ = estimated maternal breeding value, $TM\hat{B}V$ = estimated total maternal breeding value

Appendix Table 6 Cost for producing weaned kid

Item	Cost (baht)
Variable cost	
Feed cost for kid from birth to weaning age	208.50
Milk powder 0.03 kg/day for 90 days, 35 baht/kg	94.50
Concentrate 0.10 kg/day for 90 days, 14 baht/kg	84.00
Forage 1 kg/day for 60 days, 0.50 baht/kg	30.00
Feed cost for dam from previous kidding to the next kidding	1,233.00
Concentrate 0.30 kg/day for 264 days, 10 baht/kg	528.00
Forage 4 kg/day for 264 days, 0.50 baht/kg	660.00
Medicine and deworming	45.00
Fixed cost	
Depreciation for replacement sire	
Weight 30 kg, 80 baht/kg + extra price, longevity 3 years, sire : dam ratio 1:12, kidding frequency 1.3	51.28 to 72.65
Depreciation for replacement dam	
Weight 20 kg, 80 baht/kg + extra price, longevity 6 parities	266.67 to 433.33
Labor	286.27

Appendix Table 7 Top twenty of high potential breeding females according to index values

Female ID	Breed[1]	BW(kg)[2]			WW(kg)[2]			TB(head)[2]	KI(day)[2]	I[4] (baht)
		$D\hat{B}V$[3]	$M\hat{B}V$[3]	$TM\hat{B}V$[3]	$D\hat{B}V$[3]	$M\hat{B}V$[3]	$TM\hat{B}V$[3]	$D\hat{B}V$[3]	$D\hat{B}V$[3]	
1281	A	-0.07	0.99	0.95	2.37	4.59	5.77	0.03	13.62	455.45
1270	A	0.19	0.75	0.84	3.32	3.68	5.34	-0.05	-1.57	447.00
551	A	0.05	0.97	0.99	1.13	5.47	6.03	-0.01	19.04	436.52
1094	A	0.37	0.73	0.91	2.62	4.21	5.51	-0.08	1.13	434.36
1096	A	0.05	0.77	0.79	2.75	3.78	5.16	-0.03	0.77	431.08
1271	A	0.03	0.80	0.81	2.59	3.84	5.13	0.02	4.93	430.95
2473	A	-0.12	1.02	0.96	2.29	4.06	5.20	0.06	10.85	429.94
1795	A	0.16	0.80	0.88	2.58	4.01	5.30	-0.06	0.94	428.34
1534	A	0.38	0.72	0.92	2.59	4.07	5.36	-0.08	-0.17	426.39
1513	A	0.29	0.78	0.92	2.12	4.33	5.40	-0.03	6.78	424.82
2789	A	0.03	0.85	0.86	2.15	4.19	5.27	-0.01	6.27	424.30
4290	A	-0.26	0.93	0.80	2.46	3.79	5.02	0.00	2.95	423.71
3488	A	-0.34	1.04	0.87	2.50	3.77	5.02	0.01	3.19	423.20
1525	A	0.16	0.82	0.90	1.96	4.43	5.41	-0.04	5.93	421.75
2117	A	-0.21	0.96	0.85	2.84	3.44	4.85	-0.01	-1.04	420.69
1889	A	0.22	0.83	0.94	1.82	4.52	5.43	-0.03	8.02	419.55
994	A	0.16	0.75	0.83	1.73	4.52	5.38	-0.02	8.31	419.48
2692	A	0.03	0.90	0.92	1.38	4.79	5.48	0.01	13.73	419.23
2133	A	-0.03	0.92	0.91	1.36	5.14	5.62	-0.00	13.02	419.21
2132	A	0.10	0.86	0.91	0.97	4.81	5.50	0.02	18.10	418.42

[1] A = Anglo-Nubian

[2] BW = birth weight, WW = weaning weight

[3] $D\hat{B}V$ = estimated direct breeding value, $M\hat{B}V$ = estimated maternal breeding value, $TM\hat{B}V$ = estimated total maternal breeding value

[4] I = an index value

Appendix Table 8 Index values of top twenty females according to estimated total maternal breeding values for weaning weight

Female ID	Breed[1]	BW(kg)[2]			WW(kg)[2]			TB(head)[2]	KI(day)[2]	I[4] (baht)
		$D\hat{B}V$[3]	$M\hat{B}V$[3]	$TM\hat{B}V$[3]	$D\hat{B}V$[3]	$M\hat{B}V$[3]	$TM\hat{B}V$[3]	$D\hat{B}V$[3]	$D\hat{B}V$[3]	
551	A	0.05	0.97	0.10	1.13	5.47	6.03	-0.01	19.04	436.52
1281	A	-0.07	0.99	0.95	2.37	4.59	5.77	0.03	13.62	455.45
970	A	0.11	0.89	0.94	0.23	5.59	5.71	0.01	21.30	405.20
2132	A	0.10	0.86	0.91	0.97	4.81	5.50	0.02	18.10	418.42
2883	A	-0.10	1.02	0.96	1.27	4.89	5.53	-0.01	13.39	417.24
2071	A	-0.00	0.93	0.93	1.22	4.91	5.52	-0.02	12.56	414.79
1094	A	0.37	0.73	0.91	2.62	4.21	5.51	-0.08	1.13	434.36
2133	A	-0.03	0.92	0.91	1.36	5.14	5.62	-0.00	13.02	419.21
2692	A	0.03	0.90	0.92	1.38	4.79	5.48	0.01	13.73	419.23
3015	A	0.17	0.82	0.91	1.34	4.80	5.47	0.01	14.04	417.63
540	A	0.09	0.87	0.91	0.99	4.95	5.45	-0.04	11.27	404.32
1798	A	0.19	0.82	0.91	1.53	4.68	5.44	-0.06	7.00	412.10
555	A	-0.17	1.01	0.93	0.15	5.35	5.43	0.02	19.74	394.01
1889	A	0.22	0.83	0.94	1.82	4.52	5.43	-0.03	8.02	419.55
1525	A	0.16	0.82	0.90	1.96	4.43	5.41	-0.04	5.93	421.75
3159	A	0.08	0.88	0.91	0.78	5.02	5.41	0.02	16.55	404.07
2673	A	-0.01	0.92	0.92	1.31	4.75	5.41	-0.01	11.92	412.58
1513	A	0.29	0.78	0.92	2.12	4.33	5.40	-0.03	6.78	424.82
994	A	0.16	0.75	0.83	1.73	4.52	5.38	-0.02	8.31	419.48
3069	A	-0.12	1.01	0.95	1.62	4.57	5.38	-0.02	8.97	415.89

[1] A = Anglo-Nubian

[2] BW = birth weight, WW = weaning weight, TB = type of birth, KI = kidding interval

[3] $D\hat{B}V$= estimated direct breeding value, $M\hat{B}V$= estimated maternal breeding value, $TM\hat{B}V$= estimated total maternal breeding value

[4] I = an index value

Appendix Table 9 Index values of top twenty females according to estimated direct breeding values for type of birth

Female ID	Breed[1]	BW(kg)[2]			WW(kg)[2]			TB(head)[2]	KI(day)[2]	I[4]
		D$\hat{B}$V[3]	M$\hat{B}$V[3]	TM$\hat{B}$V[3]	D$\hat{B}$V[3]	M$\hat{B}$V[3]	TM$\hat{B}$V[3]	D$\hat{B}$V[3]	D$\hat{B}$V[3]	(baht)
904	$\frac{5}{8}$ A $\frac{3}{8}$ N	0.01	0.25	0.25	-1.20	2.58	1.98	0.13	20.10	147.57
2274	N	-0.14	0.13	0.07	0.06	0.37	0.40	0.12	13.59	32.45
3156	A	-0.22	0.76	0.65	-1.17	4.58	3.99	0.12	19.87	316.68
2229	A	0.06	0.59	0.62	-1.72	4.89	4.03	0.12	22.83	305.75
3986	A	-0.33	0.18	0.02	-1.01	0.29	-0.22	0.12	23.99	-67.81
2797	$\frac{1}{2}$ A $\frac{1}{2}$ N	-0.01	0.44	0.43	-0.97	2.83	2.34	0.11	19.96	169.43
543	A	0.02	0.69	0.71	-0.19	4.79	4.69	0.11	21.30	365.65
1971	$\frac{9}{16}$ A $\frac{7}{16}$ N	0.06	0.41	0.44	-1.80	3.79	2.89	0.10	22.97	198.77
2370	N	-0.06	0.08	0.06	0.16	0.59	0.67	0.10	13.89	44.79
2677	$\frac{1}{2}$ A $\frac{1}{2}$ N	-0.13	0.55	0.48	-0.79	3.36	2.97	0.10	23.76	200.82
3922	N	-0.37	0.21	0.03	-0.58	0.39	0.10	0.10	11.55	5.25
4028	N	-0.26	0.11	-0.02	-0.70	0.28	-0.07	0.10	10.47	-4.75
2366	N	-0.13	0.02	-0.05	0.31	-0.51	-0.35	0.09	2.90	1.92
2776	A	-0.13	0.81	0.75	-1.05	5.06	4.54	0.09	22.38	338.69
2213	N	0.01	-0.03	-0.03	-0.79	0.03	-0.36	0.09	7.89	-23.14
2973	$\frac{1}{2}$ A $\frac{1}{2}$ N	-0.33	0.22	0.05	0.71	-0.40	-0.04	0.09	9.48	-2.40
2210	N	0.02	-0.01	0.00	-0.58	0.54	0.25	0.09	12.37	9.22
4194	N	-0.41	0.25	0.05	0.21	0.10	0.20	0.09	7.72	24.33
3284	A	-0.18	0.85	0.76	0.57	4.46	4.74	0.09	16.17	381.10
1108	$\frac{3}{4}$ A $\frac{1}{4}$ N	-0.23	0.48	0.37	-0.59	2.30	2.01	0.09	15.21	148.67

[1] A = Anglo-Nubian, N = Native

[2] BW = birth weight, WW = weaning weight, TB = type of birth, KI = kidding interval

[3] D$\hat{B}$V= estimated direct breeding value, M$\hat{B}$V= estimated maternal breeding value, TM$\hat{B}$V= estimated total maternal breeding value

Appendix Table 10 Index values of bottom twenty females according to estimated direct breeding values for kidding interval

Female ID	Breed[1]	BW(kg)[2]			WW(kg)[2]			TB(head)[2]	KI(day)[2]	I[4] (baht)
		$D\hat{B}V$[3]	$M\hat{B}V$[3]	$TM\hat{B}V$[3]	$D\hat{B}V$[3]	$M\hat{B}V$[3]	$TM\hat{B}V$[3]	$D\hat{B}V$[3]	$D\hat{B}V$[3]	
2600	N	-0.04	0.08	0.07	1.59	-0.85	-0.05	-0.11	-17.34	16.24
3144	N	0.02	0.04	0.04	0.93	-0.55	-0.08	-0.13	-16.04	-0.57
641	N	-0.23	0.22	0.10	1.92	-1.03	-0.07	-0.07	-15.59	26.94
3626	N	-0.53	0.31	0.05	2.24	-1.17	-0.06	-0.03	-14.18	41.99
3127	N	-0.41	0.20	-0.00	0.55	-0.78	-0.51	-0.04	-11.15	-14.70
568	N	0.09	-0.07	-0.03	0.39	-0.40	-0.21	-0.09	-11.14	-11.35
3627	N	-0.29	0.18	0.04	1.58	-0.76	0.03	-0.04	-10.87	30.17
2457	N	0.04	0.01	0.03	0.30	-0.32	-0.16	-0.10	-10.87	-12.94
3763	N	-0.35	0.20	0.02	1.93	-0.93	0.04	-0.02	-10.83	40.92
4209	N	0.29	-0.06	0.09	1.78	-0.30	0.60	-0.10	-10.72	49.76
2195	N	-0.35	0.25	0.07	1.30	-1.09	-0.44	-0.00	-10.32	5.91
3641	N	-0.19	0.17	0.08	1.73	-1.00	-0.13	-0.01	-10.23	27.18
656	N	-0.02	0.00	-0.01	-0.34	-0.02	-0.19	-0.11	-9.56	-27.65
3919	$\frac{1}{2}$A $\frac{1}{2}$N	-0.00	0.14	0.14	2.10	-0.79	0.26	-0.10	-9.48	15.45
2861	N	0.35	-0.10	0.08	1.03	-0.10	0.41	-0.11	-9.28	24.74
4293	N	0.26	-0.08	0.05	1.30	-0.28	0.37	-0.08	-9.21	31.89
3784	N	0.06	-0.03	-0.00	0.89	-0.53	-0.09	-0.05	-9.04	8.13
2918	N	0.66	-0.35	-0.02	0.34	-0.06	0.11	-0.10	-8.24	-2.59
272	N	-0.12	0.11	0.05	0.96	-0.52	-0.04	-0.04	-7.80	13.47
4018	N	0.13	-0.02	0.04	0.24	-0.07	0.05	-0.09	-7.54	-3.97

[1] A = Anglo-Nubian, N = Native

[2] BW = birth weight, WW = weaning weight, TB = type of birth, KI = kidding interval

[3] $D\hat{B}V$ = estimated direct breeding value, $M\hat{B}V$ = estimated maternal breeding value, $TM\hat{B}V$ = estimated total maternal breeding value

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